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Economic Growth and International Trade with Capital Goods

Theories and Empirical Evidence

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... therefore, the most advantageous method in which a landed nation can raise up artificers, manufacturers and merchants of its own, is to grant the most perfect freedom of trade to the artificers, manufacturers and merchants of all other nations.

Adam Smith ([1776]1994:728)

Since the Trojans were given a wooden horse by the Greeks, it has become a dangerous thing for one nation to accept gifts from others.

Friedrich List (1841: 218; translation by the author)

Preface

Capital goods play an important role in international trade. More than one third of total world trade is trade with capital goods and this share is still increasing. Although the classical theory of international trade basically neglects that trade can have dynamic effects, economic theory of today offers a set of different hypotheses on the effects of international trade with capital goods on economic growth. The neoclassical growth theory implies that trade with capital goods can increase the speed and improve the efficiency of capital accumulation and consequently the growth rate in transition towards the steady state. The theory of endogenous growth shows that trade with capital goods can also increase steady state growth. However, the relationship between capital goods trade and economic growth in the various models of endogenous growth is complex and ambiguous. Several sets of specification exist where international trade can also negatively affect economic growth.

Taken together, the development of economic theory seems to have reached a state where empirical research is necessary to clarify the empirical performance of the different theories. With this study I would like to contribute to this research. I focus on two potential effects of international trade with capital goods on economic growth: The effect of trade with capital goods on capital accumulation in transition towards steady state and the effect of trade with capital goods on steady state growth (total factor productivity growth). The results indicate that countries open for capital good imports display an increased and more efficient accumulation of capital in transition towards the steady state and perform better in terms of total factor productivity growth.

This study was carried out when working in the research department "Economic Growth, Structural Policy and International Division of Labor" of the Kiel Institute of World Economics. I would like to thank my colleagues of the Kiel Institute for helpful discussions. In particular, I thank Professor Dr. Horst Siebert, Professor Dr. Gerd Hansen, and Professor Dr. Karl-Heinz Paqué. Thanks are also due to Helga Huß, Jutta Stribny, and Regina Arnhold for their assistance with the manuscript and the graphs as well as to members of the editorial division.

I dedicate this study to my parents, Gabriele and Willi Maurer, to whom I am deeply indebted for their love and attention and the freedom they granted me to let me find my way.

Bad Homburg vor der Höhe, June 1998 Rainer Maurer

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A. Overview: Economic Growth and International Trade with Capital Goods

New developments in the theory of economic growth have stimulated the interest in the consequences of international trade for the dynamic development of countries. The identification of conditions necessary to generate endogenous growth has offered new possibilities to theoretically analyze the interrelationships between economic growth and international trade. This progress in economic theory has yielded new insights in both the effects of international trade on economic growth and the effects of economic growth on the pattern and volume of international trade.

The starting point of these new theories was the work of Romer (1983), who showed that endogenous long-run growth is possible, if at least one accumulating production factor with the property of nondiminishing marginal returns exists. Since then, many variants of models built on this condition have been developed. Their basic difference lies in the assumption concerning the production factor which displays nondiminishing marginal returns. One interesting class of these models are the research and development models of endogenous growth. Within this model variant, accumulated technological knowledge produced in the research and development sector of an economy displays nondiminishing marginal returns in the production of new technological knowledge. One unit of technological knowledge, i.e., a blueprint, enables its owner to produce one specific type of a differentiated capital good. A larger set of differentiated capital goods increases the total factor productivity of consumption and capital goods production. As a result the economy grows through the production of new technological knowledge. Hence, new technological knowledge is the engine of growth.[1]

Within this model setup, international trade has two effects. On the one hand, it transmits total factor productivity growth from one country to the other through the imports of capital goods. On the other hand, it increases the demand for capital goods and, thereby, the incentives for the production of new technological knowledge. Consequently, international trade with capital goods is both an additional incentive for the production of new technological knowledge and a means of transmission of embodied new technological knowledge. The latter implies that countries

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1 Examples for these types of models are Romer (1990), and Rivera-Batiz and Romer (1991a, 1996b). For a detailed description see Section B.III.1.

with a trade regime open for capital goods imports can participate from the technological progress of other countries.

These effects of a free trade regime are long-run steady-state effects. However, there are several empirical hints that most existing countries are out of their steady state.[2] In this case, the trade regime for capital goods can affect the rate of capital accumulation and, hence, the rate of economic growth in transition towards the steady state. This is due to the effect of the trade regime on the relative price of capital goods. If domestic capital goods do not perfectly substitute for foreign capital goods, trade restrictions can increase the relative price of capital goods. As a consequence, less capital goods per period are accumulated and the composition of domestically and foreign produced capital goods in the capital stock is not efficient. These transitional effects of the trade regime for capital goods can emerge in models of endogenous growth as well as in special types of the Solow-type growth model.[3] Consequently, following these theories international trade with capital goods can affect both the rate of economic growth in transition towards the steady state and the rate of total factor productivity growth. If these theories correctly reflect the interrelationship between international trade and economic growth, international trade with capital goods plays the central role.

This study focuses on the empirical estimation of the impact of international trade with capital goods on economic growth. Thereby, the empirical analysis centers on the estimation of two effects: (i) the effect of import restrictions on capital goods on economic growth in transition towards the steady state, and (ii) the effect of international trade with capital goods on total factor productivity growth. The study has two main parts. The first part provides a discussion of economic theories on the interrelationships between economic growth and international trade (Chapter B). The second part presents the empirical analysis (Chapter C).

The theoretical part begins with a brief overview of the historical roots of the theory of international trade (Section B.I). Based on this background, the effect of international trade with capital goods in a Solow–Ramsey model is analyzed under the assumption of perfect and imperfect competition on the domestic capital goods market (Section B.II). The effect of international trade with capital goods in endogenous growth models is discussed for the case of two identical countries (Section B.III.1) as well as for the case of countries that differ in the endowment with resources (Section B.III.2) and technological knowledge (Section B.III.3). Following

2 See the empirical results in Section C.II.1.

3 See the analysis in Sections B.II.2 and C.II.1.

this theoretical analysis, the basic conclusions for the empirical analysis are drawn (Section B.IV).

The empirical analysis focuses first on the characteristics of the time series behavior of economic growth (Section C.I.1) and the effect of trade liberalization episodes on the time series behavior of economic growth (Section C.I.2). Following this, the effects of capital goods imports on economic growth in transition towards steady state and on total factor productivity are estimated. The first estimation is based on a Solow–Swan model (Section C.II.1). The second estimation directly measures the effect of capital goods imports on total factor productivity growth (Section C.II.2). The study is closed by a summary of the results and an evaluation of their consequences for economic policy (Chapter D).

> Dostoyevski apparently once remarked that all of the Russian literature emerged from Gogol's "Overcoat." It is at least as true that all of the pure theory of international trade has emerged from Chapter 7 of Ricardo's "Principles." One topic, however, that was almost entirely absent from the formal literature was any consideration of the connection between economic growth and development and international trade, despite the famous quotation from Marshall that "the causes which determine the economic progress of nations belong to the study of international trade" (Findlay 1984: 186).

B. Economic Reasoning on Trade and Growth

I. The Old and the New Gains from International Trade

1. Historical Origins of Theories of International Trade

Abstract: *This section discusses the relations between modern theories of international trade and their historical predecessors. It is argued that "classical" theories of international trade of authors like Adam Smith and Friedrich List primarily focused on its dynamic implications, while "neoclassical" theories of international trade primarily focused on its static implications. New attempts to overcome this static orientation have led to theories of international trade that have much in common with the "classical" theories.*

Ricardo's simple but amazing calculation, how international trade with cloth and wine can increase the total output quantities of cloth and wine without increasing any input, was a starting point for the theory of international trade (Ricardo [1817] 1951).[4] Since then, the explanation of the pattern and the terms of trade has been the major issue in this branch of economic theory (Dixit and Norman 1980: 1). As Ricardo's example is set up in a static framework, the traditional theory primarily focused on the static implications of international trade.

In a sense, it is an irony that most classical economists hold the gains from trade to be dynamic. Even Ricardo himself directed much effort to the construction of a

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4 For a numeric example of Ricardo's theorem see Dixit and Norman (1980: 2–3).

dynamic theory of international trade and growth (Ricardo [1817] 1951).[5] Perhaps better known than Ricardo's dynamic theory is Adam Smith's "learning by doing theory." According to Smith the division of labor increases productivity, because it increases the "throughput" per production activity. This enables a worker to learn more about how to improve the execution of his work (Smith [1776] 1994: 9). Smith combines this hypothesis with the hypothesis that the extent of the division of labor is limited by the extent of the market. From these two hypotheses, he draws the conclusion that an extension of the market by international trade leads to higher productivity gains through intensified learning by doing.[6]

Even the first critics of the "free trade paradigm" based their arguments in a dynamic setting. Perhaps, Friedrich List was one of the first free trade skeptics who presented a complete theory. He states that a mutually advantageous division of labor by free trade only works between economies with an equal state of development of agriculture and industry. Free trade between economies with an uneven state of development is advantageous for the industrial economy only, but disadvantageous for the agricultural economy (List 1841: 18, 193, 218–219).

List derives this hypothesis from his theory of "productive forces." He defines "productive forces" to be what in modern terms is called human capital and technological knowledge capital (List 1841: 208–209). He argues that the development of the industrial sector favors the accumulation of human capital and technological knowledge capital, because the industrial sector finances research and development activities as well as the education of the labor force. His crucial assumption is that the common stocks of human capital and technological capital enter the production functions of all sectors, agricultural and industrial, positively. This means, List as-

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5 Several formalizations of this dynamic theory have been derived (Samuelson 1959; Pasinetti 1960; Findlay 1974). Ricardo's dynamic model is based on the idea that the international exchange of manufacturing goods for corn allows to "feed" a permanently growing labor force in manufacturing. The labor force plays in Ricardo's model the role of an endogenously accumulated production factor.

6 "As it is the power of exchanging that gives occasion to the division of labor, so the extent of this division must always be limited by the extent of that power, or, in other words, by the extent of the market" (Smith [1776] 1994: 19). Of course, in order for the productivity improvements by an expansion of the market to be dynamic, it is necessary to assume that the learning effect per unit of output does not decrease in future periods. A similar type of assumption is also to be found in the new theories of endogenous growth (see Section B.III). It is, furthermore, interesting to note that Smith also pronounced the importance of the division of labor for research and development. Following him, the division of labor also allows to separate the process of research and development (R&D) from the process of commodity production (Smith [1776] 1994: 11). This way, the "output" per R&D activity is increased, such that more improvements of R&D productivity through learning effects become possible.

sumes that the stock of human capital and technological capital spreads positive externalities across the production of the whole economy. However, he assumes that these externalities are bounded within a country (List 1841: 212–213).[7]

Because the positive externalities are bounded within an industrial economy, they allow the industrial economy to produce industrial goods at lower costs than an agricultural economy. This cost advantage, built on a higher stock of human and institutional capital, leads to an ever-growing industrial specialization of the industrial economy. The agricultural economy, to the contrary, specializes more and more in agriculture.[8] As both the level and the growth rate of productivity in agriculture is lower than in industry, free trade perpetuates the low level and the low growth rate of productivity in the agricultural economy. Hence, free trade leads to structural hysteresis of economic development.

It is interesting to note that Smith himself discussed the effects of trade between "uneven" (i.e., agricultural and industrial) economies, too. However, contrary to List, he argued that the easiest way for an agricultural economy to develop its industry is to allow for free trade with industrial economies. This way, the gains from trade of the agricultural sector "gradually establish a fund, which in due time necessarily raise up all the artificers, industries and merchants whom it has occasion for" (Smith [1776] 1994: 728). This fund enables the agricultural economy to import capital goods that help to absorb technological progress from industrial economies.[9] This way, the agricultural economy can develop an industrial sector of its own. Hence, Smiths holds capital good imports to spread positive externalities on the productivity of all production sectors of the agricultural economy. In this sense, one

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7 List goes so far to state that the development of the industrial sector also favors the institutional and political development of a country. He argues that a growing industrial sector supports those social groups that have a self-interest in the establishment of efficient institutions and the establishment of a constitutional democracy.

8 Of course, since the positive externalities of the industrial sector also spread across the agricultural sector, the industrial economy also produces agricultural products at lower costs than the agricultural economy. Hence, it has an absolute cost advantage in both agriculture and industry. However, following the theorem of comparative advantage the agricultural economy nevertheless specializes on agriculture, if free international trade is granted.

9 Referring to the potential benefits of foreign trade for the economic development of China, Smith ([1776] 1994: 738) states: "A more extensive foreign trade, however, which to this great home market added the foreign market of all the rest of the world (...) could scarce fail to increase very much the manufactures of China, and to improve very much the productive powers of its manufacturing industry. By a more extensive navigation, the Chinese would naturally learn the art of using and constructing themselves all the different machines made use of in other countries, as well as the other improvements of art and industry which are practised in all the different parts of the world."

might say that Smith, contrary to List, holds positive externalities of the industrial sector not to be bounded within a country, but to spill over to the trade partners of industrial economies.

Both, the Smithian and the Listian theory of the interrelation between international trade and economic growth, display many features that can be found in the new theories of international trade and economic growth. For example, the endogenous growth models of Rivera-Batiz and Romer (1991a, 1991b) capture many of the ideas of Smith, while many Listian ideas can be found in the endogenous growth model of structural hysteresis of Grossman and Helpman (1991).[10] Section B.III discusses these theories in a detailed way. The new dynamic theories have rediscovered many themes of "classical" trade theory that were neglected for a long time. Today's theory of international trade displays therefore more variety than some decades ago. The renaissance of many themes from "classical" trade theories has extended the spectrum of interesting hypotheses. Especially, the set of theoretical possibilities for losses and gains from trade has been enlarged. These are the subject of the following section.

2. Basic Elements of the New and Old Theories of International Trade

Abstract: This section compares the sources of the gains from trade in the theory of comparative advantage (the "old" gains from trade) with those in modern theories of intraindustrial trade with differentiated goods (the "new" gains from trade). It is argued that both types of gains from trade are very different concerning the underlying microeconomic mechanics as well as their dynamic implications: The sources of the gains from trade in the theory of comparative advantage are due to country-specific differences in technologies, preferences and factor endowments. The sources of the gains from trade with differentiated goods run over a more complex transmission channel: International trade has a positive impact on the demand for differentiated goods. A higher demand for differentiated goods induces the production of a larger set of differentiated goods. A larger set of differentiated goods finally increases household utility or, depending on the assumptions of the model, total factor productivity. Given some further assumptions concerning the production function of the blueprints for differentiated goods, international trade may also induce a higher

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10 An early (two-period) international trade model of structural hysteresis that captures many features of the Listian theory is presented by Krugman (1981).

output of new technological knowledge per period and, thus, give rise to dynamic welfare gains.

a. The Gains from Trade in the Old Theories of International Trade

One of the basic theoretical conclusions, drawn from Ricardo's cloth and wine "parable," is the theorem of comparative advantage. According to this theorem, mutual beneficial trade is always possible, if the autarky prices of two countries are different, and free trade can never be welfare inferior to autarky, if autarky prices of two countries are identical. As is shown by Dixit and Norman (1980: Chapter 3) this theorem holds even under rather weak assumptions in a general equilibrium model.[11] Consequently, the sources for mutual beneficial trade arise from those determinants that cause a deviation of autarky prices from free trade prices. In Ricardo's example, these are the different production technologies between the countries. Different consumption preferences can be a second source of such a deviation. A third and less trivial reason, which was first stated by Heckscher (1935) and Ohlin (1933), are differences in factor endowments.[12] These differences can lead to a deviation of autarky and free trade prices even if technologies and preferences are identical.

Taken together, the gains from trade in the standard Ricardian theory of international trade arise from the differences between countries. These differences imply that production plans in a free trade equilibrium are never Pareto inferior but potentially Pareto superior to the production plans in autarky. If autarky prices differ, free trade leads to a reorganization of production plans, such that it is possible to produce more of all goods without an increase of inputs. Consequently, the old Ricardian gains from trade have the character of quantity gains. However, new developments in the theory of international trade have shown, there may be a second source of the gains from trade. These type of gains may be called quality gains.

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11 Dixit and Norman (1980: Chapter 3) prove that free trade is Pareto superior to autarky in an Arrow–Debreu-type general equilibrium economy with an arbitrary number of input factors, goods and consumers, who differ in their preferences, without the possibility of lump sum taxation, as long as each single commodity and input can be individually taxed. It should, however, be noted that the information requirements for the determination of the commodity and factor tax vector by the government are nontrivial.

12 As stated by Dixit and Norman (1980: 4), "This has proved the most enlightening explanation of comparative advantage, in that it yields the greatest variety of testable propositions."

b. The Gains from Trade in the New Theories of International Trade

Dixit and Norman (1980: Chapter 9.3) "discover" this source of the gains from trade in a model originally intended to explain the empirical observation that a large part of world trade is intraindustry trade.[13] Intraindustry trade cannot be explained within the theory of comparative advantage.[14] The basic innovation introduced by Dixit and Norman to explain intraindustry trade is the assumption of a special type of utility function (Dixit and Norman 1980: Chapter 9, 283–284).[15] Dixit and Norman assume that the number of different consumption goods is not fixed but endogenously determined within the model. As it turns out, this assumption, a minor variation of a seemingly harmless assumption of the Arrow–Debreu-type general equilibrium model, can have indeed important static and dynamic welfare implications. However, within the special setting of the Dixit–Norman model, only static welfare implications result. To derive these implications, consider the following Cobb–Douglas-type utility function:

$$[B.1] \quad u\left(X_0;\ X_1, \ldots X_n\right) = X_0^{1-\alpha}\left(\sum_i^n X_i^\beta\right)^{\frac{\alpha}{\beta}}, \text{ with } 0 < \alpha, \beta < 1 \text{ and } \alpha + \beta = 1 .$$

This function includes one "basic" good, X_0, and a set of n differentiated goods, X_i. The elasticity of substitution between two differentiated goods equals

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[13] The empirical observation that a large part of world trade is intraindustry trade was first stated in a study by Grubel and Lloyd (1975). They estimate that about 50 percent of world trade is intraindustry trade. The term "intraindustry trade" refers to the exchange of goods that are "similar", i.e., that are produced with similar factor intensities. However, by its definition, the Grubel and Lloyd index also interprets trade of goods with different factor intensities as intraindustry trade if they belong to the same statistical product category (e.g., chairs made of steel and chairs made of wood). Therefore, the Grubel and Lloyd index tends to overestimate trade of goods with similar factor intensities. For a discussion of this and related problems see Siebert (1994: 104–106).

[14] The theory of comparative advantage cannot explain the international exchange of goods with similar factor intensities, because comparative advantages refer to goods with different factor intensities only, i.e., interindustry trade. Therefore, according to the theory of comparative advantage international trade is always interindustry trade.

[15] The Dixit–Norman model reaches back to a model of Norman (1976). Similarly early approaches are Spence (1976) and Dixit and Stigliz (1977). A different approach able to explain intraindustry trade is the ideal variety model of Lancaster (1975). In this model, consumer do not prefer the pure variety of goods, but a supply of goods that help them to approach their ideal type of good.

$\varepsilon = 1/(1-\beta)$.[16] Consequently, the assumption $\beta < 1$ ensures that differentiated goods are imperfect substitutes. The assumption $\beta > 0$ ensures that differentiated goods are closer substitutes than differentiated goods and the basic good.[17] The assumptions $0 < \alpha < 1$ and $\alpha + \beta = 1$ ensure the concavity of the utility function.

The assumption that differentiated goods are imperfect substitutes implies that the introduction of a new differentiated good increases utility, although income spent for consumption stays constant. Consequently, without a quantitative increase of input, total utility grows. To derive this result from [B.1], let E be the part of income spent for consumption, p_x the uniform price for a differentiated good, and $p=1$ the price for the basic good. Given utility function [B.1], a household maximizes its utility, if he spends $(1-a)E$ on the basic good and αE on the differentiated goods.[18] As the price of differentiated goods is uniform and marginal utility of all differentiated goods is equal and decreasing, it follows that a household maximizes its utility, if αE is equally distributed across all differentiated products, i.e., $x_i = \alpha E/p_x n$. Inserting this in [B.1] yields:

[B.2] $$u(E, p_x, n) = b^b a^a E\, p_x^{-a}\, n^{a(1-b)/b}.$$

This indirect utility function shows that utility grows, if the number of differentiated goods, *n*, grows, even if everything else (i.e., total consumption expenditures and prices) stays constant. The reduction of the quantity per differentiated product that follows the introduction of a new good (remember: $x_i = aE/p_x n$) is more than compensated by the gain of marginal utility due to this reduction. Stated in another way, the property of diminishing marginal utility of differentiated goods implies that the introduction of a new good increases utility, because consumption expenditures can be spread across more goods (see Figure 1 for a graphical exposition).[19]

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16 See Appendix 1 for a derivation of ε from a similar type of function. For $\varepsilon \to \infty$, i.e., $\beta \to 1$, all X_i with $i = 1,2,3 \ldots n$ become perfect substitutes.

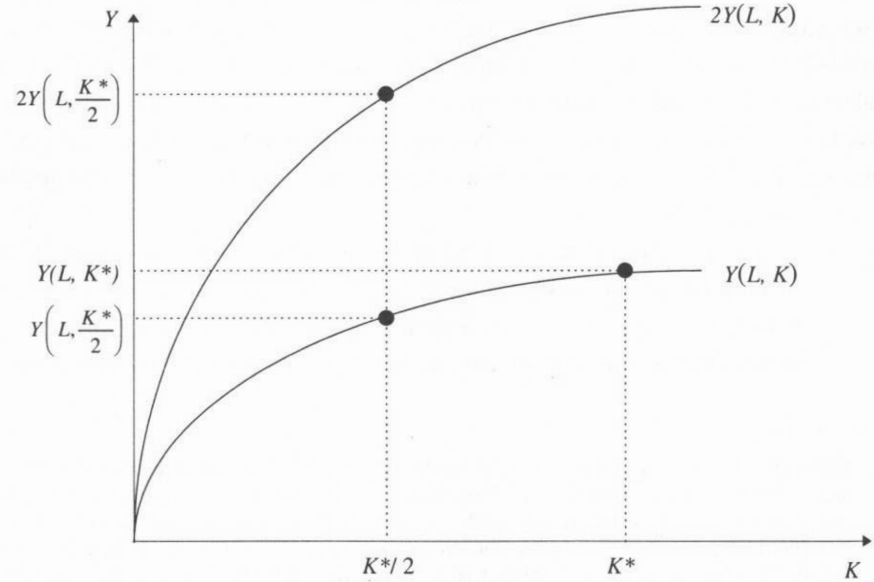
17 As the Cobb–Douglas specification implies, the technical rate of substitution between the basic good and a differentiated good equals $\varepsilon = 1$. The assumption $\beta > 0$ is "necessary" to justify the interpretation of differentiated goods as a "commodity group."

18 This follows from the first-order conditions for a maximum of [B.1], subject to the budget constraint

$$E = X_0 + \sum_i^n X_i\, p_x .$$

19 As derived in Appendix 2 this effect of the introduction of new goods holds also for less restrictive types of functions than [B.1]. A sufficient condition is a monotone function with all first-order partial derivatives positive and all second-order partial derivatives negative.

Figure 1 — The Geometry of the New Gains from Trade[a]



[a]This figure describes the "new gains from trade" due to the introduction of a new good. Two states are compared based on the production function given by [B.4]. In the first state $A = 1$ holds, i.e., only one type of capital good exists. In this case the whole stock of accumulated capital, K^*, has to be invested in this type of capital good. This leads to a total output given by $Y(L,K^*)$. In the second state $A = 2$ holds, i.e., a second type of capital good is introduced. Corresponding to [B.4], it is assumed that the marginal productivity of both types of capital goods is identical. Therefore, it is profit maximizing to allocate the stock of accumulated capital, K^*, equally across both types of capital goods. Consequently, the input per capital good now equals $K^*/2$. This leads to a reduction of output per capital good from $Y(L,K^*)$ to $Y(L,K^*/2)$. However, due to the decreasing marginal returns to capital, the reduction in output per capital good is much lower than the reduction of input quantity per capital good. As a result, total output, i.e., the sum of the output produced with both types of capital goods, is much higher than output in the first state: $2Y(L,K^*/2) > Y(L,K^*)$. Of course, this argument holds also, if $Y(L,K_i,\ i \in A)$ is interpreted as a utility function such that Y equals household utility, L equals some basic consumption good, and K_i equals a differentiated consumption good. In order for trade to increase the number of differentiated capital or consumption goods, some degree of scale economies in the production of differentiated goods must exist. In this case, a higher demand, due to international trade, makes the production of a larger variety of capital goods profitable. The most prominent candidate to cause these scale economies are of course research and development costs, necessary to invent the blueprint for the new differentiated good. As Rivera-Batiz and Romer (1991a, 1991b) show, if the accumulated knowledge, measured by the number of existing blueprints, displays the property of nondiminishing marginal returns in the production function of blueprints, there are scenarios where an increase of the demand for differentiated goods, due to international trade, can also give rise to the production of a greater number of new differentiated goods per period. Consequently, in this case, dynamic gains from international trade may arise.

Given this type of utility function, free trade can increase household utility, if it increases the number of available differentiated goods, n. Roughly spoken, there are two reasons, why trade increases the number of available differentiated goods. First, free trade allows for imports of differentiated goods produced abroad. Second, free trade increases export demand for domestically produced differentiated goods. Given some further assumptions, this can increase the domestic profits per differentiated good such that the production of a greater domestic set of differentiated goods becomes profitable.[20]

To sum up, free international trade can induce the production of new goods, because it increases demand for such goods. As the welfare gains from new goods are not generated by an increase in physical quantities, they have the nature of quality gains.[21] Romer (1994) states that the long-time neglect of welfare gains from the in-

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20 Within the model of Dixit and Norman (1980: Chapter 9.3) trade induces this effect primarily because of two assumptions. First, Dixit and Norman assume economies of scale in the production of differentiated goods. Second, they assume the range of varieties of differentiated goods to be so large that only a finite subset of this range is actually produced. The first assumption implies that a higher demand per differentiated good increases ceteris paribus profits per differentiated good. The second assumption implies that there is free entry to the production of differentiated goods. Consequently, an increase in the demand per differentiated good leads to an increase of the number of differentiated goods, until factor costs have reached a level, where profit per differentiated good is zero again. This adjustment process implies that factor inputs are shifted from the basic goods sector to the differentiated goods sector. For an analytical description see Dixit and Norman (1980: 281–294).

21 Dixit and Norman (1980: 273–281, 267–273) analyze two further "non-Ricardian" welfare effects of trade: a product selection effect, and a competition effect. The product selection effect can emerge within the above differentiated goods scenario, if the symmetry assumptions concerning the preferences and production technologies for differentiated goods are released. (Spence (1976) and Dixit and Stigliz (1977) are the first works which examine this product selection effect.) Roughly spoken, within this scenario, free trade may lead to a selection of differentiated goods by monopolistic producers, whose consumer surplus is low. If this is not compensated by a higher producer surplus, the net welfare effect may be negative. This potential negative product selection effect may reduce the above quality gains from the introduction of new products. Consequently, within the differentiated goods scenario the net welfare effect of free trade is ambiguous. It is, however, questionable, whether a monopolistic producer has actually an incentive to select typically goods whose consumer surplus is low. As monopolists try to capture a part of the consumer surplus, they have typically an incentive to select those goods whose consumer surplus is high. This possibility is excluded by some restrictive assumptions in the Dixit–Norman model (Dixit and Norman 1980: 267–273). The competition effect emerges only within a "homogenous goods scenario." Under the assumption that there are sufficient scale economies and free entry, the output of each firm engaged in the production of the homogenous good is determined by a Cournot–Nash equilibrium. Dixit and Stigliz (1977) show that an increase of demand through trade induces market entry of a greater number of firms. This, in turn, reduces the market

troduction of new goods may be due to a kind of "mental lock-in effect" of the Western way of thinking. Romer, following Lovejoy (1933), states that in Western philosophy the "principle of plenitude" is a widespread pattern of thinking. According to this principle the world is "full" in the sense that everything that can exist does already exist. Romer presumes this way of thinking to be a reflex of Plato's science theory. Plato states that the empirical world is a mirror of the "true world of ideals." As the "true world of ideals" is complete, everything already exists and nothing really new is possible.[22]

New Dynamic Gains from Trade with Consumption Goods

Within the setup of the Dixit–Norman model the quality gains from trade through the introduction of new goods are static. The ultimate reason for this is their assumption concerning the production technologies of new goods. As the introduction of a new good has no influence on the cost of the introduction of further new goods, only a fixed number of differentiated goods is introduced. However, if the production of a new good induces the production of technological knowledge, which reduces the production costs for the succeeding goods, a dynamic process of introduction of new goods and knowledge creation may emerge. As Romer (1986, 1990b) shows, in order to perpetuate this accumulation process, it is necessary to assume that accumulated knowledge displays the property of nondiminishing marginal returns in the production of new knowledge. Given this modification of the Dixit–Norman model, free trade can also affect the number of newly introduced goods per period. Consequently, free trade can give rise to dynamic quality gains. This kind of dynamic implications of a Dixit–Norman-type model are explored by the endogenous growth models of Grossman and Helpman (1991). They are discussed in Section B.III.2.

New Gains from Trade with Capital Goods

Standard models of comparative advantage focus on trade with consumption goods only. This is in a sense astonishing, because imports of capital goods may change

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power of each firm, such that the resulting Cournot–Nash price approaches the average cost price and the welfare of the representative household grows.

22 For an interesting analysis of Plato's influence on Western philosophy see Popper (1945). Popper also developed the "theory of emergence." According to this theory, in the course of evolution completely new things (physical, chemical, biological substances and regularities of their interaction, i.e., "natural laws") come into existence.

the comparative advantage of a country (Siebert 1994: Chapter 4.15).[23] Therefore, trade with capital goods may influence the predictions of the theory concerning the pattern of international trade. Additionally, from the empirical point of view, trade with capital goods plays an important role in world trade. A large and still growing part of world trade is trade with capital goods (about 30 percent of world trade and more than 50 percent of world manufacturing trade (see Section C.III.1, Figure 20).

Taking into account the basic symmetries between household and production theory, it is clear that the introduction of new capital goods can have similar effects as the introduction of new consumption goods. As is described in Appendix 2, every function with positive first-order derivatives and negative second-order derivatives, implies that the introduction of a new type of input increases the value of the function, even if the total quantity of input is held constant. The typical neoclassical production function displays these properties. Consequently, under the assumption of a neoclassical production function the introduction of a new capital good increases output, even if the total quantity of input is held constant. Therefore, the corresponding equivalent to the quality gains from the introduction of new consumption goods are productivity gains from the introduction of new capital goods. Romer (1994) demonstrates this effect based on a production function similar to the Dixit–Norman utility function ([B.1]):[24]

$$[B.3] \quad Y(L;\ X_1,\dots X_A) = L^{\alpha}\left(\sum_{i}^{A} X_i^{\beta}\right) \text{ with } 0 < \alpha, \beta < 1 \text{ and } \alpha + \beta = 1 .$$

Here Y is aggregated output, L is labor force, X_i is a differentiated capital good, and A is the number of all available differentiated goods. The interpretation of the restrictions on α and β corresponds to the interpretation of the same parameters of the utility function.

To derive the productivity gain from the introduction of a new capital good, assume for simplicity that the value of the accumulated capital stock equals K and the price of a capital good is uniform and equals unity. Since the marginal productivity of each capital good is the same, a necessary condition for a profit maximum

23 Oniki and Uzawa (1965) present a two-sector Solow–Swan growth model, where the impact of international trade with capital goods on the dynamics of comparative advantage is analyzed. One of their basic conclusions is that in transition to the steady state (due to the convergence of the per capita capital stocks) comparative advantages disappear and, hence, as the model does not include trade with differentiated goods, international trade disappears, too.

24 Ethier (1982) presents the first model of international trade which is based on this type of production function.

is that the accumulated capital stock is equally distributed across all types of capital goods, i.e., $X_i = K/A$.[25] Inserting this into [B.3] yields:

[B.4] $Y(L,K,A) = L^{1-a} A^{1-b} K^{b}$.

Consequently, even if the input of labor and accumulated capital stays constant, the introduction of a new capital good increases output. Romer (1994) shows that under similar conditions as those stated in the model of Dixit and Norman (1980: Chapter 9.3), the set of available capital goods increases, if the demand per capital good increases. Therefore, free trade increases the capital goods variety, because it increases the demand per differentiated capital good. As a result, free trade can also lead to productivity gains.[26]

Dynamic Gains from Trade with Capital Goods

Within the setup of the Romer model (Romer 1994) the productivity gains from trade through the introduction of new capital goods are static. Under similar assumptions as described above, free trade can give rise to dynamic productivity gains.[27] Consequently, free trade with capital goods can be an important determinant of economic growth. This kind of dynamic implications of trade with capital goods are explored by the models of endogenous growth of Rivera-Batiz and Romer (1991a, 1991b). They are discussed in Section B.III.1. Contrary to the dynamic quality gains, which are utility gains, the productivity gains from trade are output gains.[28] As output is, contrary to utility, directly observable, it should, in principle, be possible to derive empirically testable hypotheses from this type of model. This idea is carried out within the empirical analysis in Section C.III. The following

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25 In principle, one of two alternative assumptions is necessary to allow for this optimal adjustment of the capital stock to the number of capital goods. One assumption is capital depreciation per period is 100 percent, such that K equals investment per period. (This assumption is typically made in models of endogenous growth following Romer (1986, 1990.) The other assumption is the absence of any vintage effects, such that invested capital can be arbitrarily reallocated at each point in time.

26 The assumptions, necessary to allow for a decentralized market equilibrium given this type of production function, are discussed in Section III.1.

27 Necessary assumptions are: (1) the creation of new capital goods implies the production of technological knowledge, which reduces the production costs of further technological knowledge, and (2) the accumulated knowledge displays nondiminishing marginal returns in the production of new technical knowledge.

28 In this sense, they are of course "quantity gains." As they arise, however, from a different source as the Ricardian "quantity gains," they are labeled here with the term "productivity gains."

section explores the implications of free trade on capital accumulation in neoclassical growth models.

II. International Trade in Solow–Ramsey Growth Models

1. The One-Sector Solow–Ramsey Model: Intertemporal Trade

Abstract: This section describes the interrelation between international trade and capital accumulation in the Solow–Ramsey growth model under the assumption of perfect competition on the domestic capital goods market. Several types of free-trade steady states are discussed. From this analysis follows that international trade can only affect the transitional growth rate if financial markets allow for free international lending and borrowing. In this case capital flows to the country that displays the largest relative distance to its specific steady state and, hence, displays the highest interest rate. It turns out: this is not necessarily the country with the lowest per capita gross domestic product. Countries that experience capital inflows in transition to the steady state reach a higher transitional growth rate. However, the "price" for this faster transition to the steady state is a lower steady-state level of the gross national product, because the accumulated debt causes permanent (steady-state) interest payments to the creditor country. The steady-state level of per capita gross domestic product is not affected by capital flows. Depending on the relative size of a country, capital inflows from abroad do not necessarily lead to an immediate jump to the steady state.

a. The Setup of the Solow–Ramsey Model

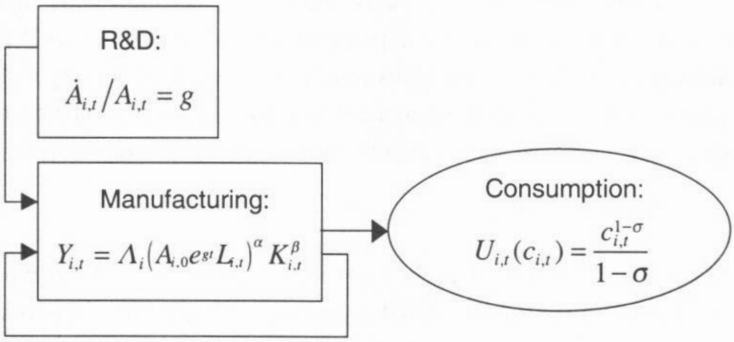
Standard neoclassical growth models focus on the interrelation between savings, capital accumulation and the development of per capita income. Their primary concern is not the explanation of the interdependence of international trade and economic growth. Nevertheless, within a standard neoclassical growth model of the Solow–Ramsey type, international trade can affect the development of per capita income via its impact on the process of capital accumulation in transition to the steady state.

To demonstrate this effect, consider the following two-country version of the Solow–Ramsey model (Figure 2).[29] Aggregate output (i.e., GDP) of country i at period t is given by the following Cobb–Douglas-type function:

[B.5] $Y_{i,t} = \Lambda_i \left(A_{i,t} L_{i,t}\right)^{\alpha} K_{i,t}^{\beta}$ with $\alpha+\beta=1$, $0<\alpha,\ \beta<1$, and $i=A,B$,

where $L_{i,t}$ is population and labor force of country i at period t, $A_{i,t}$ is a measure of labor productivity, $K_{i,t}$ is the stock of accumulated capital, Λ_i is a measure of government performance and/or the endowment of the economy with public goods not accumulated by market forces. For the ease of exposition, Λ_i is assumed to be exogenous.[30] It is assumed that A and L grow with exogenous rates, $A_{i,t} = A_{i,0}\, e^{gt}$ and $L_{i,t} = L_{i,0} e^{nt}$.

Figure 2 — The Standard Solow–Ramsey Model with Exogenous Productivity Growth



29 The Solow–Swan model differs from the Solow–Ramsey model by the assumptions concerning savings behavior: while the Solow–Ramsey model assumes intertemporal utility maximization (see Appendix 3) the Solow–Swan model assumes a constant savings quota. However, this difference does not essentially change the above results.

30 For example, Λ_i may reflect tax policies, implementation of property rights, legal and political security, transport and telecommunication infrastructure, education services and so on. The reasons, these public goods are not accumulated by market forces, may be of economic (exclusion of nonpayers is not possible) or legal (private investments in this sphere are prohibited by law) nature. This way of reflecting all these factors is of course a bold simplification: the assumption $\alpha + \beta = 1$, implies that Λ_i is nonrival in consumption (Romer 1990a). While this holds for some public goods (the "lighthouse"-type ones like legal and political security), it does not hold for others like transport and telecommunication infrastructure. For these, some allocation or compensation rules have to be introduced. However, given the setup of this model, this would presumably not change the above results qualitatively.

The capital stock $K_{i,t}$ consists of homogenous capital goods and is accumulated endogenously. A speciality of this model is the assumption that there exists only one good, the fabulous neoclassical "universal good," which can be used for consumption as well as production input. Consequently, the relative price of capital goods and the price of consumption goods is identical and equals unity. In order to derive the steady-state solutions, all variables have to be expressed in effective labor intensities. Define therefore $\bar{y}_{i,t} = Y_{i,t}/A_{i,t}L_{i,t}$ and $\bar{k}_{i,t} = K_{i,t}/A_{i,t}L_{i,t}$.[31] Using these definitions, [B.5] can be rewritten:

[B.6] $\bar{y}_{i,t} = \Lambda_{i,t}\,\bar{k}_{i,t}^{\beta}$.

In an open economy, total expenditure adds up to GDP according to the following identity:

[B.7] $Y_{i,t} = C_{i,t} + \delta K_{i,t} + \dot{K}_{i,t} + X_{i,t} - M_{i,t}$,

where $C_{i,t}$ is consumption in country i at period t, $\delta K_{i,t}$ is capital consumption per period, $\dot{K}_{i,t}$ is net investment, $X_{i,t}$ are exports and $M_{i,t}$ are imports.[32] By the current account identity the trade balance surplus equals the decrease of country i's net debt position plus interest payments to foreign holders of domestic debt. Hence, defining $D_{i,t}$ to equal the countries net debt position, the trade balance surplus equals:

[B.8] $X_{i,t} - M_{i,t} = -\dot{D}_{i,t} + r\,D_{i,t}$.

Rewriting [B.7] in terms of effective labor intensities yields the consumption per effective worker in dependence of capital and foreign debt per effective worker:[33]

[B.9] $\bar{c}_{i,t} = \Lambda_i\,\bar{k}_{i,t}^{\beta} - \dot{\bar{k}}_{i,t} - (g+n+\delta)\bar{k}_{i,t} + \dot{\bar{d}}_{i,t} - (r-g-n)\bar{d}_{i,t}$.

In a steady state all variables expressed in effective labor intensities are constant, i.e., $\dot{\bar{k}}_{i,t} = \dot{\bar{d}}_{i,t} = 0$. The transversality condition implies $r > g+n$.[34] Consequently, a

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31 As follows from these definitions, a bar above a variable ($\bar{\ }$) indicates that the variable is measured in efficiency units.

32 A point above a variable ($\dot{\ }$) indicates the first derivative of this variable with respect to time. Consequently, a variable with a point divided by the same variable without a point equals the growth rate of this variable.

33 See Appendix 3 for an explicit derivation.

34 The transversality condition follows from the first order conditions for an intertemporal utility maximum. Intuitively spoken, if the transversality condition does not hold, i.e., $r < g + n$, it would be suboptimal for a household to accumulate savings, because inter-

country that has accumulated in its transition to the steady state a net debt position against foreign countries, $\overline{d}_{i,t} > 0$, will have a lower steady-state level of gross national product (GNP) and a lower steady-state level of consumption.

b. The Autarky Steady State in the Solow–Ramsey Model

To derive the consequences of free trade for the development of both economies, it is useful to determine first the autarky steady states. Consider therefore Figure 3. The upper diagram is the $(\overline{c},\overline{k})$ plane. The semicircles are the $\dot{\overline{k}}_{i,t} = \dot{\overline{d}}_{i,t} = \overline{d}_{i,t} = 0$ loci of country A and B. The condition $\overline{d}_{i,t} = 0$ implies that each locus describes such $(\overline{c},\overline{k})$ combinations reached without international lending or borrowing, i.e., in autarky. The locus of country B lies inside the locus of country A, because the endowment of country B with public goods is assumed to be smaller than the endowment of country A, i.e., $\Lambda_A > \Lambda_B$.[35]

The $\dot{\overline{k}}_{i,t} = \dot{\overline{d}}_{i,t} = 0$ loci enclose all those $(\overline{c},\overline{k})$ combinations which are candidates for autarky steady states, because $\dot{\overline{k}}_{i,t} = \dot{\overline{d}}_{i,t} = 0$ holds along these loci. Which $(\overline{c},\overline{k})$ combination is chosen, depends on the intertemporal consumption preferences of the households. If Ramsey-type intertemporal utility maximization is assumed, the first-order conditions for an intertemporal utility maximum imply the following optimality condition to hold:[36]

$$[\text{B.10}] \quad \frac{\dot{\overline{c}}_{i,t}}{\overline{c}_{i,t}} = \sigma^{-1}\left(r_{i,t} - \rho - \sigma g\right),$$

where σ equals the elasticity of intertemporal consumption substitution and ρ is the rate of time preference (see Appendix 3). Consumption growth is only possible, if households save. Consequently, [B.10] implies that saving takes place as long as the market interest rate, $r_{i,t}$, is higher than the marginal utility loss of saving. The marginal utility loss of saving equals the rate of time preference, ρ, plus a term σg,

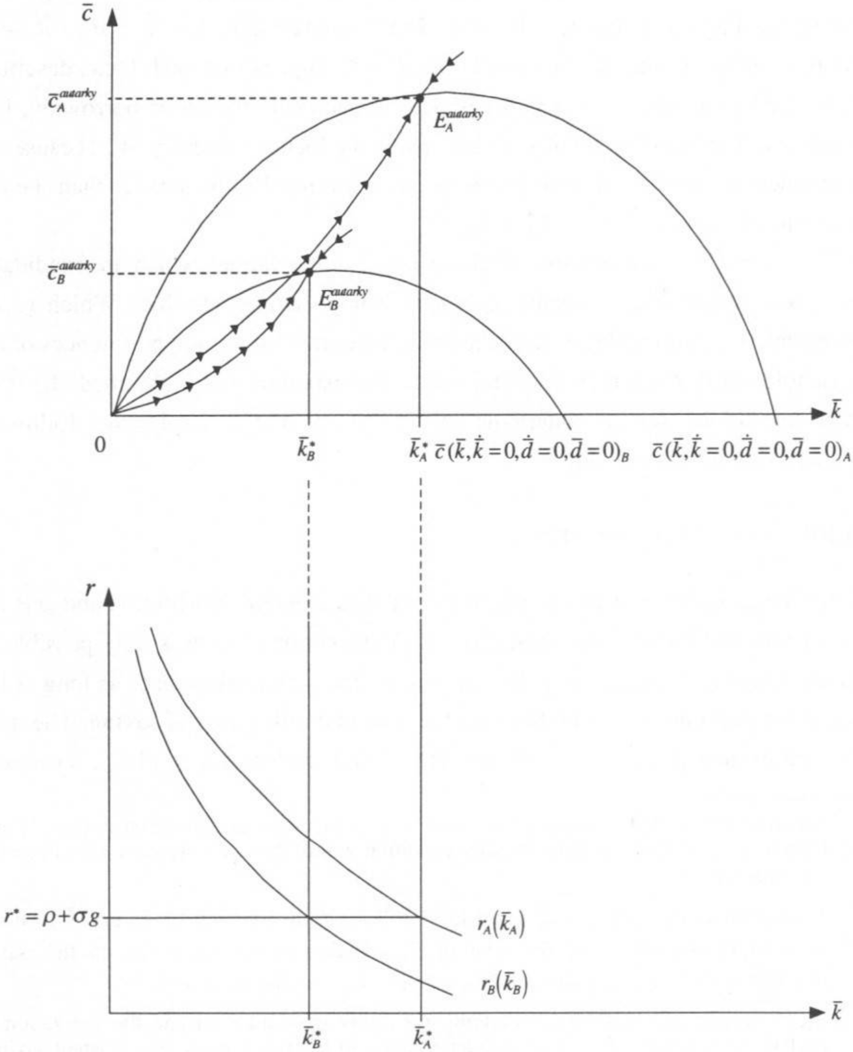
temporal utility could always be increased if savings were used for consumption. For a formal derivation of the transversality condition within the above type of growth model see Appendix 3.

35 The curvature of the ($\dot{\overline{k}}_{i,t} = \dot{\overline{d}}_{i,t} = 0$) locus follows from equation [B.9]. For $\overline{k}_{i,t} = 0$ and $\overline{k}_{i,t} = (\Lambda_i / (g+n+\delta))^{1/(1-\beta)}$ the value of $\overline{c}_{i,t}$ equals zero and the locus cuts the x-axis. For $\overline{k}_{i,t}^{\max} = (\beta\Lambda_i / (g+n+\delta))^{1/(1-\beta)}$ the value of $\overline{c}_{i,t}$ reaches its maximum.

36 For a description of Ramsey intertemporal utility maximization and the derivation of [B.10] see Appendix 3. Instead of intertemporal utility maximization a constant savings ratio can be assumed. The first assumption yields the Solow–Ramsey model, the latter yields the Solow–Swan model.

which emerges due to the fact that consumption is measured here per effective worker. A steady state requires that all variables expressed in effective worker intensities are constant. Hence, in the steady state the growth rate of consumption per effective worker is zero, i.e., $\dot{\bar{k}}_{i,t} = \dot{\bar{d}}_{i,t} = 0$. Consequently, it follows from [B.10] that in the steady state the interest rate must equal:

Figure 3 — The Autarky Steady States in Country *A* and *B*



[B.11] $r_{i,t} = \rho + \sigma g$.

Capital demand per effective worker follows from the first-order conditions for a profit maximum of the representative firm. This implies the equalization of marginal net productivity of capital with the interest rate (see Appendix 3.4 for a derivation).[37] This yields:

[B.12] $r_{i,t} = \Lambda_{i,t} \beta \bar{k}_{i,t}^{-(1-\beta)} - \delta$.

The lower diagram in Figure 3 displays the curvature of the capital demand function per effective worker in the $(r, \bar{k})$ plane. As follows from [B.12], the higher the interest rate, the lower capital demand per effective worker.

The horizontal line in the $(r, \bar{k})$ plane gives the value of the steady-state interest rate according to [B.11]. The intersection point of this horizontal line with the capital demand per effective worker determines the steady-state capital stock per effective worker, $\bar{k}_A^*$ and $\bar{k}_B^*$. Analytically, this capital stock can be derived by inserting the steady-state level of the interest rate from [B.11] in [B.12] and solving for $\bar{k}_{i,t}$. This yields the steady-state level of the capital stock depending on the structural parameters of the economy and its endowment with public goods:

[B.13] $$\bar{k}_i^* = \left(\frac{\beta \Lambda_i}{\rho + \sigma g + \delta} \right)^{\frac{1}{1-\beta}} .$$

Hence, the steady-state capital stock per effective worker is higher, the higher the endowment of the economy with public goods, Λ_i . Dynamic efficiency holds only, if it is not possible to increase steady-state consumption per effective worker without increasing the capital stock per effective worker. Hence, all $(\bar{c}, \bar{k})$ combinations to the right of the capital stock per effective worker, where $\bar{c}_{i,t}$ reaches its maximum, i.e., the so-called "golden rule" capital stock, $\bar{k}_i^{\max}$ (see Footnote 35), cannot be dynamically efficient. The transversality condition, $r > n + g$, together with [B.10] implies that $\bar{k}_i^* < \bar{k}_i^{\max}$ holds, if and only if $\rho > n + (1 - \sigma) g$ (see Appendix 3). Hence, in order to have a dynamically efficient steady-state solution, it has to be assumed that the rate of time preference, ρ, is sufficiently high. Beside this, the inequality $\rho > n + (1 - \sigma) g$ is necessary to ensure that the household intertemporal utility problem is well defined (see Appendix 3). In Figures 3–6, the optimal capital stock per effective worker, $\bar{k}_i^*$, is plotted to the left of $\bar{k}_i^{\max}$, indicating that the optimal capital stock is smaller than the "golden rule" capital stock. As $\Lambda_A > \Lambda_B$ is assumed,

37 Marginal net productivity of capital equals marginal productivity of capital minus the rate of capital depreciation.

this implies that the steady-state capital stock per effective worker in country A is higher than in country B. The intersection points of the vertical lines at $\bar{k}_A^*$ and $\bar{k}_B^*$ with the corresponding $(\dot{\bar{k}}_{i,t} = \dot{\bar{d}}_{i,t} = 0)$ loci determine the autarky steady-state value of consumption per effective worker, $\bar{c}_A^{autarky}$ and $\bar{c}_B^{autarky}$.

Now consider the transition path of both economies in autarky. Given the setup of the above model, the steady state is saddlepoint stable (Intrilligator 1971). Therefore, only one stable transition path to the steady state exists. In Figure 3 this transition path is indicated by arrows $(0, E_A^{autarky})$ and $(0, E_B^{autarky})$. A deviation from this path would eventually hurt the conditions for an intertemporal household optimum. Consequently, given an initial capital stock, $\bar{k}_A^0 < \bar{k}_A^*$ and $\bar{k}_B^0 < \bar{k}_B^*$, households choose their consumption level such that their $(\bar{c}_{i,t}, \bar{k}_{i,t})$ combination lies on the stable transition path.[38] Along this path, capital stock per effective worker grows such that, according to the assumption of marginal diminishing returns to capital, the market interest rate decreases until it reaches the level where, according to [B.10], no more saving per effective worker takes place and the steady-state capital stock per effective worker is reached (see the lower diagram of Figure 3).

c. The Free-Trade Steady States in the Solow–Ramsey Model

Consider now what happens, if both economies open for free trade. The term "free trade" is defined here as free trade with goods as well as free trade with capital services. Hence, not only perfect international mobility of goods but also perfect international mobility of capital is postulated.[39] In this case several different scenarios can emerge. To display the basic mechanisms, four of these scenarios are discussed in the following. First, think of a situation where both countries are in their autarky steady states, i.e., $\bar{k}_A = \bar{k}_A^*$ and $\bar{k}_B = \bar{k}_B^*$ (Figure 3). In this case a change of the trade regime from autarky to free trade has no consequences. No international exchange of goods takes place. This follows from the assumption that only one type of good exists, the neoclassical universal good. This assumption obviously implies that countries cannot display different comparative advantages in the production of goods.

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38 This implies the assumption that households have perfect foresight.

39 In general, international trade with goods is also possible without international capital mobility. In this case, the trade balance has to be in equilibrium each point in time, i.e., exports of goods must equal imports of goods. However, this excludes the possibility of "intertemporal trade," i.e., the possibility of buying (or selling) goods abroad today and paying (or charging) them tomorrow inclusive the corresponding interest payments. As it turns out, without this possibility, no international trade with goods takes place in Solow–Ramsey models with a homogenous "universal" good only.

Consider now, for simplicity, a situation wher e country A, call it the developed country, is already in steady state, while country B, call it the developing country, has not yet reached its steady state. In Figure 4 this implies that the capital stock per effective worker of country A equals its steady-state level, i.e., $\bar{k}_A = \bar{k}_A^*$, while country B has a capital stock per effective worker lower than its steady-state level, $\bar{k}_B^0 < \bar{k}_B^*$. This configuration implies that the interest rate in country B is above its steady-state value and, therefore, above the interest rate in country A (lower diagram of Figure 4). A change from autarky to free trade offers now a possibility to exploit this interest rate difference: Country A lends capital to country B at the interest rate r_B^0. Thereby, it realizes an arbitrage profit per unit capital of $r_B^0 - r^* > 0$. In turn, country B uses this credit to import the corresponding amount of the universal good from country A. Finally, these imports are invested in the capital stock of country B. These investments will instantaneously reduce the interest rate in country B such that (by [B.11]) the optimal growth rate of consumption in country B decreases and households of country B save less. Consequently, the transition path to the steady state in country B lies now at a lower level. In Figure 4 this is indicated by the arrows. During the transition to the steady state, the net debt position of country B against country A grows, until the steady-state capital stock per effective worker is reached (middle diagram in Figure 4). In the steady state, the interest payments from country B to country A increase the consumption per effective worker in country A from $\bar{c}_A^{autarky}$ to $\bar{c}_A^{trade}$. In country B the interest payments lead to a lower steady-state level of consumption per effective worker than in autarky, i.e., $\bar{c}_B^{trade} < \bar{c}_B^{autarky}$. This relation of steady-state consumption and debt is described by [B.9]. The difference between $\bar{c}_A^{trade}$ and $\bar{c}_A^{autarky}$ and between $\bar{c}_B^{trade}$ and $\bar{c}_B^{autarky}$ corresponds to the difference between GNP per effective worker and GDP per effective worker. The capital exports from country A to country B increase of the transitional rate of capital accumulation in country B. This, in turn, increases the transitional growth rate of GDP per effective worker. As a consequence, country B reaches its steady state faster than in autarky. The "price" the households of country B have to pay for this shorter transition period, is a lower steady-state consumption per effective worker.[40]

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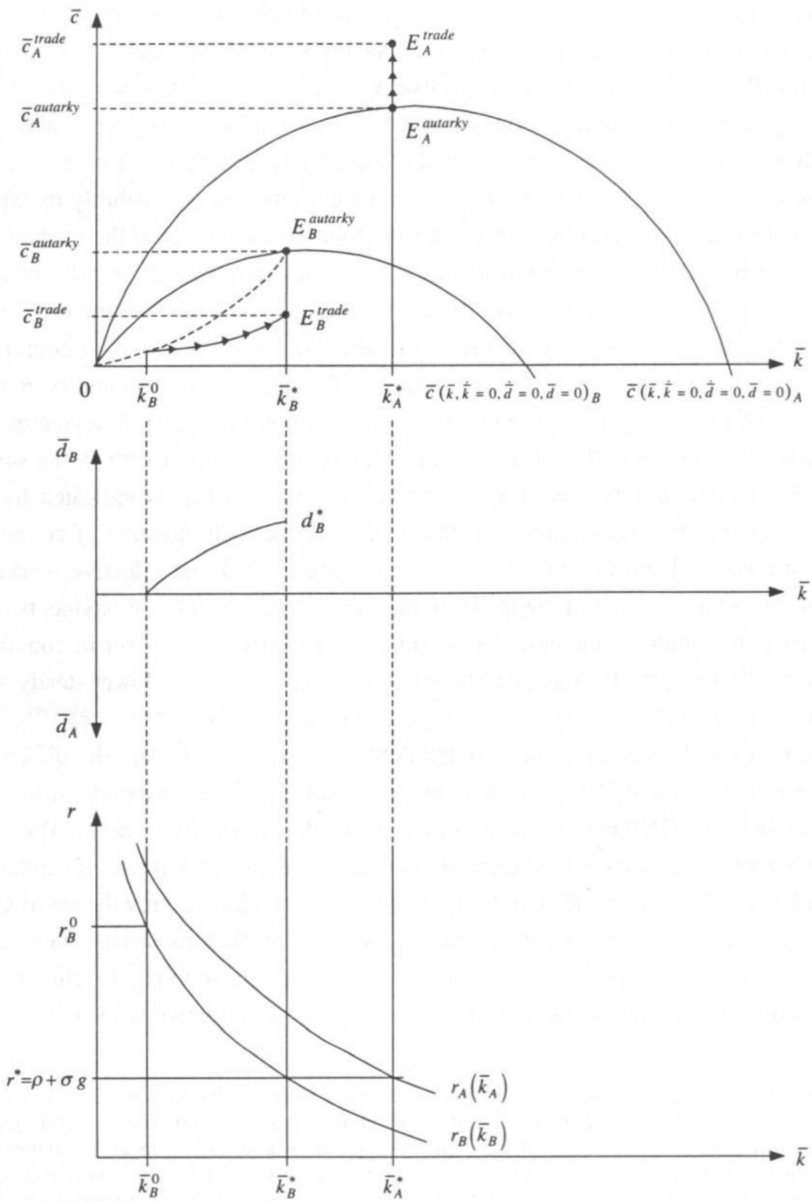
[40] This scenario is called the half-debt cycle (Siebert 1987, 1989). In general it is possible to assume that the net debt position of both countries has to be zero after a certain period of time. In this case a path of development evolves where country B accumulates debt during the transition period and repays its debt, when it has reached its steady state. One reason for the imposition of a finite credit horizon may be the fact that parents typically do not want to leave debt to their children. However, within the framework of the model a net debt position of a country does not necessarily imply that debt is left to children. One can interpret a net debt position as a situation where the households of country A own a part of the capital stock of country B, such that no direct personal creditor–debtor

Figure 4 — Free-Trade Transition Path with Out-of-Steady-State Starting Position of Country B



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relation exists. Therefore, households of country B do not have to leave debt to their children, even if the country as a whole displays a net debt position against country A.

The free trade transition path displayed by Figure 4 is based on the simplifying assumption that country A is already in its steady-state position. Consider now the case where both country A and country B are out of steady state when the transition from autarky to free trade takes place. Several scenarios are possible depending on the relative out-of-steady-state position of each country. In Figure 5 a scenario is shown where in the beginning the capital stock per effective worker of country A is, although out of steady state, so large that the autarky interest rate in country A is lower than in country B, i.e., $r_A^0 < r_B^0$ (lower diagram of Figure 5). Consequently, immediately after the transition to free trade capital accumulation in country A stops and instead the savings of country A flow to country B yielding a higher interest rate there. In the upper diagram of Figure 5, this is indicated by the vertical intercept of the transition path of country A. After the interest rate in country B reaches the level of the interest rate in country A, i.e., $r_B = r_A^0$, a part of the further savings made by country A remains in country A. Precisely spoken, only a quantity of savings large enough to equalize the interest rate of country B with the interest rate of country A still flows from country A to country B. In the middle diagram of Figure 5, this reduction of the capital flow from country A to country B is indicated by a slower increase of the net debt position path of country B. At the end of the transition process, the free-trade steady states correspond to the steady states described in Figure 4 with one exception: since after the equalization of interest rates in both countries a part of the savings of country A remains in country A, the net debt position of country B is not that large as in Figure 4. This implies that the transition period of country B is now longer than in the scenario described by Figure 4.

In the scenarios displayed by Figures 4 and 5, capital flows from the capital-rich country to the capital poor country. Hence, roughly spoken, capital flows from the "rich" to the "poor." However, as displayed by the scenario of Figure 6, the neoclassical growth model is also able to explain the case where capital flows from the "poor" country to the "rich" country.

In this scenario the capital stock per effective worker in country A is lower than its steady-state level, i.e., $\bar{k}_A^0 < \bar{k}_A^*$, while the capital stock of country B is in the steady state, $\bar{k}_B = \bar{k}_B^*$. Consequently, the interest rate in country A is higher than in country B. Therefore, capital now flows from country B to country A, and country A accumulates in transition to the steady state a net debt position (middle diagram of Figure 6). In the steady state, this net debt position equals d_A^*. As a result, the steady-state consumption per effective worker in country A is lower than in autarky,

Figure 5 — Free-Trade Transition Path with Out-of-Steady-State Starting Position of Country *A* and *B*

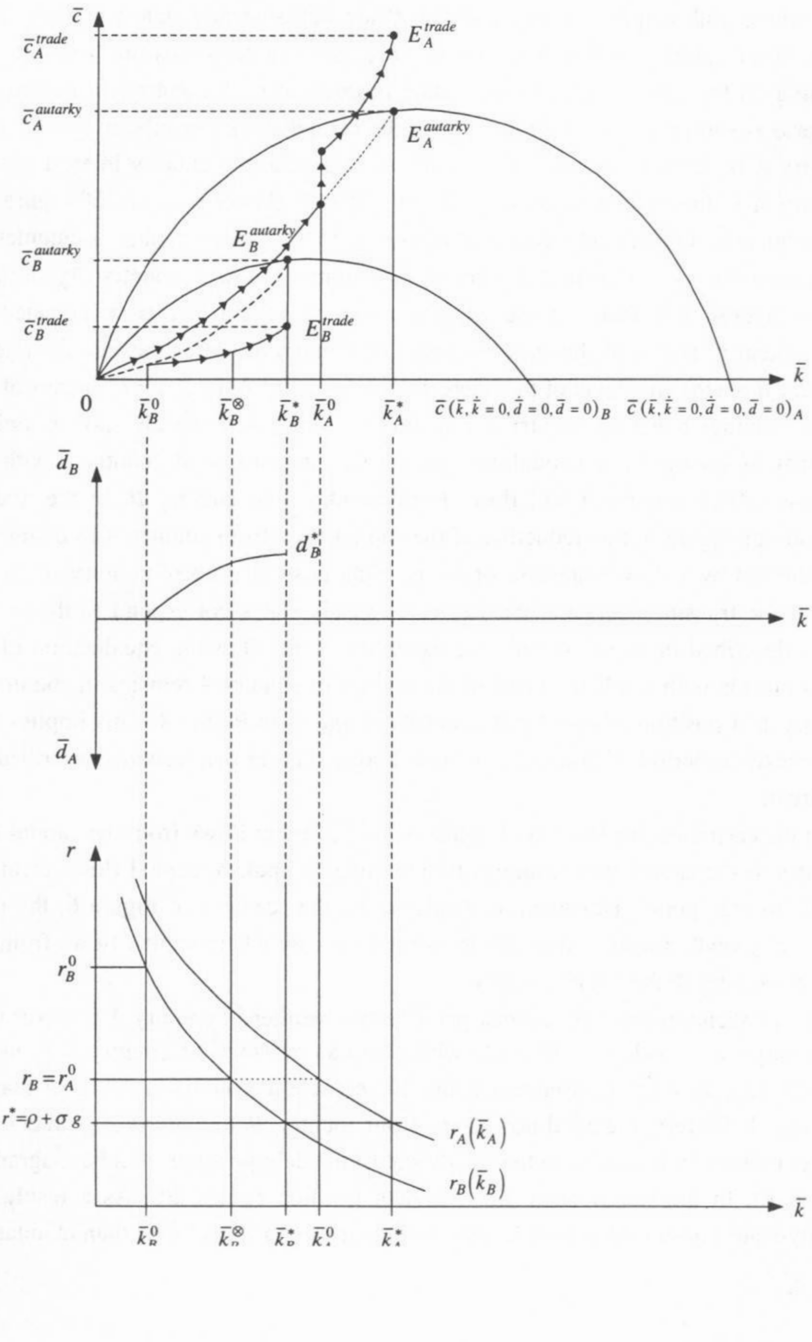
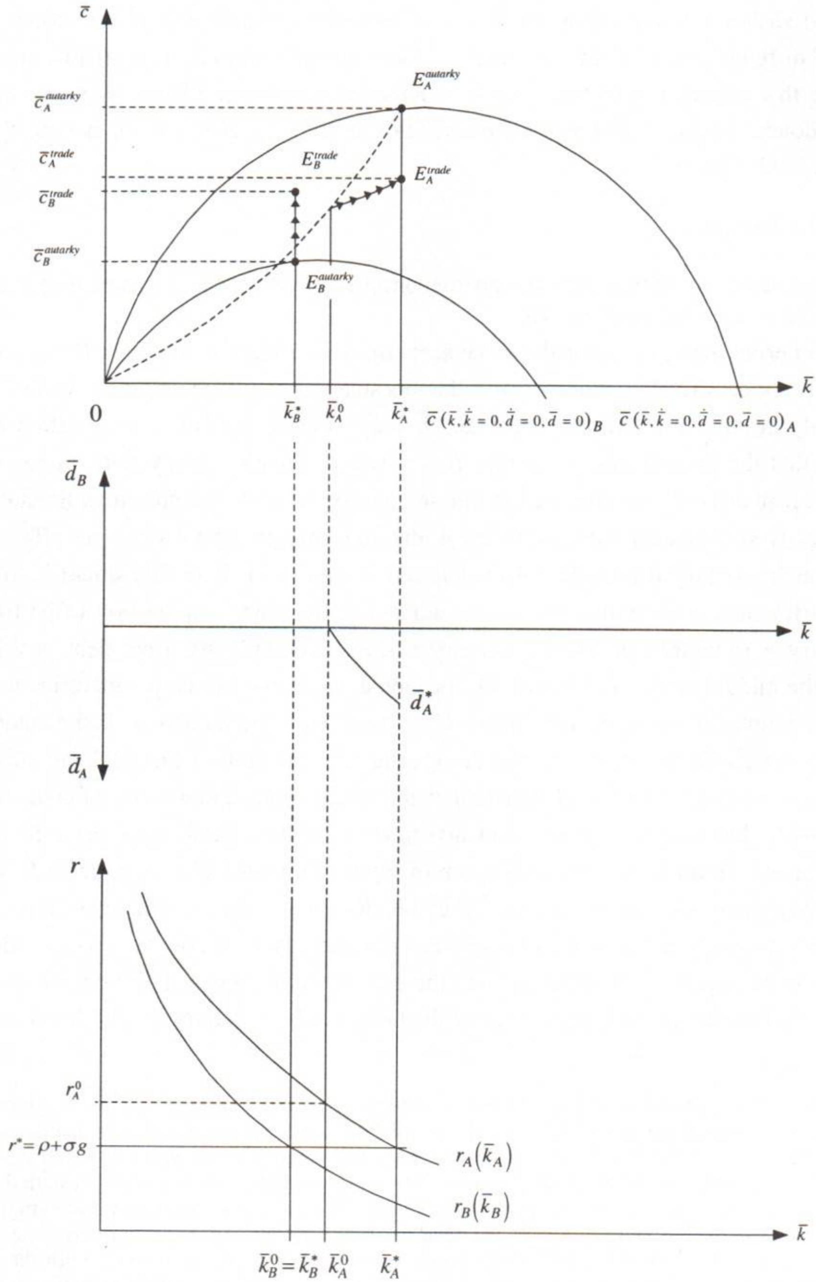


Figure 6 — Free-Trade Steady State with Out-of-Steady-State Starting Position of Country *A*



i.e., $\overline{c}_A^{trade} < \overline{c}_A^{autarky}$ and the steady-state consumption in country B is higher than in autarky, i.e., $\overline{c}_B^{trade} > \overline{c}_B^{autarky}$ (Figure 6).[41]

A fourth scenario can emerge, if the representative households of both countries have different rates of time preference. This scenario implies that [B.11], which states that households of both countries have the same rates of time preference, is abandoned. Suppose that instead households in country B are more patient than households country A:

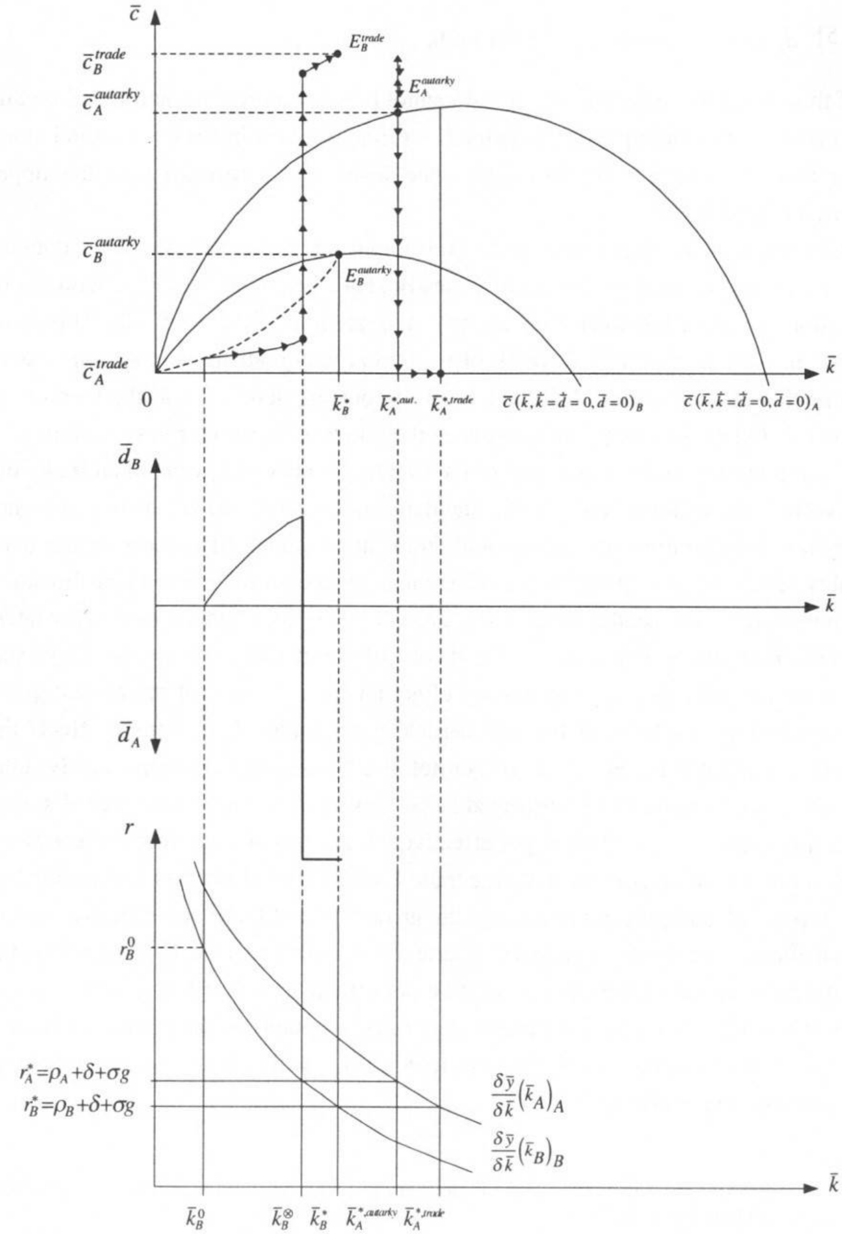
[B.14] $\rho_B < \rho_A$.

As it turns out in this case, the open-economy version of the standard model displays some extreme implications.

To derive these, consider the same scenario as in Figure 4. Country B has a capital stock per effective worker lower than its steady-state value, $\overline{k}_B^0 < \overline{k}_B^*$, while A is already in its autarky steady state, i.e., $\overline{k}_A = \overline{k}_A^*$ (Figure 7). This configuration implies that the interest rate in country B is above its autarky steady-state value. Assume, furthermore, that the interest rate in country B is even higher than the autarky steady-state interest rate in country A, due to a smaller capital stock per effective worker in country B (see the lower diagram in Figure 7). If in this situation, both countries change the trade regime from autarky to free trade, capital flows first from country A to country B. Hence, country B starts accumulating a net debt position (see the middle diagram of Figure 7). As soon as the capital stock per effective worker in country B has reached the level $k_B^{\otimes}$, where the interest rate equals the autarky steady-state interest rate of country A, r_A^*, the accumulation of physical capital per effective worker in country B stops. Since the return from capital assets of country A is now higher than the return from investments in the capital stock per effective worker in country B (see lower diagram of Figure 7), households of country B start to repay their debt to country A. After all debt has been repaid, households of country B start to accumulate a net creditor position vis-à-vis country A (see middle diagram of Figure 7). Country A uses the credits from country B for consumption only. As the rate of time preference of the households in country A is higher than in

41 A further scenario, which can generally emerge within the standard model, is given if both countries are out of their steady states. However, the results are not qualitatively different from the above scenarios, where only one country is out of steady state. If both countries are out of steady state, capital flows to that country whose ratio of installed capital stock to the steady-state capital stock is smaller, such that its interest rate is higher. Once the international capital flows have equalized the interest rates, both countries simultaneously approach their steady states. In the steady state, the country with the net foreign debt position has a lower level of consumption per effective worker than in autarky, while the other country has a correspondingly higher level.

Figure 7 — Free-Trade Steady State with Higher Rate of Time Preference in Country *A*



country B, country A accumulates more and more debt until its interest payments are so high that consumption per effective worker equals zero. From [B.9] follows:

$$[B.15] \quad \bar{d}_{i,t}\left(r-g-n\right)=\Lambda_i\,\bar{k}_{i,t}^{\beta}-\left(g+n+\delta\right)\bar{k}_{i,t}\,.$$

If this situation is reached, country A cannot pay the interest for additional credits from country B. Consequently, country B returns to invest in his own capital stock per effective worker, until the steady-state level $\bar{k}_B^*$ is reached (see the upper diagram in Figure 7).[42]

As a result, in the final steady state, consumption per effective worker in country B is much higher than in the autarky steady state, i.e., $\bar{c}_B^{trade} > \bar{c}_B^{autarky}$, while consumption per effective worker in country A is zero, $\bar{c}_A^{autarky} > \bar{c}_A^{trade} = 0$. This is of course an extreme result.[43] To think of it in a halfway realistic manner, one has to assume that at least some subsistence level of consumption is left to the workers in country A. Otherwise, they cannot produce the goods to serve their interest duties.

To sum up the results: compared to the standard theory of international trade, the motive for international trade in the standard neoclassical growth theory does not arise from comparative advantages, but from international differences in the marginal productivity of capital. These differences induce an international reallocation of savings. In this sense the neoclassical growth theory highlights a motive for international trade that is not found in the theory of comparative advantage. However, free trade can only display a temporary effect on the dynamics of the model: given the standard assumptions of the neoclassical growth model, free trade affects the growth rate of GDP per effective worker not, if all economies are in the steady state. The influence of free trade is restricted to periods where countries are out of steady state. If a country's capital stock per effective worker is that small that it exceeds the interest rate of the other countries, free trade leads to capital imports to this country. The imports of foreign capital increase the growth rate of GDP per effective worker in transition to the steady state, but decrease the incentive to save. Consequently, the resulting steady-state level of consumption per effective worker is lower than in autarky. Therefore, given the consumer behavior assumptions of the standard model, a quicker transition to the steady state has to be "paid" with a lower steady-state level of consumption per effective worker.

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42 Consequently, the development of the net debt position of country B induces a full debt cycle (Siebert 1987, 1989).

43 To prevent this kind of extreme result several types of modifications of the standard model are possible (Barro and Sala-i-Martin 1995: Chapter 3).

What is perhaps the most characteristic implication of the standard model, is the fact that the steady-state level of GDP per effective worker is not affected by free trade. Imports of foreign capital goods do neither increase the total productivity of the capital stock, nor do they induce additional incentives to accumulate capital. There are no productivity gains from free trade. Consequently, compared to autarky the steady-state level of GDP per effective worker remains unchanged.

2. Trade Policy and the Price of Capital in the Solow–Ramsey Model

Abstract: This section explores the impact of trade policy in the one-sector Solow–Ramsey model, if the assumption of perfect competition on the domestic capital goods market is changed. Instead of perfect competition a closed domestic oligopoly on the capital market is assumed. As it turns out, in this case the price of capital goods is the higher the less members are in the domestic oligopoly and the stronger the trade policy restrictions against capital goods imports. The price of capital negatively affects the incentives for capital accumulation. As a consequence, the growth rate during transition to the steady state and the steady-state level of per effective worker GDP is reduced by restrictions on capital goods imports.

In the preceding section, the indifference of the steady-state level of per effective worker GDP to the trade regime implicitly depends on the assumptions concerning the market structure for capital goods. Following the standard neoclassical assumptions, the one-sector Solow–Ramsey model assumes perfect competition on the market for capital goods. If this assumption is modified, trade policy can, in principle, affect the price of capital and, as a consequence, the transitional growth rate and the steady-state level of per effective worker GDP.

Consider a closed oligopoly on the domestic market for capital goods, for example, caused by restricted access to the technological knowledge to produce capital goods. Assume that only a fixed number of N_D domestic firms have the technological knowledge to transform one unit GDP into one unit of capital goods. Furthermore, assume that the number of foreign capital goods producers is N_F. Let N_F be finite but sufficiently large. Following these assumptions, [B.5] can be rewritten in the following way:

$$[\text{B.16}] \quad Y_{i,t} = \Lambda_i \left(A_{i,t}\, L_{i,t}\right)^{\alpha} \left(\sum_{i}^{N_{D,i}} X_{i,t} + \sum_{j}^{N_{F,i}} X_{j,t} \right)_{i,t}^{\beta},$$

with $\alpha + \beta = 1$, $0 < \alpha,\ \beta < 1$, and $i = A, B$, where $\sum_i^{N_{D,i}} X_{i,t}$ equals the real stock of domestic capital goods and $\sum_j^{N_{F,i}} X_{j,t}$ equals the real stock of foreign capital goods of country *i*. Production function [B.5] implies that domestic and foreign capital goods are perfect substitutes. As it turns out, given these assumptions concerning the market structure, the market result depends on the assumptions concerning market conduct. Two different scenarios can be distinguished: one scenario, where the oligopolists choose prices as interaction parameters, and another scenario, where the oligopolists choose quantities as interaction parameters.

If the domestic oligopolists choose prices as interaction parameter and if the demand for capital goods has perfect information about the price of each oligopolist, the market result is Bertrand competition. Thus, all existing Nash equilibria imply a market price that equals marginal costs. A capital goods price higher than marginal costs cannot be a Nash equilibrium, because in this case each oligopolist has an incentive to lower his price marginally in order to attract the whole demand and realize thus a positive profit. Consequently, as in the case of atomistic competition, imports of capital goods cannot increase domestic competition. Therefore, if prices are chosen as interaction parameters, import restrictions on capital goods have no effect on the price of capital goods.[44]

If, however, the domestic oligopolists choose quantities as interaction parameters, a Nash equilibrium with prices higher than marginal costs can evolve. As Appendix 3.6 shows, under this assumption, the domestic per period rental price of one unit of capital goods equals:

$$[B.17] \quad p_i = (r+\delta)\left(1-\alpha\,\frac{(1-q_i)}{N_{D,i}}\right)^{-1},$$

where q_i equals the share of foreign capital goods in the domestic capital goods market of country i (see Appendix 3.6). Assume that the government quantitatively restricts foreign imports and determines in this way the value of q_i.[45] Consequently, the domestic price for capital goods is the lower, the higher the number of

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44 For a formal derivation of this result see the analysis of Bertrand competition in Tirole (1988: Chapter 5). One possibility to prevent this outcome of Bertrand competition is to introduce some kind of demand inertia. (Further possibilities are discussed in Tirole 1988: Chapter 5.) For example, due to asymmetric information or transport costs, each oligopolist may face a declining demand curve and may thus have some price-setting power. This approach is not elaborated here, because the result should, in principle, not differ much from the result obtained by the second scenario.

45 For simplicity, assume that q_i is chosen by the government depending on an exogenous political bargaining process.

domestic oligopolists, $N_{D,i}$, and the lower the import restrictions on foreign capital goods, $(1-q_i)$. This follows from taking the limits: If the number of domestic oligopolists approaches infinity, $N_{D,i} \to \infty$, then the domestic price of capital goods approaches $p_i \to r+\delta$, which equals the marginal costs and, hence, the price in the case of perfect competition. Hence, if $N_{D,i}$ is positively related to country size, the conventional wisdom follows that "import restrictions hurt the economic performance of small countries more than that of large countries." If foreign capital goods producers are free to supply the whole domestic capital goods market, $q_i = 1$, the price for capital goods equals again $p_i = r+\delta$.[46] In this case the domestic oligopoly has no market power. If foreign capital goods imports are restricted to zero, the domestic oligopoly can display its maximum market power and the price for domestic capital goods equals $p_i = (r+\delta)(1-\alpha / N_{D,i})^{-1}$.

Consider now the consequences of the capital goods price on the steady-state level of GDP per effective worker. In a market equilibrium, the one-period rental price for one unit of a capital good, p_i, must equal its marginal productivity. As shown in Appendix 3.6, this yields the following formula for the steady-state capital stock per effective worker:

$$\text{[B.18]} \quad \bar{k}_i^* = \left(\frac{\beta \Lambda_i}{p_i}\right)^{\frac{1}{1-\beta}} = \left(\frac{\beta \Lambda_i}{(\rho+\sigma g+\delta)\left(1-(1-\beta)\ \dfrac{(1-q)}{N_D}\right)^{-1}}\right)^{\frac{1}{1-\beta}}.$$

Consequently, the steady-state capital stock per effective worker is lower, the higher the domestic price for capital goods, p_i. Given the formula for the domestic price of capital goods, [B.18] implies that the steady-state capital stock per effective worker, and hence the steady-state level of GDP per effective worker, is the lower the higher the import restrictions on foreign capital goods, $1-q_i$. Hence, contrary to the Solow–Ramsey model with perfect competition, now trade policy influences the steady-state level of per capita GDP via its impact on the intensity of competition on the domestic capital goods market. Despite this difference in comparison to the model with perfect competition, the results of the two-country analysis apply here, of course, too: a high domestic price of capital goods has the same impact as a low Λ_i. Consequently, a high price of capital goods negatively affects real net productivity

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46 Strictly speaking, this holds only if the total number of foreign capital goods producers is that high, that there is atomistic competition on the world market. This assumption is compatible with the assumption of oligopolies on the domestic markets.

of capital investments ([B.12]) and reduces therefore the incentive to save ([B.10]) in transition to the steady state. As a result, restrictive trade policies negatively affect the transitional growth rate of per effective worker GDP.

To sum up: The discussion of the neoclassical Solow–Ramsey growth model in the preceding sections has shown that the influence of trade policies on economic growth in this model type is temporarily restricted on the transition period to the steady state. As the steady-state growth rate of technological progress is exogenous, it can of course not be affected by trade policies. However, depending on the specification of the model, trade policies can display an important impact on the steady-state level of GDP and GNP. The next section turns towards growth models where the growth rate of technological progress is endogenous. Within this type of models, various transmission channels of trade policy on technological progress and, hence, steady-state growth exist.

III. International Trade in Models of Endogenous Growth

1. Growth and International Integration: The Rivera-Batiz–Romer Model

Abstract: This section describes the impact of international trade on steady-state growth in the Rivera-Batiz–Romer model of endogenous growth. It shows that, within this model, free trade affects the growth rate of per capita GDP primarily via its influence on the allocation of human capital. If free trade increases the profits from R&D such that human capital is reallocated from manufacturing to R&D, then ceteris paribus the growth rate of the stock of technological knowledge and, hence, the growth rate of per capita GDP increases. However, as it turns out, important additional determinants of the growth rate are the degree of mobility of technological knowledge and international patent protection. Without international patent protection, free international trade may even induce a rate of economic growth of zero. All the results of the analysis depend on the assumption of identical resource endowments of all countries.

a. *The Requirements for Endogenous Growth*

The key requirement, necessary (although not sufficient) to generate endogenous growth, is the existence of at least one accumulating production factor with the property of nondecreasing marginal returns. Without such a type of production factor, investment incentives peter out in the long run. Therefore, in models with decreasing marginal returns of all accumulating production factors, the level of per worker GDP is constant in steady state, unless some kind of exogenous productivity growth is assumed. The Solow–Ramsey model described in the preceding sections is one example for this type of model. The only accumulating production factor in this model is physical capital, $K_{i,t}$. The marginal productivity of capital in the aggregated GDP production function is determined by its production elasticity, β. Since β holds the inequality $0<\beta<1$ ([B.4]), the second derivation of the aggregated production function with respect to physical capital is negative.[47] Therefore, marginal productivity of the capital stock per effective worker decreases as capital per effective worker increases. In the long run, marginal net productivity of capital per effective worker reaches a level equal to the marginal rate of ("effective") time preference, $\rho + g\sigma$. When this level is reached, the return from additional net investments is too low to induce households to invest (in terms of per effective worker ([B.10]). Consequently, in order to keep the incentives to invest large enough to induce permanent net investments, it is necessary to assume nondecreasing marginal returns to investment, or, what turns out to be the same, nondecreasing marginal returns to an accumulating production factor. However, the introduction of such an assumption into a model of economic growth causes some problems. Up to now, three different strategies to cope with these problems have been proposed in the theoretical literature. These are described in the following.

The first endogenous growth model was presented by Arrow (1962). This model is based on Smith's idea that new knowledge generated by learning due to the division of labor can give rise to productivity growth (Smith ([1776] 1994: 9); see also Section B.I.1). Arrow assumes in this model that the productivity of an individual firm grows when the accumulated aggregate investment of total industry grows. This assumption is based on the idea that investment and production induce the discovery of new knowledge. Hence, "accumulated investment" is used as a measure for "accumulated knowledge." A consequence of this assumption is that the aggregate production function displays increasing returns to scale. Since the accumulated aggregate investment enters the individual production functions as a positive externality, the individual firm's production function displays constant returns to scale. The latter ensures that the increasing returns to scale do not induce a monopolization of production. It ensures, consequently, the existence of a com-

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47 The second derivation of the aggregated production function with respect to capital equals according to [B.5]: $\delta Y_{i,t} / \delta K_{i,t} = -(1-\beta)\beta \Lambda_i (A_{i,t} L_{i,t})^{\alpha} K_{i,t}^{\beta-2} < 0$.

petitive equilibrium.[48] However, within this model, the increasing returns to scale can give rise to another type of problem: if the consumers take the increasing returns to scale in the aggregate production function into regard when maximizing their intertemporal utility, the objective function may not be finite such that an intertemporal utility maximum does not exist. In order to cope with this problem, Arrow assumes that output as a function of capital and labor exhibits increasing returns to scale but that the marginal product of capital is diminishing given a fixed supply of labor. Consequently, the rate of output growth is limited by the rate of labor force growth. As a result, this implies that the rate of per capita growth is a monotonically increasing function of the population growth rate: if population growth is zero, per capita output growth is zero, too. However, this result is empirically questionable. Therefore, although Arrow's model gives a microeconomic elaborated explanation of endogenous growth, it is not very satisfying from the empirical point of view.

Uzawa (1965) uses another strategy in deriving a model of endogenous growth. In his model, two accumulating production factors exist: physical capital and human capital. In order to generate endogenous growth, Uzawa assumes that human capital exhibits constant marginal returns in the production of new human capital. As human capital is the only input in the production function of new human capital, no increasing returns to scale exist in this model. Consequently, Uzawa does not have to cope with the problems concerning the existence of a competitive market equilibrium and an intertemporal utility maximum. However, Uzawa's assumption of (exactly) constant marginal returns is a "knife-edge case," i.e., it is not generically robust from the empirical point of view. If the marginal return to human capital is not exactly constant, but slightly decreasing, long-run per capita growth approaches zero in the long run. If, however, the marginal return to human capital is slightly increasing, the existence of a competitive market equilibrium and of an intertemporal utility maximum is not guaranteed. Consequently, from the empirical point of view Uzawa's model is not satisfying either.

Therefore, Romer (1983, 1986) proposes another way of coping with these problems. He sets up a model that resembles very much the model of Arrow (1962). Similar to Arrow, he assumes that aggregated accumulated knowledge enters the production function of an individual firm as a positive externality. As in Arrow's model, this assumption allows the existence of a competitive market equilibrium.

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48 Of course, if share holders are aware of the fact that (at the aggregate) level production gives rise to increasing returns to scale, they have an incentive to buy and to merge the single firms to a single monopoly. Consequently, a competitive equilibrium strictly speaking emerges only, if the increasing returns to scale are somehow latent to capital markets (for a discussion of this problem, see Romer (1983: 18)).

However, unlike Arrow, he assumes that the creation of new knowledge is not a side effect of physical investment, but an intentional act of profit maximizing investors. This idea is based on the knowledge production function of Griliches (1979). It takes care of the empirical observation that firms intentionally invest in R&D in order to produce new knowledge. As far as this aspect of Romer's model is concerned, Romer succeeded in the integration of two, up to then, different domains of economic theory: growth theory and innovation theory. However, the major innovation of Romer's model is his proof (Romer 1983: Theorem 1) that, even in the presence of increasing marginal returns to the accumulating production factor, an intertemporal utility maximum can exist, if a condition holds, which is similar to the transversality condition in the neoclassical growth model. This condition relates the parameters of the production technologies to the rate of time preference (i.e., the discount factor in the intertemporal utility function). As Romer shows, if $\alpha\beta<\rho$ holds,[49] an intertemporal utility maximum can exist, even in the presence of increasing marginal returns, i.e., $\beta>1$.[50] Therefore, contrary to the model of Arrow (1962), Romer's model allows for the existence of a nonnegative growth rate of per capita GDP even if no population growth takes place. As Romer shows, if $\beta>1$ actually holds, the steady-state growth rate of per capita GDP is permanently increasing, although bounded from above by α.[51]

Although the assumption that $\alpha\beta<\rho$ is ad hoc — since there is no microeconomic reason why such an assumption should actually hold[52] — Romer's proof that, even in the presence of increasing marginal returns to the accumulating production factor, an intertemporal utility maximum can exist gave rise to the development of numerous new models of endogenous growth that now bear the label "new growth theory." It is, however, somehow surprising to note that indeed all of these models (even those follower models presented by Romer himself) do not follow Romer's strategy of allowing for increasing marginal returns and assuming $\alpha\beta<\rho$. Instead, they follow Uzawa's strategy of assuming the knife-edge case of constant marginal

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49 Where ρ is the rate of time preference, β follows from the upper bound of the aggregate production function $F(A)<\mu+A^{\rho}$, and α is the upper bound of the knowledge production function per unit time $\dot{A}/A = g(x) \leq \alpha$.

50 Remember that the transversality condition, which ensures the existence of an intertemporal utility maximum in the neoclassical growth model, states that $g(1-\sigma)<\rho$ if population growth is zero.

51 Romer (1983, 1986), based on the Maddison (1992) data for the early industrialized countries, presents some empirical evidence in favor of the hypothesis that the long-run growth rate of per capita GDP is permanently increasing.

52 The same holds of course for the neoclassical transversality condition.

returns. Romer (1994) justifies this procedure, because it makes the models much simpler. He presumes that it is always possible to modify these models to allow for increasing marginal returns without changing the results. "Once it is clear that we could build a complicated model that is robust, there is every reason to work with the simple special case whenever possible" (Romer 1994: 18). The next section discusses a model of international trade and endogenous growth by Rivera-Batiz and Romer (1991a, 1991b) that is built along these lines.[53]

b. The Analysis of the Dynamic Implications of International Integration

Figure 8 displays the Rivera-Batiz–Romer model (Rivera-Batiz and Romer 1991a, 1991b). This model is based on a two-sector economy. The manufacturing sector is represented by a production function similar to the one discussed in Section B.I.2 ([B.3]).[54] The only difference is the introduction of a third production factor, $H_{Y,k,t}$, which equals the endowment of the economy with human capital.[55] For simplicity,

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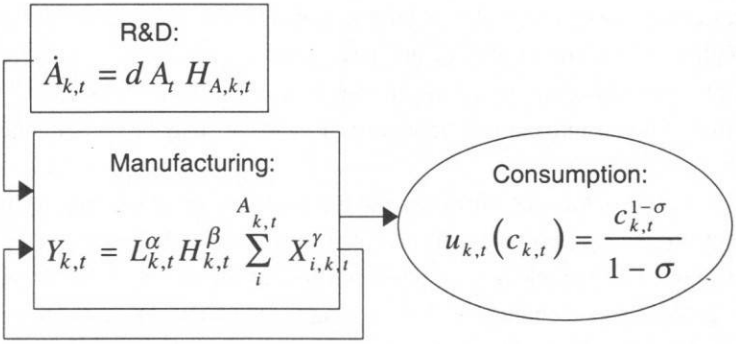
53 Besides the model of Rivera-Batiz and Romer (1991a, 1991b), there exists a second prototype model of endogenous growth that can be used to study the interrelations between international trade and steady-state growth. This model was developed by Aghion and Howitt (1992). It is based on the assumption of vertical product differentiation, contrary to the Rivera-Batiz–Romer model, which is based on the assumption of horizontal product differentiation. The Aghion–Howitt model is a very interesting attempt to formalize Schumpeter's theory of economic growth through "creative destruction." However, as Grossman and Helpman (1991) show, the impact of international trade on steady-state growth does not differ much between endogenous growth models with horizontal and vertical product differentiation. Therefore, the following analysis focuses on the Rivera-Batiz–Romer model only.

54 In order to avoid integer problems in the list of differentiated products, $A_{k,t}$ (which may arise from the formula of the R&D production function), an integral symbol (indicating a continuous list of differentiated capital goods) should be used in the manufacturing production function instead of the summation symbol. For simplicity this formal rigor is disregarded here and in the following.

55 It is assumed that human capital is a nonaccumulating production factor. This assumption may be empirically questionable. However, it simplifies the analysis and allows a concentration on the questions of interest. For an analysis of the effects of human capital accumulation within a R&D model of endogenous growth see Grossman and Helpman (1991: Chapter 5.2.). This Grossman–Helpman R&D model of endogenous growth with human capital accumulation has to be distinguished from the human capital model of endogenous growth presented by Lucas (1988) and Mulligan and Sala-i-Martin (1992). In these human capital models of endogenous growth, human capital is assumed to be an accumulating production factor with constant marginal returns. However, this implies that per individual human capital can be infinitely accumulated. Hence, the "intellectual capacity" of a single individual is unbounded. This assumption is empirically doubtful. Technological knowledge is a much better candidate for the assumption of an infinite accumulation capacity (Romer 1990b). Therefore, the following discussion is restricted to R&D models of endogenous growth only.

Figure 8 — The Rivera-Batiz–Romer Model of Endogenous Growth



it is assumed that raw labor measured by the number of workers, $L_{k,t}$, does not grow.[56] As a consequence, the resulting steady-state growth rate equals per capita growth. The output of the manufacturing sector can be used for consumption and investment. If a firm owns a blueprint for a specific differentiated capital good, it is able to transform one unit of manufacturing output into one unit of this specific capital good.[57]

Remember that the assumption that a capital stock is composed out of a set of $A_{k,t}$ differentiated capital goods, $X_{k,t}$, each one displaying diminishing marginal returns, implies new types of differentiated capital goods to increase the productivity of the total capital stock (see Section B.I.2). The blueprints for new types of differentiated capital goods, $\dot{A}_{k,t}$, are created in the R&D sector, the second sector of the economy. The production function for blueprints contains the inputs human capital, $H_{A,k}$, and accumulated technological knowledge, $A_{k,t}$. Three characteristics of this production function are remarkable:

- First, it implies that technological knowledge is an accumulating production factor with nondiminishing marginal returns. This is the crucial assumption that generates endogenous growth. The assumption ensures that the incentive to produce new blueprints for differentiated capital goods does not decrease as the stock of knowledge capital grows. It implies, furthermore, that the pool of unknown technological knowledge is infinite, because the marginal productivity of new technological knowledge does not decrease, no matter how much knowl-

56 A modification of this assumption corresponding to the Solow–Swan model of Section B.II is straightforward, but does not qualitatively alter the results.

57 This assumption is also made in the Solow–Swan model of Section B.III.

edge has been accumulated in the past. Whether the pool of unknown knowledge is actually infinite, is an interesting question: as only "one" reality exists, the total knowledge about this reality should in principle be finite. Consequently, the assumption of an infinite pool of unknown knowledge may be wrong from this point of view. However, given the current state of "known knowledge," the assumption of an infinite pool of "unknown knowledge" may be a justifiable empirical approximation.

- Second, it implies that each firm can use the total amount of existing technological knowledge, $A_{k,t}$, no matter by which firm it is created. Consequently, existing technological knowledge spreads a positive externality to all firms engaged in the production of blueprints. This assumption has important implications. It ensures that "latecomers" have the same chances to produce new blueprints, as those firms that have already successfully produced blueprints. Hence, it excludes "first-mover advantages" such that there is free entry to R&D-production.
- Third, human capital enters the production function with nondiminishing marginal returns. This assumption implies that an increase of human capital input by factor λ causes an increase of output by λ, although the level of accumulated knowledge stays constant. This assumption is basically for convenience and has no qualitative consequences on the result. It implies that the whole stock of technological knowledge can be used by each unit human capital without depriving other units of human capital from using it. This means that technological knowledge can be nonrivally used (Romer 1990a).[58] Ostensibly, given the specific qualities of technological knowledge this is a justifiable assumption.

Since free access to existing technological knowledge within a country is assumed, a free-rider problem emerges: because anyone can use existing technological knowledge without paying, no incentive to produce technological knowledge exists. Consequently, it is necessary to grant producers of blueprints a property right for the exclusive utilization of their blueprints. Therefore, it is assumed that the government grants an eternal patent to a producer of a blueprint.

This implies, of course, that each producer of a blueprint has a monopoly for the production of the corresponding capital good. His monopoly power is, however, restricted due to the possibility to substitute a specific capital good for another capital good. As a result, the market structure on the capital goods market is characterized by monopolistic competition between the owners of patents for capital goods. The

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58 The expression "nonrivally" refers only to the technical property of technological knowledge. It does, of course, not mean that the usage of certain technological knowledge by one firm has no consequences on the profit possibilities of other firms.

price for each capital good is the lower the higher the potential to substitute one capital good for another.[59]

Given this setup of the model, Rivera-Batiz and Romer (1991a, 1991b) analyze the effects of economic integration through free trade between two countries, $k=A,B$. In order to concentrate on integration effects and to exclude allocation effects caused by comparative advantages, they assume that both countries display identical endowments with raw labor, $L_{k,t}$, human capital, $H_{k,t}$, and accumulated technological knowledge, $A_{k,t}$.[60] This is, of course, a restrictive assumption. The consequences of a modification are described in Section B.III.2.

Within this model setup, free trade can affect the level as well as the steady-state growth rate of per capita GDP. To reveal these effects, the autarky solutions have to be compared with the free trade solutions. As it shows up, two additional assumptions crucially influence the result of such a comparison: international protection of patents and international mobility of technological knowledge. Together with the alternative autarky versus free trade eight different cases can arise. They are displayed in Table 1. A formal derivation of the results is given in Appendix 4.[61]

As follows from Table 1, if international protection of patents is granted, the magnitude of the growth rate of per capita GDP does not depend on the alternatives free trade or autarky, but on the alternatives mobility or immobility of technological knowledge. If technological knowledge is internationally mobile, the growth rate of per capita GDP is substantially higher than in the case of international immobility of technological knowledge, no matter whether there is free trade or autarky. Free trade does primarily influence the level of manufacturing output. If knowledge is internationally mobile and international protection of patents is not granted, free trade adversely affects the growth rate of per capita GDP, but in turn affects the level of manufacturing output positively. Consequently, given this specification of the model, it is the protection of international patents and the degree of mobility of tech-

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59 The elasticity of substitution between capital goods is given by the formula $\varepsilon = 1/(1-\gamma)$ (see Appendix 1), where γ equals the production elasticity of a single capital good. Hence, if γ approaches unity, capital goods are perfect substitutes. As the solution of the profit maximization problem of a blueprint owner shows, the profit-maximizing price equals $1/\gamma$. Therefore, if capital goods were perfect substitutes, i.e., $\gamma = 1$, the profit maximizing price would equal unity, which corresponds to the marginal costs of producing a capital good (see Appendix 4 for the explicit solution of the model).

60 Although the number of blueprints is assumed to be identical in both countries, i.e., $A_{A,t} = A_{B,t}$, the above assumptions concerning the market structure imply that in case of free trade the intersection set is empty, $A_{A,t} \cap A_{B,t} = 0$.

61 Rivera-Batiz and Romer (1991b) discuss Cases 1, 2 and 6.

Table 1 — Growth and International Integration in the Rivera-Batiz–Romer Model[a]

	International mobility of technological knowledge	International immobility of technological knowledge
A. Free international trade		
International patent protection	**Case 1** $\hat{g}_k = \frac{2\delta H_k - \Lambda\rho}{1+\Lambda\sigma}$ $\bar{Y}_{k,t} = 2^{\frac{\alpha}{\alpha+\beta}} \Omega\left(g_k \sigma + \rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}} A_{k,t}$	**Case 2** $\breve{g}_k = \frac{\delta H_k - \Lambda\rho}{1+\Lambda\sigma}$ $\hat{Y}_{k,t} = \Omega\left(g_k \sigma + \rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}} 2A_{k,t}$
No international patent protection	**Case 3** $\tilde{g}_k = 0$ $\tilde{Y}_{k,t} = \left(g_k \sigma + \rho\right)^{\frac{-\gamma}{\alpha+\beta}} 2A_{k,0} \gamma^{\frac{2\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}} H_k^{\frac{\beta}{\alpha+\beta}}$	**Case 4** (see Case 2)
B. No international trade		
International patent protection	**Case 5** $\hat{g}_k = \frac{2\delta H_k - \Lambda\rho}{1+\Lambda\sigma}$ $\breve{\breve{Y}}_{k,t} = 2^{\frac{-\beta}{\alpha+\beta}} \Omega\left(g_k \sigma + \rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}} A_{k,t}$	**Case 6** $\breve{g}_k = \frac{\delta H_k - \Lambda\rho}{1+\Lambda\sigma}$ $\breve{Y}_{k,t} = \Omega\left(g_k \sigma + \rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}} A_{k,t}$
No international patent protection	**Case 7** $\ddot{g}_k = \frac{\delta H - \Lambda\rho}{0{,}5+\Lambda\sigma}$ $\hat{Y}_{k,t} = \Omega\left(g_k \sigma + \rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}} 2A_{k,t}$	**Case 8** (see Case 6)

[a]For a definition of the parameters see Appendix 4.

nological knowledge, which display the dominant influence on the long-run growth rate of per capita GDP. Free trade with capital goods does primarily affect the level of manufacturing output.[62]

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62 However, what is not displayed by Table 1, if instead of the extremes free trade and autarky the effects of a uniform import tariff on capital goods is analyzed in the presence of mobility of technological knowledge and international patent protection, the level of the tariff can affect the growth rate of per capita GDP. However, if the tariff level, τ, approaches the extremes "free trade," $\tau \to 0$ (Case 1), and "autarky," $\tau \to \infty$ (Case 5), the growth rate is identical for both extremes.

The intuitive explanation for these results is given in the following: Consider first the cases of autarky without international mobility of technological knowledge (Cases 6 and 8). The absence of international mobility of technological knowledge implies that only the country-specific stock of technological knowledge enters the production function of R&D. As a result, the growth rate of per capita GDP depends only on the domestic endowment with human capital.[63] The larger the total endowment with human capital, the higher the absolute level of human capital, allocated to the R&D sector.[64] Consequently, the endowment with human capital positively affects the growth rate. The absence of free trade restricts the set of available capital goods to the domestically produced varieties. Consequently, the level of manufacturing output is not affected by the set of foreign varieties of capital goods. As knowledge is internationally immobile, international patent protection does not matter and the results of Cases 6 and 8 are identical.

Compare now Case 6 with Case 2 or 4. In the latter case, free international trade is possible but technological knowledge is internationally immobile.[65] This comparison shows that international trade positively affects the productivity of the manufacturing sector as well as the productivity of the R&D sector: free trade doubles the productivity of the manufacturing sector, because international trade doubles the available set of differentiated capital goods.[66] As is discussed in Section B.I.2, the special type of production function implies that the higher the number of available differentiated goods, the higher the total factor productivity of the manufacturing sector. Consequently, the marginal productivity of all manufacturing inputs, i.e., $H_{Y,k,t}$, $L_{k,t}$, and $X_{k,t}$, doubles. At the same time, the marginal productivity of human capital (measured in manufacturing output units) in the R&D sector,

63 As shown in Appendix 4, the growth rate of per capita GDP equals the growth rate of the output of the R&D sector as well as the growth rate of the manufacturing sector. Consequently, in the following, for convenience, the term "the growth rate" is used.

64 See Appendix 4 for the determination of the allocation of human capital to the manufacturing sector and to the R&D sector.

65 As knowledge is internationally immobile, international patent protection does not matter. Therefore, the results of Cases 2 and 4 are identical.

66 As there is free entry to the R&D market, in the presence of free international trade R&D firms refrain from producing blueprints which have already been produced in another country. Consequently, the "wheel is not reinvented" and the sets of blueprints for available differentiated capital goods in both countries do not include blueprints for identical capital goods. As the above mentioned symmetry assumption implies that the number of differentiated capital goods in the sets of both countries is identical, free trade doubles the available set of differentiated capital goods, i.e., $A_t = 2A_{t,A} = 2A_{t,B}$, where the indices A and B indicate countries A and B.

$H_{A,k,t}$, doubles. This is caused by the fact that, given the assumption of identical factor endowments of both countries, the demand for capital goods doubles in the case of free trade. Since the above described monopolistic competition implies the existence of nonzero, positive profits on the market for capital goods, a doubling of demand induces a doubling of profits. Since the producers of blueprints, given their domestic patent protection, are able to absorb the positive profits from the selling of capital goods, the value of a blueprint doubles (compare [A.4.9] with [A.4.35], Appendix 4). As a consequence, the marginal productivity of human capital used for the production of blueprints doubles. The fact that the marginal productivity of human capital in the R&D sector as well as in the manufacturing sector doubles, implies that free trade does not induce a reallocation of human capital from the manufacturing sector to the R&D sector. Therefore, none of the input factors of the R&D sector is increased and the output of the R&D sector stays the same as in autarky. However, as the output of the R&D sector determines the per capita GDP growth rate, the growth rate is equivalent to the growth rate in autarky. The only difference compared to autarky is the doubling of manufacturing output caused by the doubling of the available varieties of differentiated capital goods.

Compare now Case 2 with Case 1. In the latter case, free international trade is possible, international patent protection is guaranteed and technological knowledge is internationally mobile. The international mobility of technological knowledge implies that the knowledge of both countries enters the production function of the R&D sector. Consequently, marginal productivity of human capital in R&D doubles compared to Case 2. At the same time, marginal productivity of human capital in manufacturing is equivalent compared to Case 2. Therefore, now human capital is reallocated from the manufacturing sector to the R&D sector. As a result the output of the R&D sector rises for two reasons: the influx of foreign technological knowledge plus the reallocation of human capital. Taken together, both effects imply that the output of the R&D sector rises by more than 100 percent compared to Case 2. Accordingly, the per capita GDP growth rate rises also by more than 100 percent compared to Case 2 (see Appendix 4, [A.4.49]). On the contrary, the reallocation of human capital from the manufacturing sector to the R&D sector implies that the output of the manufacturing sector decreases below its level attained in Case 2.[67]

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67 This holds, of course, only if the stock of technological knowledge in both cases is assumed to be identical for comparison. As the stock of technological knowledge grows faster in Case 1, the level effect of a reallocation of human capital from manufacturing to R&D in Case 1 is, of course, overcome in the long run.

In the presence of international mobility of technological knowledge and free trade, it is important for the growth performance that international patent protection is guaranteed. Without international patent protection, each foreign firm can use the blueprints of the domestic country and export the capital goods to the domestic country (and vice versa). Therefore, monopolistic profits from the selling of differentiated capital goods disappear such that the value of a blueprint is zero, even if domestic patent protection is guaranteed. As a result, no incentive for the production of blueprints exists, such that no R&D is undertaken and per capita GDP does not grow. This is the scenario of Case 3.[68] For in Case 3 all human capital is concentrated in manufacturing, the level of manufacturing output increases compared to Case 1.[69]

If it is not possible to establish international patent protection, in the presence of internationally mobile knowledge, the worst case growth scenario of Case 3, can only be overcome by restricting international trade (Case 7). Compared to Case 3 the prohibition of international trade implies that the domestic market is protected against foreign imitators of domestically produced blueprints. Consequently, domestic owners of blueprints are able to sell their differentiated capital goods at monopolistic prices at the domestic market. This, in turn, allows them to make positive nonzero profits. Therefore, in the absence of international patent protection, restrictions on foreign trade can ensure the incentives to perform R&D. Accordingly, a positive nonzero steady-state growth rate results. As it shows up, the resulting growth rate lies in between the growth rates of Case 6 and Case 1. The growth rate is higher than in Case 6, because foreign technological knowledge enters the R&D production function in Case 7. Consequently, the output of the R&D sector (as well as the marginal productivity of human capital) doubles compared to Case 6, such

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68 The intermediate case, where the government grants the right to use foreign patents to a finite number of firms, n, is analyzed by Maurer (1993). In this case, if n is not too large (and under the assumption of Cournot–Nash equilibrium on the market for capital goods), the steady-state per capita GDP growth rate does not necessarily equal zero, but may as well fall under the autarky growth rate. Helpman (1992) develops a scenario, where technological knowledge is not perfectly mobile and a neglect of international patent rights may indeed increase the global growth rate of R&D output. This result emerges because of the asymmetrical structure of this world economy: The imitation of high-tech products by the South increases the global supply of high-tech goods such that the labor demand of the high-tech sector of the North is reduced. Hence, a relatively larger part of the labor force of the North works in the R&D sector. This in turn increases the output of the R&D sector such that the global innovation rate grows. This result is possible, because the South has no R&D sector. Consequently, the production of high-tech goods by the South cannot reduce the R&D output of the South.

69 Again, this holds only if the stock of technological knowledge is assumed to be identical for comparison.

that the growth rate increases over the level attained in Case 6. However, the growth rate in Case 7 is lower than in Case 1: for technological knowledge is internationally mobile, the knowledge to produce foreign capital goods is available, such that the whole set of foreign capital goods is domestically produced.[70] Consequently, the marginal productivity of human capital in manufacturing doubles. As a result, marginal productivity of human capital in both sectors doubles, such that no reallocation of human capital takes place, compared to Case 1. Therefore, the growth rate does not reach the level of Case 1. By the same reason, manufacturing output reaches a level higher than in Case 1.[71]

Surprisingly enough, if the assumption of international mobility of technological knowledge and absence of free international trade is combined with the assumption of international patent protection (Case 5), the growth rate reaches the same level as in Case 1.[72] This is caused by the fact that international patent protection and absence of international trade restricts the set of differentiated capital goods to the domestic set. Consequently, marginal productivity of human capital in the manufacturing sector is not increased by the mobility of technological knowledge. However, compared to a scenario without international mobility of technological knowledge, the input of technological knowledge in the R&D sector doubles, such that marginal productivity of human capital in the R&D sector doubles, too. Therefore, human capital is reallocated from the manufacturing sector to the R&D sector. As a result, the growth rate finally reaches indeed the same level as in Case 1. However, as human capital is reallocated from manufacturing to R&D, the level of manufacturing output is lower than in Case 6. Consequently, compared to Case 7, the effect of international patent protection is to reduce the marginal productivity of human capital in manufacturing such that human capital flows from manufacturing to R&D.

Summing up, the discussion of the results of Table 1 shows that within the above model free trade affects the growth rate of per capita GDP primarily via its influence on the allocation of human capital. If the scenario implies that free trade increases ceteris paribus the profits of R&D such that human capital is reallocated from manufacturing to R&D, the growth rate of the stock of technological knowledge and, hence, the growth rate of per capita GDP increases. However, important additional

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70 For the sake of simplicity, assume that the government grants one domestic patent for each foreign blueprint.

71 Remind that this holds only, if the stock of technological knowledge is assumed to be identical for comparison.

72 This is, of course, a somewhat peculiar combination of assumptions: two countries succeeding in establishing international patent protection should in principle also succeed in establishing international free trade.

determinants of the growth rate are the degree of mobility of technological knowledge and the international patent protection. Without international patent protection, free trade may indeed induce a zero growth rate (Case 3). This results, because without international patent protection foreign "pirate firms" can provide the domestic market with domestically invented capital goods and eliminate, thus, the profits from R&D. In this sense, the analysis of the interrelation between free international trade and economic growth yields an "unexpected" result: free international trade has to be complemented by international intellectual property rights, in order to prevent a potential negative effect on economic growth.

Another conclusion from Table 1 is that, given the specification of the model, free trade does not affect the growth rate of per capita GDP, if international patent protection is guaranteed. This follows from a comparison of Case 1 with Case 5 and Case 2 with Case 6. Basically, this result stems from the fact that free trade increases productivity of human capital in manufacturing and R&D by exactly the same degree. Therefore, free trade by itself causes no reallocation of human capital from the manufacturing sector to the R&D sector. Within this model only the influx of mobile foreign technological knowledge increases the productivity of human capital in the R&D sector more than in the manufacturing sector. Therefore, only in the case of international mobility of technological knowledge human capital is reallocated from manufacturing to R&D such that R&D output and, hence, the steady-state growth rate increases (compare Case 1 with 2, and Case 5 with 6).

However, this conclusion results only, because the assumption is made that autarky can go hand in hand with perfect international mobility of technological knowledge. Although this assumption is interesting from the analytical point of view, because it allows insights in the mechanics of the model, it is questionable whether it is plausible from the empirical point of view: given the assumptions of the model, free trade is the transmission channel for embodied technological knowledge.[73] However, from the empirical point of view, it is likely that international trade is also an important channel for the transmission of disembodied technological knowledge. In this case, autarky precludes the inflow of disembodied technological knowledge and, hence, cannot go hand in hand with perfect international mobility of technological knowledge. Consequently, Cases 2, 4, 5 and 7 are simply not likely to emerge from the empirical point of view. Therefore, accounting for the potential

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73 Embodied technological knowledge is bounded in a machine. Within the setup of the model, the differentiated capital goods include embodied technological knowledge. Disembodied technological knowledge is not bounded in a machine. Within the setup of the model, it exists in form of the set of blueprints, $A_{k,t}$, which positively influence the productivity of human capital in the R&D production function.

role of international trade as a transmission channel of technological knowledge, the model predicts a positive impact of international trade on steady-state growth.[74]

All the results of the Rivera-Batiz–Romer model crucially depend on the assumption that the resource endowment of both countries is identical such that no comparative advantages emerge. The following section displays the effect of international trade on economic growth, if this assumption is modified.

2. Comparative Advantage for Growth? The Grossman–Helpman Analysis

Abstract: This section describes the effect of different relative resource endowments on growth performance in a two-country model of Grossman and Helpman (1991). It shows that within this model, comparative advantage can affect growth performance. If high-tech production is more human-capital-intensive and displays a higher steady-state growth rate than low-tech production, a country with a relatively high human-capital endowment specializes in high-tech production and displays therefore a higher steady-state growth rate. However, even if a country specializes in low-tech goods and does not grow in terms of GDP, the utility of the representative household can nevertheless grow. If international financial markets allow for international borrowing and lending, the households of the low-tech country can invest in the accumulation of blueprints in the high-tech country. Therefore, households in the low-tech country are not necessarily in a welfare-inferior position compared to households in the high-tech country. A low-tech specialization, however, can be welfare inferior for a country, if wages in the low-tech sector are lower than wages in the high-tech sector.

Grossman and Helpman (1991: Chapter 7) present a model of international trade and economic growth, where countries specialize according to their relative endow-

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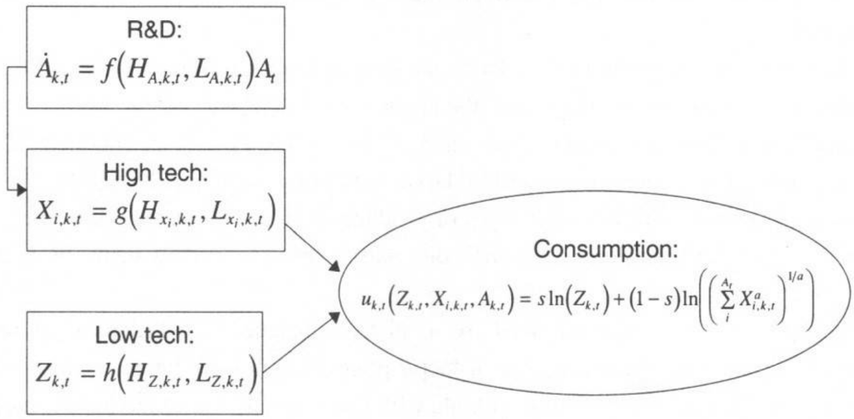
74 Rivera-Batiz and Romer (1991b) also analyze the effects of a transition from autarky to free trade, if instead of the R&D production function of Figure 7 a "research lab-equipment" production function of the following type is used:

$$\dot{A}_{k,t} = L_{k,t}^{\alpha} H_{k,t}^{\beta} \left(\sum_{i}^{A} X_{i,k,t}^{\gamma} \right).$$

As the total productivity of this type of production function positively depends on the available set of capital goods (see the discussion of [B.3] in Section B.I.2), free trade does positively affect the per capita GDP growth rate, whether technological knowledge is mobile or not. For a discussion of the implications of this model variant see Maurer (1993: Table 2).

ments with human capital, $H_{k,t}$, and raw labor, $L_{k,t}$. Figure 9 displays the structure of this model. The economy comprises three sectors: the R&D sector, the high-tech sector, and the low-tech sector. Each production sector uses human capital and raw-labor as input. The production technologies, *f(.)*, *g(.)*, *h(.)*, are assumed to display constant returns to scale. By assumption, R&D is the most human-capital-intensive activity and low-tech production is the most raw-labor-intensive activity. The human-capital intensity of the high-tech sector is lower than the human capital intensity of the R&D sector, but higher than the human capital intensity of the low-tech sector.

Figure 9 — The Grossman–Helpman Model of Dynamic Comparative Advantage



The R&D sector produces blueprints for the high-tech goods. Again, the stock of accumulated technological knowledge enters the production function of the R&D sector with nondiminishing marginal returns. This ensures long-run endogenous growth. Technological knowledge is perfectly free within and between all countries. To provide incentives for the production of new blueprints, it is necessary to exclude nonpayers from the usage of blueprints. Therefore, governments grant eternal patents to the producers of new blueprints. These patents are internationally protected.

The high-tech sector produces a set of $A_{k,t}$ high-tech goods, $X_{i,k,t}$. The low-tech sector produces one homogenous type of low-tech good, $Z_{k,t}$. The access to the technological knowledge for the production of the low-tech good is free. The consumption function is a log-linearized version of the Dixit and Norman (1980) utility function of Section B.I.2 ([B.1]).[75] Two types of goods enter the consumption func-

[75] The parameters of the consumption function hold $0<\sigma<1$ and $0<\alpha<1$.

tion: the low-tech good and the set of high-tech goods.[76] As the discussion in Section B.I.2 has shown, this specification implies high-tech goods to be imperfect substitutes.[77] Accordingly, a positive relation exists between the level of utility and the number of available types of high-tech goods. Hence, contrary to the Rivera-Batiz–Romer model of the preceding section, a rise in the number of available differentiated goods does not now increase total factor productivity in the production sector but, instead, household utility ([B.2], Section B.I.2).[78] As high-tech goods are imperfect substitutes, each patent owner has a monopoly for the production of a differentiated good. His monopoly power is, however, restricted by the potential of households to substitute high-tech goods. Therefore, similarly to the Rivera-Batiz–Romer model of the preceding section, the resulting market structure is monopolistic competition.

Grossman and Helpman (1991) derive the pattern of production and trade of this model in a two-country world, where the countries specialize according to their endowments with human capital and raw labor.[79] To do this, Grossman and Helpman use a graphical procedure developed by Dixit and Norman (1980: Chapter 4). They show that basically four different types of production and trade pattern can emerge depending on four different "regions" of relative resource endowments of both countries:

The first region is characterized by a relative "balanced" distribution of resources.[80] Therefore, the divergence of factor prices, which would emerge in autarky,[81] can be "offset" by international trade with low-tech and high-tech goods, such that all resulting equilibria in this region are characterized by factor price equalization. As a consequence, both countries produce blueprints as well as both types of

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76 In this section, the term "high-tech" good is used synonymously with the term "differentiated" good.

77 The elasticity of substitution between two variants of a high-tech good equals $\varepsilon = 1/1(1-\alpha)$. Since by assumption $0<\alpha<1$, the elasticity of substitution is finite, $\varepsilon < \infty$. Therefore, high-tech goods are only imperfect substitutes.

78 Grossman and Helpman (1991) propose a second interpretation, according to which the subutility index $\sum_i^{A_t} X_{i,k,t}^{\alpha}$ can be interpreted as a production function of a composed household good, $D = \sum_i^{A_t} X_{i,k,t}^{\alpha}$. Following this interpretation an increase of the set of high-tech goods, A_t, implies an increase of household goods.

79 Contrary to the analysis of the Rivera-Batiz–Romer model, mobility of technological knowledge and international patent protection are taken to be guaranteed here.

80 For an explicit exposition see Grossman and Helpman (1991: Figure 7.1).

81 As preferences and technologies are identical in both countries, the only source for diverging autarky factor prices is the divergence of relative resource endowments.

goods. Nevertheless, although the distribution of resources is "balanced," the country with the relatively larger endowment with human capital has a comparative advantage for the production of blueprints and high-tech goods and, thus, has a larger share of blueprints and high-tech goods in total GDP.

The resulting pattern of international trade depends on the existence of international capital markets: if no international borrowing and lending is possible, the trade balance has to be equalized in each period. As Grossman and Helpman show, in this case the human-capital-rich country will be a net exporter of high-tech goods[82] and the human-capital-poor country will be a net exporter of low-tech goods. Hence, interindustry trade emerges according to the predictions of the Heckscher–Ohlin theorem. At the same time there is intraindustry trade caused by the existence of the differentiated high-tech goods: as both countries produce blueprints in steady state, both countries produce a significant amount of high-tech goods, too.

If, however, international borrowing and lending is possible, the trade balance must not be balanced in steady state. Instead, a possible deficit in the trade balance can be offset by a surplus in the service balance, i.e., by interest payments.[83] In this case, if the deficit in the trade balance is large enough, a human-capital-rich country may be a net importer of both the low-tech and high-tech goods. Nevertheless, in this case, the share of high-tech goods in total imports will be lower than the share of low-tech goods. Hence, a "weak" version of the Heckscher–Ohlin theorem still holds.

To derive the effect of sectoral specialization on steady-state GDP growth, consider the definition of GDP by activity:[84]

$$[B.19] \quad GDP_{k,t} = p_z Z_{k,t} + p_x X_{k,i,t} A_{ki,t} + p_A \dot{A}_{k,t},$$

where p_Z is the price of the low-tech good, $Z_{k,t}$ is the physical quantity of the low-tech good of country k, p_X is the price of the high-tech good, $X_{k,i,t}$ is the physical quantity of the high-tech good, p_A is the price of a blueprint, and $\dot{A}_{k,t}$ is the number

82 Remember that blueprints are not tradable and no multinational enterprises exist by assumption.

83 As in steady state the net debt position of a country must stay constant, the current account balance (i.e., the sum of the trade and service balances) must be balanced in steady state.

84 Because of the assumptions stated in Footnote 82, the number of high-tech good varieties produced in each country corresponds to the number of blueprints accumulated in each country, i.e., $A_{i,t}$.

of new blueprints per period. The index i indicates the country. The growth rate of real GDP equals the weighted average of the output growth of each sector. The weights correspond to the share of each sector in total GDP. As the real output of the low-tech sector does not grow, the real growth rate of per capita GDP equals:[85]

$$[B.20]\quad \frac{G\dot{D}P_{k,t}}{GDP_{k,t}} = g_t \, \frac{1-\alpha}{\alpha} \, \frac{p_x \, X_{k,t} \, A_{k,t}}{GDP_{k,t}} + g_t \, \frac{p_A \, \dot{A}_{k,t}}{GDP_{k,t}},$$

where g_t corresponds to the growth rate of the stock of blueprints.[86] From [B.20] follows that the country with a higher share of blueprints and high-tech goods in total GDP displays a higher GDP growth rate.[87] This follows by taking the limit: If the share of blueprints and high-tech goods in total GDP approaches zero, the GDP growth rate will approach zero, too.

Consequently, since the model predicts that a country with a relatively high human capital endowment displays a higher share of blueprints and high-tech goods

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85 Given the setup of the model, the "value" of the high-tech sector output, $p_X \; X_{i,t} \, A_{i,t}$, does not grow in steady state, because p_X is constant and $\dot{X}_{i,t} \, / \, X_{i,t} = -\dot{A}_{i,t} \, / \, A_{i,t}$. However, as Feenstra (1990) shows, given the CES-type utility function of the model an ideal price index should reflect the introduction of a new high-tech good. Intuitively spoken, the introduction of a new good implies the price of this good to fall from infinity to some finite level. Accordingly, the price index for high-tech goods has to be deflated as a new good emerges, such that the introduction of a new good implies the real value of $p_X \, X_{i,t} \, A_{i,t}$ to grow. Based on the results of Feenstra, this implies, given the CES-type utility function, that the real growth rate of the high-tech output equals $\left(1-\alpha/\alpha\right) g_{i,t}$ (see Grossman and Helpman 1991: 62–63). However, this procedure has one problematic feature: since statistical conventions do not use the ideal Feenstra price index to count for the introduction of new goods, the model predicts that real statistical data would display a nongrowing high-tech sector.

86 The steady-state growth rate of the stock of blueprints, g_t, of both countries must be identical. If it were different, the country with the lower growth rate would finally approach a zero share of high-tech goods in total GDP. This, however, would not be compatible with a stable steady-state allocation of resources. Consequently, in a steady state with active R&D sectors in both countries, the growth rate of the stock of blueprints must be equal in both countries. Grossman and Helpman (1991: 183–187) show that this is a feasible allocation, too.

87 Within the special framework of the model, the share of the value of blueprints and the share of the value of high-tech goods in GDP is equal for each country, i.e., $p_X X_{i,k,t} A_{k,t} / GDP_{i,t} = p_A \dot{A}_{k,t} / GDP_{i,t}$. Consequently, if the share of the value of blueprints and high-tech goods in GDP equals unity, then $p_X X_{i,k,t} A_{k,t} / GDP_{i,t} = p_A \dot{A}_{k,t} / GDP_{i,t} = 0.5$ holds. In this case, the GDP growth rate reaches its maximum, i.e., $G\dot{D}P / GDP = 0.5 \, g / \alpha$.

in total GDP, the model predicts that a country with a relatively high human capital endowment displays a higher GDP growth rate.[88] As the following shows, this holds a fortiori for steady states without factor prize equalization.

The second region of resource endowment is characterized by a more "unbalanced" distribution of human capital relative to raw labor across both countries.[89] Thus, international trade does not lead to factor price equalization. Therefore, the wage rate for human capital is lower in the human-capital-rich country. As a consequence, the relatively human-capital-rich country entirely specializes in the production of high-tech goods and blueprints. Its GDP growth rate reaches therefore the maximum growth rate. The relatively raw-labor-rich country produces all three types of products. Consequently, the share of blueprints and high-tech goods in total GDP is smaller than one such that its real GDP growth rate is smaller than the maximum growth rate.

In the third region the distribution of human capital relative to raw labor is still more "unbalanced."[90] Factor price equalization does a fortiori not hold. The wage rate for human capital in the human capital rich country is that low that the entire production of blueprints is now concentrated in the human-capital-rich country. The raw-labor-rich country produces only the low-tech good and a fixed amount of high-tech goods. However, as no new blueprints for high-tech goods are invented, the high-tech sector does not grow. Consequently, the raw-labor-rich country exhibits no real GDP growth in steady state.

The fourth region is again characterized by a relatively more "balanced" distribution of human capital to raw labor. However, factor price equalization does nevertheless not hold. The raw-labor-rich country produces no blueprints and only a fixed and rather "small" amount of high-tech goods. Hence, this country displays no GDP growth. The human-capital-rich country produces now all three types of goods. The share of high-tech goods and human capital in total GDP is smaller than one such that its real GDP growth rate is smaller than the maximum growth rate.

Summing up, the Grossman–Helpman analysis reveals that the comparative advantage of a country can indeed determine its rate of per capita GDP growth. The ultimate reason for this dynamic effect of comparative advantage is the fact that

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88 Since there is no population growth by assumption, the GDP growth rate equals the per capita GDP growth rate.

89 In Grossman and Helpman (1991: 190, Figure 7.2), "region two" corresponds to "region I."

90 In Grossman and Helpman (1991: 190, Figure 7.2), "region three" corresponds to "region II."

there is one production sector, which displays a lower productivity growth rate than the other. However, it is important to note that even in the case, where the raw-labor-rich country is completely specialized in low-tech goods (i.e., in regions three and four) and does not grow in terms of GDP, the utility of its representative household does grow nevertheless. This is the case because, given the special type of utility function (see Figure 9) the permanently growing variety of high-tech goods induces permanent growth of utility, even in the country that does not produce blueprints and high-tech goods. If international financial markets allow for international borrowing and lending, the households of the low-tech country can invest in the accumulation of blueprints in the high-tech country in the same way as the households of the high-tech country can do. Therefore, they are not necessarily in a welfare-inferior position. A specialization in low-tech goods can only be welfare-inferior for a country, if the per capita wage payments to the immobile production factors (i.e., human capital and raw labor) are lower than in the high-tech country. A central premise for this analysis of the dynamic implications of comparative advantage is the existence of perfect international mobility of technological knowledge. If technological knowledge is internationally immobile, a country may specialize in high-tech goods, even though it has no comparative advantage for high-tech goods by its resource endowment. The implications of this scenario are analyzed in the following section.

3. Immobile Knowledge and Structural Hysteresis: The Worst Case Scenario for Growth? On Low-Tech and High-Tech Traps

Abstract: This section explores the implications of immobile technological knowledge for growth performance. It shows that immobile technological knowledge can induce a complete specialization of a country in high-tech or low-tech production. This specialization can affect growth performance, if the high-tech sector displays a higher steady-state growth rate than the low-tech sector. If, for example, the low-tech sector displays no steady-state growth, as in the model of structural hysteresis by Grossman and Helpman (1991), a perfect specialization on low-tech production leads to zero steady-state growth of per capita GDP. If, however, technological progress spreads evenly over high-tech and low-tech production, as in a modified version of the Rivera-Batiz–Romer model, a specialization in the low-tech sector caused by immobility of technological knowledge does not affect growth performance. The analysis shows furthermore that, depending on the setup of the model, low-tech specialization can be welfare-inferior compared to high-tech specialization

(low-tech trap) and high-tech specialization can be welfare-inferior compared to low-tech specialization (high-tech trap).

a. Structural Hysteresis in the Grossman–Helpman Model

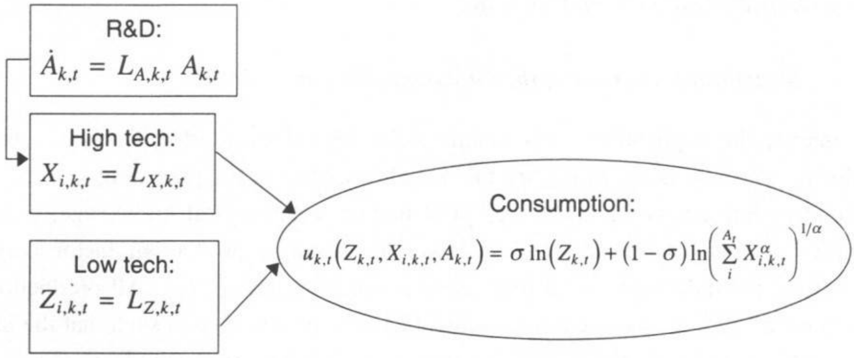
To analyze the implications of immobile technological knowledge, Grossman and Helpman (1991: Chapter 8) modify the model described in the preceding section.[91] To concentrate on the consequences of immobile technological knowledge, comparative advantages are excluded by assuming a single production factor only. Therefore, the only input of all production functions is labor, $L_{k,t}$. All production functions display constant returns to scale. Output units are chosen such that the input coefficients in all three sectors equal one. Consequently, simple production functions result, where the volume of labor input equals the volume of output (see Figure 10). Technological knowledge, $A_{k,t}$, is internationally immobile. This is indicated by the country index k (Figure 10). All other assumptions of the preceding model are maintained.

Given this setup of the model, in a two-country world with free trade, four types of steady states can emerge. (1) One country is active in R&D and produces high-tech goods, the other not; both countries produce low-tech goods. (2) One country is specialized in R&D and high-tech production; the other country is completely specialized in low-tech production. (3) Both countries are active in all three sectors. (4) Both countries are active in R&D and high-tech production, but only one country produces low-tech goods.

If within this model setup, a country displays a higher stock of technological knowledge at some point in time, a steady state necessarily emerges, where only this

91 Krugman (1981) presents another type of trade hysteresis model. Growth in this model is generated by the assumption that capital is an accumulating production factor with non-diminishing returns in the production function of manufacturing. However, a limitational manufacturing production function in labor and capital and a finite labor force sets an upper boundary for the accumulated capital stock and, hence, for economic growth. The setup of this model implies that the country that has a marginally higher stock of capital in the beginning of the growth process is able to produce manufacturing goods with lower costs, because the higher stock of capital makes production cheaper via its positive externalities. Therefore, in the case of free trade with manufacturing goods, the manufacturing sector of the country that starts with the higher capital stock can outperform the manufacturing sector of the other country. In the long run, a steady state results, where only the country that starts with the higher stock of capital produces manufacturing goods, while the other country produces only agricultural products. As wages in manufacturing are higher than wages in agriculture, workers in the manufacturing country fare better.

Figure 10 — The Grossman–Helpman Model of Structural Hysteresis



country is active in R&D and high-tech production. Consequently, the final state of both economies depends on some singular conditions in their past. The past of a country determines ultimately the future. This extreme result is caused by the immobility of technological knowledge. The intuition for this dominant effect of immobile technological knowledge is given in the following.[92] Consider a situation where both countries are active in all three production sectors. Now think what happens, if some exogenous shock drives the stock of accumulated technological knowledge in country *A* at a higher level than in country *B*. As follows from the production function of the R&D sector, this implies that labor productivity in R&D of country *A* increases above the level of labor productivity in R&D of country *B*. Consequently, country *A* gains a cost advantage in R&D. As there is free trade, this implies that country *A* specializes more and more in R&D. This implies that more and more labor is reallocated from the other sectors to the R&D sector. The more a country specializes in R&D, the stronger becomes its prevalence in the level of accumulated knowledge and, hence, its cost advantage in R&D. Eventually, only country *A* performs R&D and produces new high-tech goods. Country *B* specializes entirely in low-tech goods and produces only a fixed amount of high-tech goods, which correspond to the set of high-tech blueprints produced in its past.

These mechanics of the model imply that the steady states (3) and (4), where both countries are active in R&D, cannot be stable equilibria. A small exogenous shock is sufficient to cease R&D production in one country. Consequently, a scenario where both countries are permanently active in R&D is not very likely to occur. The stable

92 A formal analysis of this mechanism is presented in the next section, within the framework of a simplified Rivera-Batiz–Romer model.

steady states (1) and (2), however, imply that the country specialized in low-tech production experiences no real output growth, since the composition of GDP by sector corresponds to that of the model in the preceding section ([B.19]).

However, similar to the model of the preceding section, a zero rate of GDP growth is not necessarily welfare-inferior to a nonzero rate of GDP growth. If both countries are active in low-tech production (steady state (1)), wages in both countries must be equal. If furthermore financial markets allow for international borrowing and lending, investment opportunities for the households of both countries are equal. Consequently, welfare in both countries is identical. If, however, financial markets are imperfect, the households of the low-tech country cannot invest in the growing high-tech industries of the high-tech country. Therefore, they cannot participate from the income growth of the high-tech country. In this case, welfare in the low-tech country can be lower than in the high-tech country.

However, even in the presence of perfect financial markets, low-tech specialization can be welfare-inferior, if the other country entirely specializes in R&D and high-tech production. In this case, wages in the high-tech country can be higher than wages in the low-tech country, such that the households of the low-tech country are worse off (steady state (2)). Grossman and Helpman (1991) show that in this case (and in the case of imperfect international financial markets) it may be welfare improving for the government of the low-tech country to subsidize R&D in order to increase the long-run wage level. Since the subsidy is only necessary to overcome the technological gap between the two countries, a temporary subsidy is principally sufficient.[93]

An alternative to R&D subsidies are, of course, trade restrictions, since in autarky each country has an active R&D sector.[94] In this sense, free trade between a technologically advanced and a technologically backward country fosters the technological gap between both countries, in a similar way as stated by List (1841) (Section B.I.1). Hence, free trade displays the danger of a low-tech trap.

However, the extreme dynamic implications of immobility of technological knowledge do not necessarily emerge. They are primarily caused by the special sectoral structure of the Grossman–Helpman model of Figure 10. This model implies that the low-tech sector is not exposed to technological progress. Productivity in

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93 However, given the intrinsic instability of steady states with active R&D in both countries, a "careful" accommodation of temporary shocks might be necessary.

94 However, trade restrictions are likely to be more expensive in terms of forgiven welfare than subsidies, because subsidies do not exclude domestic households from the consumption of foreign high-tech goods.

low-tech production stays constant no matter what level of technological progress is made by R&D. This is of course an extreme assumption. If one thinks of the low-tech sector to correspond to primary and agricultural production, there is no empirical evidence in favor of such an assumption. Additionally, it seems to be rather restrictive to assume that no trade in capital goods takes place. Capital goods might embody technological knowledge, and, hence, foreign R&D activities might spill over from one country to another. This way, free trade may be a source of productivity growth even in a country that performs no own R&D. The following section presents a modified version of the Rivera-Batiz–Romer model that allows to study the spillover effects from trade with capital goods in the presence of immobility of technological knowledge.

b. Structural Hysteresis in the Rivera-Batiz–Romer Model

Contrary to the Grossman–Helpman model discussed in the preceding section the Rivera-Batiz–Romer model of Section B.III.1 implies that technological progress by R&D spreads evenly across an economy: new capital goods invented by R&D activities increase the total factor productivity of the aggregated production function. Consequently, a country which performs no R&D of its own may be able to benefit by free international trade from new capital goods developed abroad.

The Structure of the Model

To analyze the consequences of structural hysteresis within the Rivera-Batiz–Romer model, consider its modification given by Figure 11. There are two countries labeled North and South, $k=N, S$.[95] Instead of two types of labor input, raw labor and human capital, now only one aggregated measure of labor input, $L_{k,t}$, enters the production function. The same assumption is made by Grossman and Helpman in the model described in the preceding section. This excludes comparative advantages of countries due to differences in factor endowments and allows a concentration of the analysis on the effects of immobile technological knowledge. The immobility of technological knowledge is indicated by the country indices of the knowledge stocks, which enter the production function of R&D, $A_{N,t}$ and $A_{S,t}$. Throughout the analysis, free trade between both countries is assumed.[96]

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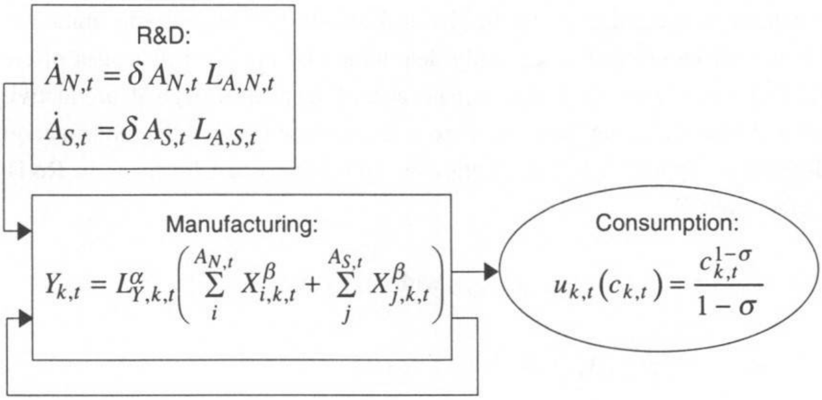
95 The labels North and South do not indicate differences in factor endowments. In this sense, the model is not a typical North–South model.

96 In general, free trade does also include trade with blueprints. As will be seen, there exists indeed a steady state where trade with blueprints can emerge. However, it is assumed that imports of blueprints do not add to the stock of technological knowledge in the im-

Figure 11 — A Rivera-Batiz–Romer-Type Model of Hysteresis



The market structure of the model is equivalent to the Rivera-Batiz–Romer model discussed in Section B.III.1: The R&D sector produces blueprints, i.e., the technological knowledge which is necessary to produce new capital goods. The government grants an eternal patent for each blueprint. As differentiated capital goods are only imperfect substitutes, each owner of a patent has monopolistic price-setting power. The result is monopolistic competition on the market for differentiated capital goods, such that the price for a capital good equals the well-known mark-up formula (see [A.5.9] in Appendix 5). All other markets are characterized by perfect competition.

The model displays four different steady states.[97] The different patterns of specialization in R&D and manufacturing characterize these steady states. Their stability properties are discussed in the following order. (1) The North and the South perform manufacturing and R&D. (2) The North performs manufacturing and R&D; the South is specialized in manufacturing. (3) The North is specialized in R&D; the South is specialized in manufacturing. (4) The North is specialized in R&D; the South performs manufacturing and R&D.

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porting country. The same assumption is made by Grossman and Helpman in their hysteresis model presented in the preceding section. Its justification is based on the special characteristics of R&D: to use knowledge to produce a new capital good based on a new blueprint does not necessarily improve the capability to produce new blueprints.

97 In a strict formal sense four further steady states exist. They follow by changing the labels "North" and "South." These steady states differ not in their economic contents from those steady states described above. One additional steady state follows, if zero technological knowledge is assumed. In this case, no incentive to produce anything exists.

Steady State (1): North and South Perform Manufacturing and R&D

The pattern of specialization in the Rivera-Batiz–Romer model with immobility of technological knowledge is primarily determined by the level of wages offered in R&D and manufacturing. Labor is paid according to its marginal productivity in R&D and manufacturing, because there is free competition on the labor market. As is derived in Appendix 5, this implies the following wage formulas in R&D and manufacturing:[98]

[B.21] $w_{A,k,t} = \Lambda_{k,t} L_{Y,N,t} + \Lambda_{k,t} L_{Y,S,t}$, with $\Lambda_{k,t} = \delta A_{k,t} \alpha \beta^{1+\frac{2\beta}{\alpha}} r_t^{-1}$,

[B.22] $w_{Y,k,t} = \alpha \beta^{\frac{2\beta}{\alpha}} \left(A_{N,t} + A_{S,t}\right)$,

where $w_{A,k,t}$ is the wage paid by the R&D sector of country k, $w_{Y,k,t}$ is the wage paid by the manufacturing sector of country k, $L_{Y,k,t}$ is the labor force used in manufacturing in country k, $A_{k,t}$ is the stock of technological knowledge of country k, r_t is the market interest rate.

It is a somehow peculiar feature of these wage formulas that the marginal productivity of labor in R&D depends on the labor input of manufacturing, while the marginal productivity of labor in manufacturing is indeed independent of the labor input in manufacturing. The intuition behind these formulas is given in the following.

First, consider the formula for R&D wages. Labor enters the R&D production function with constant marginal returns. Therefore, the physical marginal productivity of labor used in R&D is constant (see [A.5.14] in Appendix 5). The marginal productivity of labor in R&D measured in units of manufacturing output depends on the price of the R&D output, i.e., on the price of blueprints, p_A (see [A.5.15] in Appendix 5). The price of a blueprint, however, depends on the productivity of capital goods. The productivity of a capital good in manufacturing, finally, depends on manufacturing labor input. Hence, R&D wages depend on manufacturing labor input.

Second, consider the formula for manufacturing wages: Manufacturing wages do not depend on manufacturing labor input. As is shown in Appendix 5 ([A.5.4]), this is due to the fact that any change of labor input is accommodated by a corresponding change in capital goods input in such a way that marginal productivity of labor in manufacturing stays always constant. In this sense, marginal productivity of labor is independent of the level of labor input.

98 [B.21] and [B.22] correspond to [A.5.15] and [A.5.19] in Appendix 5.

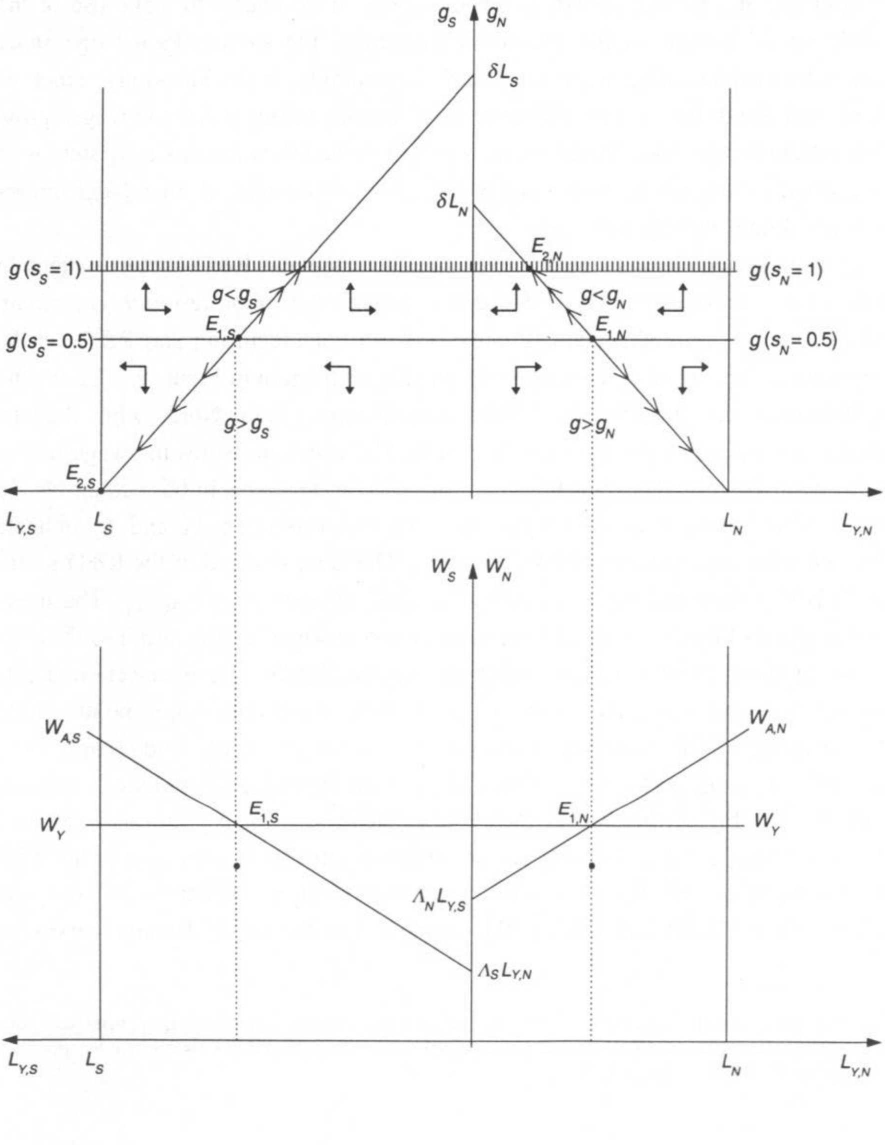
An important feature of the wage formulas is the fact that wages in R&D are solely determined by the domestic stock of technological knowledge, $A_{k,t}$, while wages in manufacturing are determined by the sum of the domestic and the foreign stock of technological knowledge, $A_{N,t}+A_{S,t}$. This stems from the assumption that technological knowledge is immobile. Following this assumption, it is only the domestic stock of technological knowledge which enters the R&D production function such that marginal labor productivity in R&D solely depends on the domestic knowledge stock. On the contrary, manufacturing wages are determined by the sum of domestic and foreign knowledge, because free trade allows to make use of the whole set of foreign capital goods. Consequently, the foreign knowledge stock enters the manufacturing wage formula.[99] Accordingly, if the knowledge stock of North and South grows with different rates, manufacturing and R&D wages grow with different rates, too. Therefore, as is shown in the following, a steady state with diversified production in North and South can only emerge, if knowledge grows with equal rates in both countries.

In a market equilibrium with active manufacturing and R&D sectors, wages in both sectors must equal. From this condition and the labor resource constraint, $Lk=L_{Y,k,t}+L_{A,k,t}$, the allocation of labor between manufacturing and R&D can be determined. This relation is displayed by the lower diagram in Figure 12. There, the right-hand x-axis measures labor input of manufacturing in the North, while the left-hand x-axis measures the same for the South. The y-axis measures the wage rate in both countries. From [B.22] follows that manufacturing wages in both countries are equal and independent of labor input. The verticals standing on L_N and L_S indicate the total labor endowments of both countries. The labor demand of the R&D sector ([B.21]) is represented by the curves $\left(L_S L_{Y,S}, w_{A,N}\right)$ and $\left(L_N L_{Y,N}, w_{A,S}\right)$. The intersection point of these curves with the manufacturing wage level determines the allocation of labor input between manufacturing and R&D. The intersection points labeled $E_{1,N}$ and $E_{1,S}$ have an important property: these intersection points imply the level of labor input in R&D to be equal in North and South, i.e., $L_{A,S}=L_S-L_{Y,S}=L_{A,N}=L_N-L_{Y,S}$. Following the R&D production functions this implies the equality of the growth rates of knowledge stocks in both countries, i.e., $\dot{A}_{N,t}/A_{N,t}=\delta L_{A,N,t}=\dot{A}_{S,t}/A_{S,t}=\delta L_{A,S,t}$. Consequently, given the allocation of labor indicated by $E_{1,N}$ and $E_{1,S}$ wages in both countries grow with the same rate. As follows from [B.21] and [B.22], this implies that the labor demand curves of

99 For an explicit discussion of the manufacturing production function properties concerning the relation between the set of available differentiated goods and factor productivity, see [B.4] in Section B.I.2.

manufacturing and R&D permanently shift upward. As they move with the same "speed," the status points $E_{1,N}$ and $E_{1,S}$ move upward along a vertical such that the allocation of labor between both sectors does not change. The upper diagram in Figure 11 reproduces, roughly spoken, the lower diagram in terms of growth rates. As follows from [B.22], the growth rate of the manufacturing wages corresponds to the growth rate of the world knowledge stock in $E_{1,N}$ and $E_{1,S}$:

Figure 12 — Steady State (1): North and South Perform Manufacturing and R&D



[B.23] $$\frac{\dot{w}_{Y,k,t}}{w_{Y,k,t}} = s_N g_N + s_S g_S,$$

$$\text{with } s_N = \frac{A_{N,t}}{A_{N,t} + A_{S,t}},\ s_s = \frac{A_{S,t}}{A_{N,t} + A_{S,t}},\ g_N = \frac{\dot{A}_{N,t}}{A_{N,t}},\ g_s = \frac{\dot{A}_{S,t}}{A_{S,t}}.$$

The growth rate of technological knowledge in a steady state with both countries active in both sectors is given by the following formulas (see Appendix 5.5):

[B.24] $$g_N = \frac{\beta\delta\left(L_N + L_S\right) - s_N^{-1}\rho}{\beta + s_N^{-1}\sigma},$$

[B.25] $$g_S = \frac{\beta\delta\left(L_N + L_S\right) - s_S^{-1}\rho}{\beta + s_S^{-1}\sigma}.$$

As the growth rates must equal in steady state, $g_N = g_S = g$, it follows that $s_N = s_S = 0.5$ must hold. Consequently, given the fixed labor endowments of both countries a unique growth rate exists in a steady state with diversified production in North and South. This unique growth rate is indicated in Figure 12 by the horizontal lines labeled $(g(s_S = 0.5)$ and $g(s_N = 0.5))$.

The growth rate of the R&D wage rate follows from [B.21]. It equals the growth rate of the domestic knowledge stock:

[B.26] $$\frac{\dot{w}_{A,k,t}}{w_{A,k,t}} = \frac{\dot{A}_{k,t}}{A_{k,t}}, \qquad \text{with} \qquad k = N, S.$$

The growth rate of the domestic knowledge stock in dependence from labor input is given by the R&D production functions. In Figure 12, the R&D production functions are given by the curves $\left(L_N, \delta L_N\right)$ and $\left(L_S, \delta L_S\right)$. The intersection points, $E_{1,N}$ and $E_{1,S}$, of these curves with the horizontal lines $g\left(s_S = 0.5\right)$ and $g\left(s_N = 0.5\right)$ determine the steady-state allocation of labor between both production sectors.

Steady State (2): The North Performs Manufacturing and R&D, the South is Specialized in Manufacturing

Steady State (1) is locally unstable. Consider, for example, what happens, if a small exogenous shock induces an increase of knowledge growth in the North above g. From [B.23] and [B.26] follows that R&D wages in the North grow faster than manufacturing wages. Consequently, labor flows from manufacturing towards R&D. This reallocation of labor towards R&D, however, implies that knowledge growth in the North is now permanently higher than in the South, $g_N > g_S$ (consider the $(L_N, \delta L_N)$ curve). Therefore, R&D wages in the North grow permanently faster than manufacturing wages:[100]

[B.27] $$g_N > g_S \Rightarrow \frac{\dot{w}_{A,N,t}}{w_{A,N,t}} = g_N > \frac{\dot{w}_{Y,N,t}}{w_{Y,N,t}} = s_N\, g_N + s_S\, g_S\,.$$

Therefore, more and more labor flows from manufacturing towards R&D. At the same time R&D wages in the South grow slower than manufacturing wages because:

[B.28] $$g_S < g_N \Rightarrow \frac{\dot{w}_{A,S,t}}{w_{A,S,t}} = g_S < \frac{\dot{w}_{Y,S,t}}{w_{Y,S,t}} = s_N\, g_N + s_S\, g_S\,.$$

Therefore, more and more labor is reallocated from R&D to manufacturing in the South. As a result, a self-enforcing process emerges, where the North specializes more and more in R&D production, while the South specializes more and more in manufacturing. Thereby, the North moves towards status point $E_{2,N}$ and the South moves towards status point $E_{2,S}$ along the path indicated by the arrows in Figure 12. These status points indicate steady state (2). In $E_{2,N}$ only the North is active in manufacturing and R&D, while in $E_{2,S}$ the South is completely specialized in manufacturing.[101] However, strictly speaking, starting in $E_{1,N}$ or $E_{1,S}$ the status points $E_{2,N}$ and $E_{2,S}$ are actually never reached. This stems from the fact that the share of the North in the world knowledge stock, s_N, can never reach unity, because the South always holds a fixed amount of technological knowledge, $A_S > 0$, for all times. However, s_N asymptotically approaches one. Thus, taking the limit $t \to \infty$ yields $s_N \to 1$ and $s_S \to 0$. Therefore, in the limit, inequality [B.27] can be rewritten:

[B.29] $$\frac{\dot{w}_{A,N,t}}{w_{A,N,t}} = g_N = \frac{\dot{w}_{Y,N,t}}{w_{Y,N,t}} = s_N\, g_N + s_S\, g_S \text{ with } s_N = 1 \text{ and } s_S = 0\,.$$

This equality describes the situation in status point $E_{2,N}$. Consequently, in $E_{2,N}$ manufacturing and R&D wages in the North grow again with the same rate. Therefore, no reallocation of labor from manufacturing to R&D takes place. In the South

100 The shock implies: $s_N > s_S$.

101 If the opposite shock occurs (such that the growth rate of the South is larger than the aggregated world growth rate), the reverse development takes place: The North finally specializes in manufacturing (status point $E_{3,N}$) and the South is finally active in both sectors (status point $E_{3,S}$). The mechanics of the process are of course the same.

in status point $E_{2,S}$ manufacturing wages grow with the same rate as in the North. This follows from [B.23] and is due to the fact that the South imports all new capital goods from the North.

The growth rate of the world knowledge stock in this steady state equals:

$$\text{[B.30]} \quad g_N = \frac{\beta\delta\left(L_N + L_S\right) - s_N^{-1}\,\rho}{\beta + s_N^{-1}\,\sigma}, \text{ with } s_N = 1 .$$

As g_N depends positively on s_N, this implies that the knowledge growth rate of the North in $E_{2,N}$ is now higher than in $E_{1,N}$. This is due to the specification of the R&D production function: the higher the accumulated technological knowledge of a country, the higher is its labor productivity in R&D. Consequently, more R&D output can be produced with the same amount of labor, if R&D production is concentrated on one country.[102]

In steady state (2), the manufacturing output in the North may be very low such that it is not sufficient to produce the amount of capital goods, which corresponds to the blueprints produced in the North. In this case, the North can import the missing amount of the "universal manufacturing" good and transform it into capital goods, or (equivalently) the North can sell the blueprints to the South so that the capital goods are produced there.

Consider now the situation on the labor markets in steady state (2), as shown by the lower diagram in Figure 13. R&D wages in the South are zero, because in status point $E_{2,S}$ the knowledge stock of the South is zero. This follows from the R&D wage [B.21], where the coefficient $\Lambda_{S,t} = 0$, if $A_{S,t} = 0$. Therefore, the entire labor force is working in manufacturing, where wages are paid according to [B.22]. In the North the knowledge stock is larger than zero, such that $L_{N,t} > 0$ and the R&D wage curve given by [B.21] cuts the manufacturing wage curve at $E_{2,N}$. Wages in both countries grow at the same rate, which is given by the growth rate of the knowledge stock in the North ([B.23] and [B.26]).

Steady state (2) is locally stable. To see this, consider the effect of an exogenous shock that drives the knowledge growth rate of the North above g_N. As g_N equals the growth rate of wages in R&D and manufacturing, this shock generates, contrary to the conditions in status point $E_{1,N}$, no incentive for a reallocation of labor. The same holds for a shock that drives the knowledge growth rate of the North below

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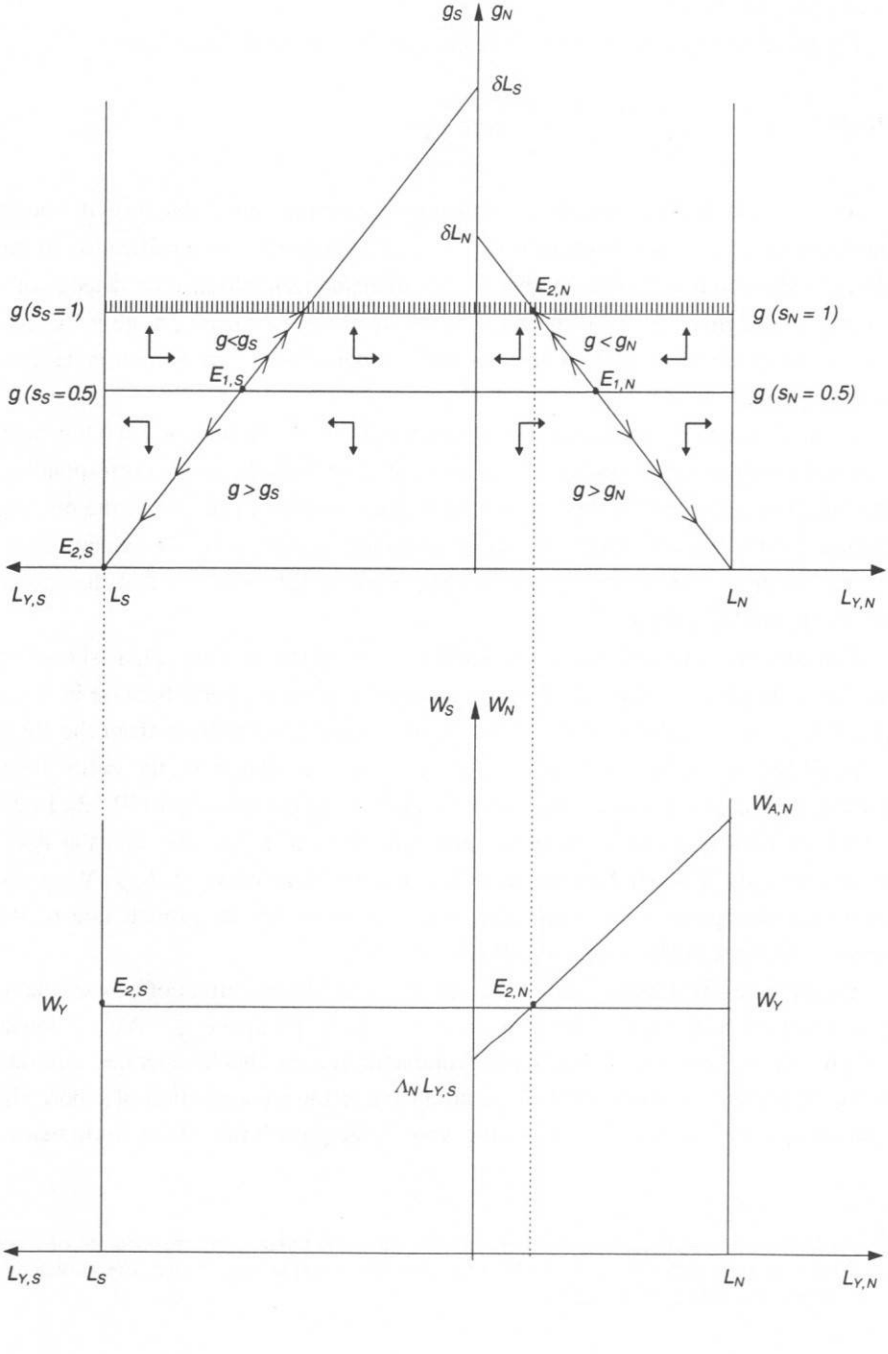
102 Additionally, the higher productivity of labor in R&D induces the reallocation of labor from manufacturing towards R&D, such that R&D output and, hence, the knowledge growth rate is further increased.

Figure 13 — Steady State (2): The North Performs Manufacturing and R&D, the South Is Specialized in Manufacturing



g_N. Consider the effect of an exogenous shock that induces the South to accidentally produce a small amount of technological knowledge. „Small" in the context of local stability means that the shock occurs only in the immediate neighborhood of $E_{2,S}$, a small shock is not sufficient to generate in the South a growth rate of R&D wages higher than manufacturing wages. Hence, no reallocation of labor from manufacturing towards R&D takes place after the shock has occurred. In the North, for a moment, the growth rate of manufacturing sector wages will be higher than the growth rate of R&D wages as a result of the shock in the South. This induces a reallocation of labor from R&D to manufacturing in the North. However, after the shock, the growth rates of wages will be equal again, such that the reallocation of labor is gradually reduced. Hence, steady state (2) is locally stable.

Steady state (3): The North Is Specialized in R&D, the South Is Specialized in Manufacturing

The R&D wage curve of the North in Figure 13 shows that wages offered by the R&D sector may be higher than manufacturing wages, if the labor force of the South, L_S, is sufficiently large ([B.21]). In this case, the North completely specializes in R&D production. This type of steady state is displayed by status point $E_{3,N}$ in Figure 14. As the total labor force of the North is now active in R&D, the knowledge growth rate is no longer given by [B.30], but by the R&D production function and equals therefore:

[B.31] $$g_N = \frac{\dot{A}_N}{A_N} = \delta\, L_N .$$

The South completely specializes in manufacturing (see status point $E_{3,S}$ in Figure 14). Since there is no accumulated knowledge in the South, marginal productivity of labor in the R&D sector of the South is zero. Therefore, no incentive exists for the South to produce technological knowledge. Steady state (3) is locally stable by the same arguments that hold in steady state (2).[103]

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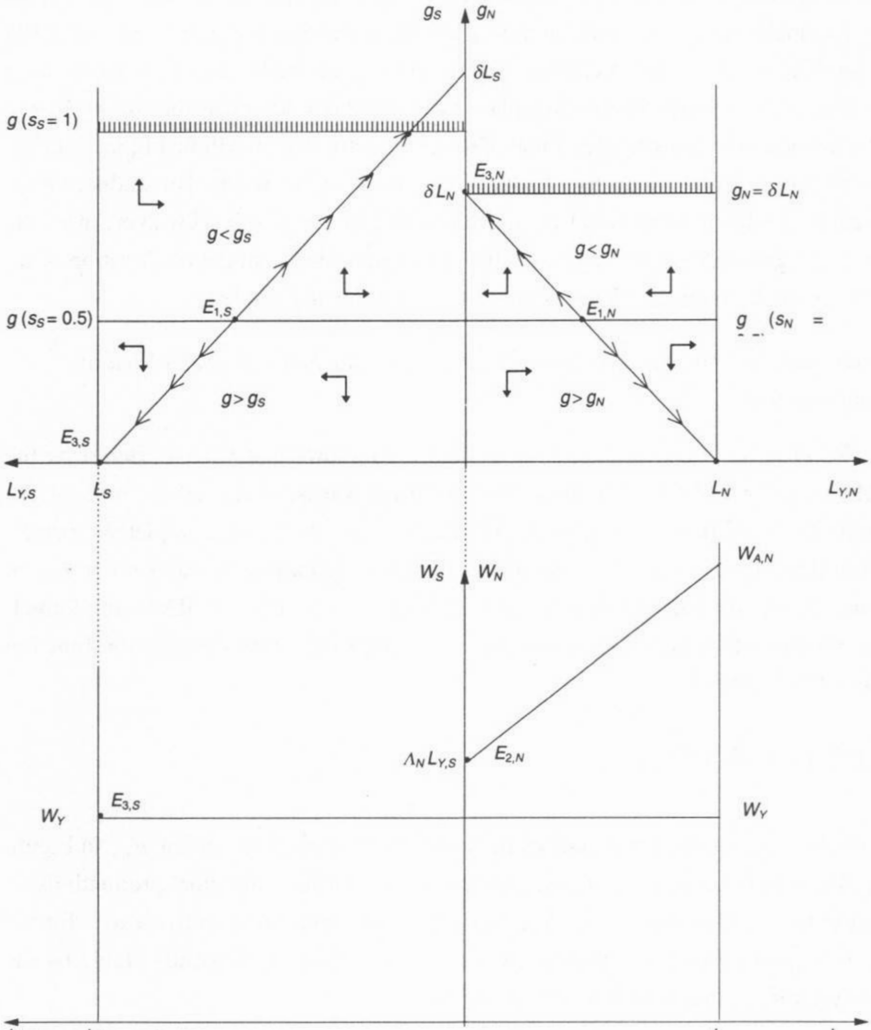
[103] As in steady state (3), the North is not active in manufacturing. It has either to import the "universal manufacturing" good and transform it into capital goods, or, equivalently, it can sell the blueprints to the South and capital goods are produced there.

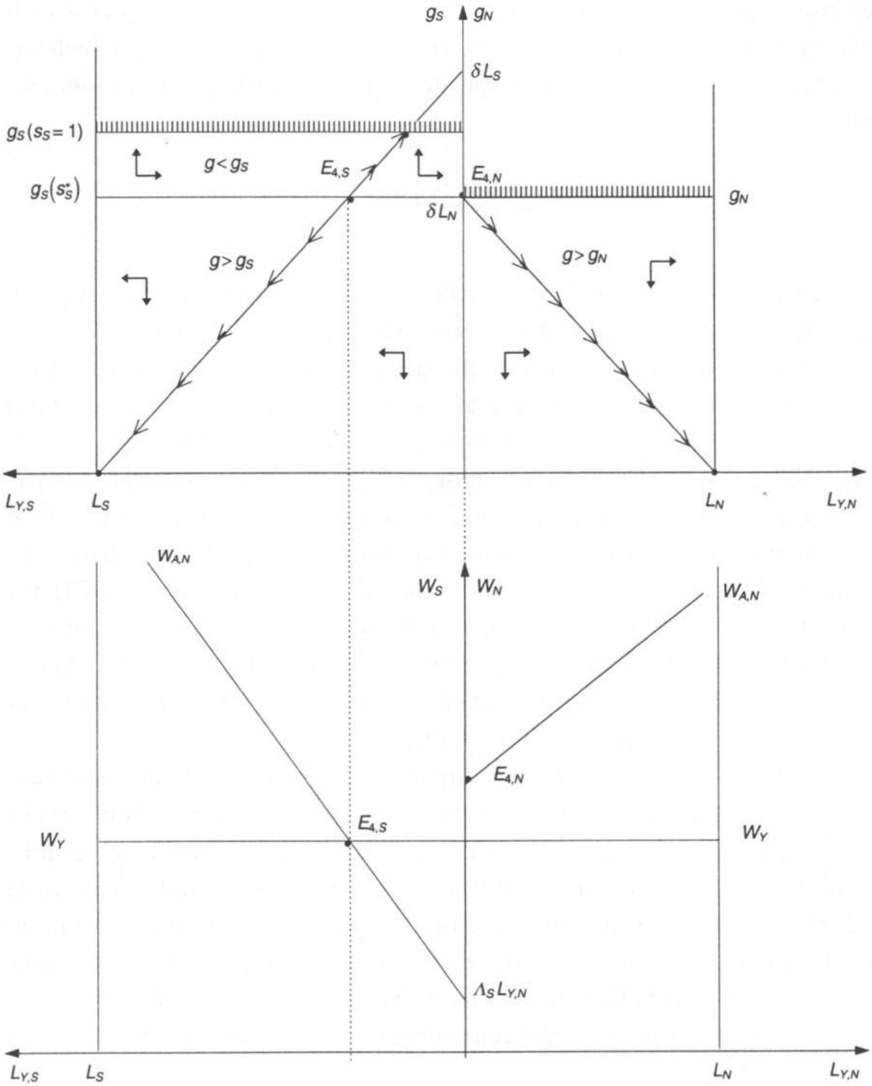
Figure 14 — Steady State (3): The North Is Specialized in R&D, the South Is Specialized in Manufacturing



Steady State (4): The North Specializes in R&D, the South Performs Manufacturing and R&D

However, if the South is sufficiently large (measured in terms of its labor force), it is also possible that the South is active in R&D, too. This last type of steady state is displayed by Figure 15. Here, the South is so large that R&D wages in the North are

Figure 15 — Steady State (4): The North Is Specialized in R&D, the South Performs Manufacturing and R&D



higher than the manufacturing wage level, given by [B.22]. Therefore, as indicated by status point $E_{4,N}$, the North is again completely specialized in R&D. At the same time the knowledge stock in the South is large enough such that the R&D wage curve in the South cuts the manufacturing wage curve exactly at status point $E_{4,S}$. In this status point the knowledge stock of the South grows with the same rate as the knowledge stock of the North. Consequently, by [B.23] and [B.26] manufacturing and R&D wages in the South grow with the same rate such that the allocation of labor between both sectors is fixed. As the North is, again, completely specialized in R&D, its growth rate is given by [B.31]. The South, however, is active in both sectors. Therefore, its growth rate corresponds to [B.25]. Equating both growth rates yields:

$$[B.32] \quad g_S = g_N \Leftrightarrow \frac{\beta\delta\left(L_N + L_S\right) - s_S^{-1}\rho}{\beta + s_S^{-1}\sigma} = \delta L_N .$$

Since all variables of these formulas with exception of s_S are exogenously given, steady state (4) is only possible, if s_S takes a value that fits the equality.

However, steady state (4) is not locally stable. A small shock of the knowledge growth rate of the South can give rise to a total reallocation of labor. If this shock drives the growth rate of the South above the growth rate determined by [B.32], R&D wages grow faster than manufacturing wages in the South such that a reallocation of labor from manufacturing towards R&D takes place. At the same time in the North, R&D wages grow more slowly than manufacturing wages, such that a reallocation of labor from R&D towards manufacturing takes place ([B.23] and [B.26]). Consequently, this shock implies that the South completely specializes in R&D, while the North completely specializes in manufacturing. If, to the contrary, a shock drives the growth rate in the South below the growth rate given by [B.32] the South completely specializes in manufacturing.

To sum up, this analysis of the four different steady states shows that only those steady states where one country is completely specialized in manufacturing are locally stable (i.e., steady states (2) and (3)). All steady states where both countries perform R&D are locally unstable. In this case, a small shock is sufficient to cause steady state (2) or (3) to emerge. Consequently, it is not very likely that one of the unstable steady states is realized. Therefore, the following analysis of the steady-state levels of per capita GDP focuses on the stable steady states only. First, however, the implications of the model concerning the steady-state growth rates of per capita GDP are discussed.

The Steady-State Growth Rates of Per Capita GDP

The preceding section has shown that there are three possible patterns of specialization for each country: specialization in manufacturing, specialization in R&D, and diversification in manufacturing and R&D. Hence, the GDP of a country can in principle equal each of the following aggregates:

[B.33] $GDP^{(1)}_{k,t} = Y_{k,t}$,

[B.34] $GDP^{(2)}_{k,t} = \dot{A}_{k,t}\; p_{A,t}$,

[B.35] $GDP^{(3)}_{k,t} = Y_{k,t} + \dot{A}_{k,t}\; p_{A,t}$.

As derived in Appendix 5.3, the steady-state growth rate of manufacturing output as well as the steady state growth rate of R&D output valued at manufacturing units equal the steady-state growth rate of the knowledge stock. Consequently, the GDP of North and South grows with equal rates in all types of steady states.

This means that contrary to the Grossman–Helpman model of the preceding section, the pattern of specialization does not lead to different GDP growth rates of per capita GDP in the North and South.[104] However, as described in the next section, in steady states (2) and (3), the level of per capita GDP depends on the pattern of specialization.

The Level of Wages and Per Capita GDP in Steady State (2)

In steady state (2), the South is specialized in manufacturing, while the North performs manufacturing and R&D. As displayed by Figure 13, the fact that North and South perform manufacturing implies that steady-state wages in both countries are equal. Therefore, the workers of both countries enjoy the same welfare, if there are perfect international capital markets such that identical saving possibilities exist. If, however, capital markets are imperfect, the workers of the country with the larger investment possibilities may have higher incentives to save and, hence, to enjoy a higher steady-state income from their savings. As wages (per capita labor income) in both countries are identical, the differences of investment possibilities correspond to the differences of per capita GDP. Inserting [A.5.29] and [A.5.13] (Appendix 5), into [B.35] yields the following formula for per capita GDP in the North:

[B.36] $$\frac{GDP_{N,t}}{L_{N,t}} = \beta^{\frac{2\beta}{\alpha}} A_N \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{g}{r}\, \alpha \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{L_{S,t}}{L_{N,t}} \right) \right) .$$

Inserting [A.5.29] (Appendix 5) into [B.33] yields the following formula for the per capita GDP of the South:

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104 As the labor force equals population and does not grow by assumption, the growth rate of GDP equals the growth rate of per capita GDP.

[B.37] $$\frac{GDP_{S,t}}{L_{S,t}} = \beta^{\frac{2\beta}{\alpha}} A_N .$$

Consequently, combining [B.36] with [B.37] yields for the per capita GDP of the North:

[B.38] $$\frac{GDP_{N,t}}{L_{N,t}} = \frac{GDP_{S,t}}{L_{S,t}} \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{g}{r} \alpha \beta \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{L_{S,t}}{L_{N,t}} \right) \right) .$$

Consequently, per capita GDP in the North is higher than per capita GDP in the South, if the terms in the right-hand brackets exceed unity and vice versa. To determine the magnitude of the brackets, insert [A.5.38], [A.5.40] and [A.5.41] (Appendix 5) into the expression in the brackets of [B.36]. This yields the following expression:

[B.39] $$1 - \frac{\beta}{\beta+\sigma} - \frac{\beta L_{S,t} - \rho\delta^{-1}}{L_{N,t}(\beta+\sigma)}$$

$$+ \left(\sigma + \rho \frac{\beta+\sigma}{\beta\delta\left(L_{N,t} + L_{S,t}\right) - \rho} \right)^{-1} \alpha\beta \left(1 - \frac{\beta}{\beta+\sigma} - \frac{\beta L_{S,t} - \rho\delta^{-1}}{L_{N,t}(\beta+\sigma)} + \frac{L_{S,t}}{L_{N,t}} \right) .$$

The magnitude of this expression depends on the concrete values of the structural parameters of the economy and the size of North and South, $L_{S,t}$ and $L_{N,t}$. Unfortunately, the magnitude cannot be determined without further assumptions. However, it is possible to take the limits for large L_N and L_S. Doing this, it has to be taken into consideration that steady state (2), which is analyzed here, does only emerge if L_S compared to L_N is not "too large." If the ratio L_S / L_N grows large, R&D wages in the North may become higher than manufacturing wages (see [B.21] and [B.22] and the analysis in the next section). In this case the labor force of the North would completely shift from manufacturing to R&D, such that the North would completely specialize in R&D. Thus, steady state (3) would emerge. Therefore, an evaluation of expression [A.5.51] by taking the limits with respect to L_N and L_S has to be subjected to the condition that $w_{Y,N} = w_{A,N}$. As shown in Appendix 5.3, this condition can be modified to the condition $d\,s\,LN - (1+s)\,d\,L_{Y,N} + r = b\,d\,L_S$. From this follows, holding L_S constant and taking the limit with respect to $L_{N,t} \to \infty$ does not hurt the condition $w_{Y,N} = w_{A,N}$.[105] Taking the limits for $L_{N,t} \to \infty$, expression [3.35] turns to:

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[105] As L_N is allocated to manufacturing and R&D, any increase of L_N is split between both sectors such that the pattern of specialization does not change. From [A.5.19] follows that an increase of $L_{Y,N}$ that would generate a higher wage rate in R&D compared to

[B.40] $\dfrac{\beta\alpha+\sigma}{\beta+\sigma}$.

Consequently, if $0<\alpha<1$, as implied by the Cobb–Douglas specification of manufacturing production, this expression must be smaller than unity. Hence, if the North is sufficiently larger than the South, the production of blueprints in steady state (2) may indeed be compatible with a lower per capita income than the production of manufacturing goods.

If one chooses L_N such that $w_{Y,N}=w_{A,N}$ always holds, while L_S is increased, i.e., $L_N=L_S(\beta/\sigma)-(\rho/\sigma\delta)$, and takes the limit for $L_S\to\infty$, expression [3.35] equals α and is, hence, again smaller than unity.[106] Consequently, if the scale of both economies grows and L_N is not too small compared with L_S, the production of blueprints can also go hand in hand with a lower per capita income than is the case with the production of manufacturing goods. Figure 16 displays that expression [3.35] rapidly converges towards α for a "normal" calibration of the model.[107]

In a sense, this result is counterintuitive: although the North is the only country that produces high-tech goods, which can be sold at monopolistic price markups, there exists a range of parameter values and labor force sizes, where per capita income of the North is indeed smaller than per capita income of the South. Two mechanisms explain this result:

First, although capital goods are sold at monopolistic prices, the per period profit from selling a blueprint is smaller than its total productivity effect on GDP (see [A.5.30] and [A.5.35] in Appendix 5.2). Hence, the production of blueprints generates externalities, which flow from the North to the South.

Second, the income of the North from the selling of a blueprint equals the present value of the per period profit of a blueprint. Hence, it depends negatively on the steady-state interest rate. The steady-state interest rate, however, depends positively on the size of both economies. Consequently, the R&D income of the North decreases as the size of both economies grows.

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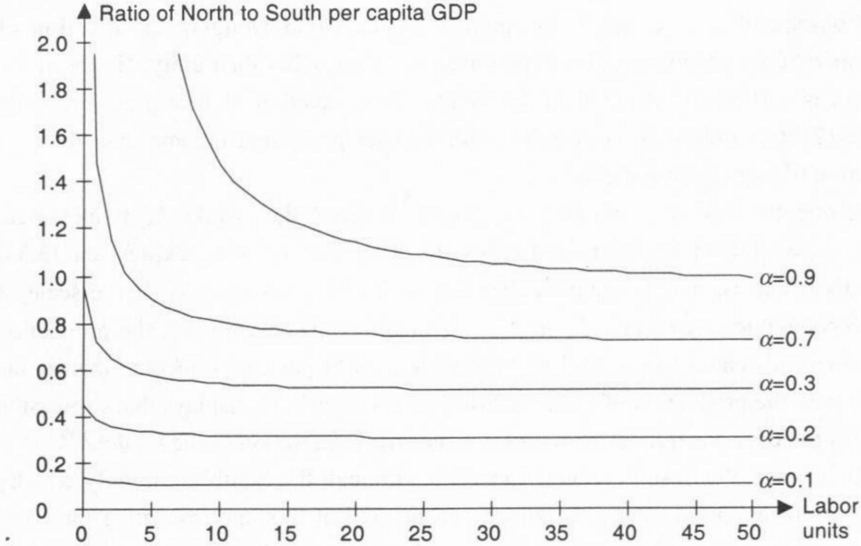
manufacturing, is automatically reduced by an reallocation of labor towards R&D (such that $L_{Y,N}$ decreases again).

106 This results by inserting $L_N = L_S(\beta/\sigma)-\rho/\sigma\delta$ into expression [A.5.51] and taking the limit $L_S\to\infty$.

107 Figure 16 is based on the following parameter values $\delta = 0.01$, $\sigma = 1$, and $\rho = 0.05$.

Figure 16 — Steady State (2): Ratio of Per Capita GDP North versus South Depending on Labor Force Size



The Level of Wages and Per Capita GDP in Steady State (3)

In steady state (3), the South is specialized in manufacturing and the North is specialized in R&D. This type of steady state always emerge if R&D wages are higher than manufacturing wages.[108] As derived in Appendix 5.4, this implies the inequality $L_S \geq L_N(\sigma/\beta)+(\rho/\sigma\delta)$ to hold. Consequently, steady state (3) emerges only, if the South is sufficiently large compared to the North.

As the wage level of the North is higher than the wage level in the South, workers in the North enjoy higher welfare in steady state (3). As derived in Appendix 5.4 the relation between per capita GDP in North and South is now given by the following equation:

$$[B.41] \quad \frac{GDP_{N,t}}{L_{N,t}} = \frac{GDP_{S,t}}{L_{S,t}} \left(\delta\alpha\beta \, \frac{L_S}{\delta L_N \sigma + \rho} \right).$$

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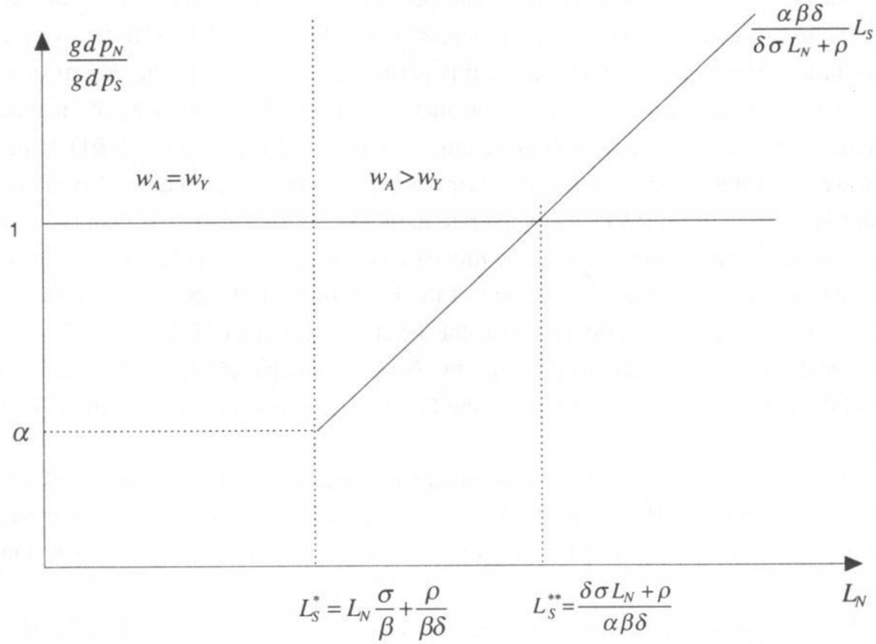
108 There exists, of course, one special case, where steady state (3) emerges, while R&D and manufacturing wages are equal. This depends on a special set of parameter values and labor force endowments. Figure 13 shows that this scenario results, if the manufacturing wage curve and the R&D wage curve intersect just at their cutting point with the *y*-axis.

Consequently, per capita GDP in the North is higher than per capita income in of the South, if the term in brackets is greater than unity and vice versa. The magnitude of this expression depends again on the concrete values of the structural parameters of the economy and the relative size of the North and South, L_S and L_N. To evaluate the term in brackets, one has to take into consideration that steady state (3) requires $L_S \geq L_N(\sigma/\beta)+(\rho/\sigma\delta)$ to hold. Inserting the minimal value of L_S that is compatible with steady state (3), i.e., $L_S = L_N(\sigma/\beta)+(\rho/\sigma\delta)$, the term in brackets just equals α. Hence, as $0<\alpha<1$, in this case per capita GDP in the North is lower than per capita GDP in the South, although the North is completely specialized in R&D and the South in specialized in manufacturing. However, holding L_N constant and increasing L_S shows that per capita GDP in the North soon approaches a value higher than per capita income in the South. This relation is displayed by Figure 17, where the y-axis measures the ratio of per capita GDP in the North to the South and the x-axis measures the labor force in the South. To the left of $L_S^* = L_N(\sigma/\beta)+(\rho/\sigma\delta)$, manufacturing and R&D wages are equal, such that steady state (3) does not emerge. To the right of L_S^*, R&D wages are higher than manufac-

Figure 17 — Steady State (3): Ratio of Per Capita GDP North versus South in Dependence of the Labor Force of the South



turing wages, such that the North is specialized in R&D only and steady state (3) does emerge. If the labor force of the South exactly corresponds to L_S^*, the ratio of per capita GDP in the North to the South will equal α. If the labor force of the South corresponds to $L_S^{**} = (L_N\sigma\delta + \rho) / \alpha\beta\delta$, the ratio of per capita GDP in the North to the South equals unity.[109] For a value of L_S higher than L_S^{**}, per capita GDP in the North is higher than per capita GDP in the South.

The discussion of steady state (3) shows that higher wages and a higher per capita GDP in the country specialized in R&D does only emerge, if the South is sufficiently larger than the North. The explanation for this interrelationship stems from the fact that in steady state (3) the interest rate depends on the size of the labor force in the North only (see [A.5.62] in Appendix 5). Therefore, a higher labor force in the South does not induce a higher interest rate, such that the present value of a blueprint is not negatively affected by the size of the South. Since, however, the per period profit from the selling of a blueprint is positively affected by the size of the South, the per capita GDP in the North is positively related to the labor force size in the South (see [A.5.60] in Appendix 5).

Summing up, this section has shown a scenario in which international immobility of technological knowledge can give rise to structural hysteresis but does not hamper the steady-state growth performance of a country. Even if a country completely specializes in manufacturing and performs no R&D of its own, it can fully participate in the technological progress made by the R&D efforts of other countries. The channel which makes this participation possible is the import of capital goods or blueprints from countries that are active in R&D. Hence, international trade is the means which enables countries to participate in foreign R&D efforts. However, if the South is sufficiently larger than the North, such that the North completely specializes in R&D, the wage rate in the North may be higher than the wage rate in the South. Consequently, in this case the welfare of the labor force in the South may be lower than the welfare of the labor force in the North. Nevertheless, there also exists a scenario in which the level of per capita GDP of the North is lower than that of the South although the North is completely specialized in R&D and displays a higher wage rate than the South. This scenario may be called "high-tech trap."

Taken together, this analysis shows that structural hysteresis does not necessarily have deteriorating effects on the dynamic performance of an economy. Although free trade may cause structural hysteresis, it may as well allow to "import techno-

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109 $L_S^{**} = (L_N\sigma + \rho) / \alpha\beta\delta$ follows by setting the right-hand brackets of [B.41] equal to unity and solving for L_S.

logical progress" such that dynamic performance is not reduced. As has been stated in the beginning of this section, the assumption that technological knowledge is actually internationally perfectly immobile may be as questionable as the assumption that technological knowledge is internationally perfectly mobile. The Rivera-Batiz–Romer analysis shows that even in the hypothetical presence of perfect international immobility of technological knowledge per capita GDP growth is possible via the import of foreign capital goods.

IV. Summary: Theoretical Interrelationships of International Trade and Economic Growth

1. The Results of the Theoretical Analysis

This chapter has discussed theoretical models which displayed various transmission channels between international trade and economic growth. Four broad types of such channels can be distinguished: the effect of international trade with capital goods on international capital flows (Section B.II.1), the effect of international trade with capital goods on the intensity of competition in domestic capital goods markets (Section B.II.2), the effect of international trade with capital goods on the allocation of resources to research and development activities (Section B.III.1), and the effect of international trade with capital goods on the pattern of sectoral specialization (Sections B.III.2 and B.III.3).

In the Solow–Ramsey model in Section B.II.1, international trade influences the transitional growth rate of per worker GDP via its impact on international capital flows. Within this model setup, the possibility of international borrowing and lending combined with free international trade allows to transfer physical capital from the country with the lower interest rate to the country with the higher interest rate.[110] If both countries are out of steady state, this increases the transitional

[110] Free international borrowing and lending has to be accompanied by international trade, because only free trade also allows to repatriate interest payments. Hence, the latter condition is as important as the first: obviously, without international trade, financial credits by foreign countries cannot be exchanged for foreign products. Consequently, without international trade, there would be no incentive to borrow at international financial markets. However, without free international trade, there would also be no incentive to lend money at international markets, because a repatriation of interest payments in terms of goods and services would not be possible. Consequently, without international trade immobile households had no possibility to consume their interest profits.

growth rate of the country with the higher interest rate and decreases the transitional growth rate of the country with the lower interest rate.

Another impact of international trade on capital accumulation within the framework of a Solow–Ramsey growth model emerges under the assumption of imperfect competition on the domestic market for capital goods (Section B.II.2). In this case, free trade with capital goods intensifies competition on the domestic capital goods market. As a result, the domestic price of capital goods decreases. This, in turn, increases domestic accumulation of real capital and, hence, the growth rate in transition towards the steady state.

However, within the framework of the Solow–Ramsey growth model, the impact of international trade is restricted to the growth rate in transition towards steady state. Within this model type, international trade affects only the steady-state level of per worker GNP (in the case of international capital flows) or GDP (in the case of imperfect competition on the domestic capital goods market). On the contrary, models of endogenous growth show that international trade may as well affect the steady state growth rate.

Within the Rivera-Batiz–Romer (1991a, 1991b) model of endogenous growth, international trade primarily affects the steady state growth rate via its impact on the allocation of resources between R&D and manufacturing. Free trade increases the demand for capital goods and, consequently, the demand for blueprints, which are necessary for the production of capital goods. This in turn increases the price for blueprints such that the value of the marginal productivity of human capital in R&D grows. Ceteris paribus, this induces a reallocation of human capital from the manufacturing sector to the R&D sector. This reallocation increases R&D output and, hence, given the positive effect of R&D output on total factor productivity, the level of per worker GDP. However, the model of Rivera-Batiz–Romer shows that this effect can be totally offset if international trade with capital goods also increases marginal productivity of human capital in manufacturing. In this case, international trade does not necessarily give rise to a reallocation of human capital from manufacturing to R&D. Consequently, international trade does not inevitably affect steady-state growth rate although it increases the output level of manufacturing and R&D. If, however, international trade facilitates the inflow of foreign technological knowledge to R&D, it can induce a second positive effect on marginal productivity of human capital in R&D. In this case, international trade causes a reallocation of human capital from manufacturing to R&D, such that the steady-state growth rate increases.

Beside this type of allocation effects, international trade can also affect steady-state growth in models of endogenous growth via its impact on the pattern of sectoral specialization. Since the GDP growth rate equals a weighted average of sectoral growth rates, the pattern of sectoral specialization can affect steady-state growth, if and only if the individual sectors grow at different rates. As the analysis of Grossman and Helpman (1991: Chapters 7 and 8) reveals, there are two causes that can determine the pattern of sectoral specialization: comparative advantage and immobility of technological knowledge.

If a human-capital rich country specializes according to its comparative advantage in human-capital-intensive high-tech industries and if high-tech industries display higher productivity growth than low-tech industries, it reaches a higher GDP growth rate than a human-capital-poor country that specializes in low-tech industries. As the analysis of Grossman and Helpman shows, comparative advantage does not necessarily cause a complete sectoral specialization. On the contrary, if technological knowledge is internationally immobile, countries completely specialize in those industries in which they initially hold a technological lead. Countries that have no technological lead in any industry specialize in low-tech industries in which production is independent of the availability of technological knowledge. Consequently, if high-tech industries display a higher rate of productivity growth than low-tech industries, countries specialized in high-tech industries reach a higher steady-state GDP growth rate.

The different transmission channels of international trade and economic growth shown by these models result under different assumption sets. Of course, these assumption sets are not necessarily mutually exclusive. Most differences in the assumptions sets are only necessary to focus the analysis on the questions of interest. For example, the analysis within the framework of endogenous growth models typically focuses on steady states. However, given the setup of these models, international trade can affect the transitional growth rate in a similar manner as in models of exogenous growth. Likewise, allocation effects and specialization effects of international trade can simultaneously emerge in models of endogenous growth. It is even imaginable that in multisector models of endogenous growth, specialization according to comparative advantage and specialization caused by international immobility of technological knowledge can simultaneously take place. Up to now, no universal model that embraces all these different aspects exists.

2. Implications for the Empirical Analysis

Taken together, the theoretical analysis suggests a broad set of potential transmission channels of international trade on economic growth. A central role in the various transmission channels, however, plays international trade with capital goods. The analysis of a Solow–Swan model with imperfect competition on the domestic capital goods market has shown that international trade with capital goods can affect the degree of competition on the domestic capital goods market, if domestic and foreign capital goods are substitutes. The analysis of the Rivera-Batiz–Romer model of endogenous growth has shown that international trade with capital goods can affect the total factor productivity in the manufacturing sector and the profits of research and development if capital goods are differentiated, i.e., imperfect substitutes. The analysis of the Rivera-Batiz–Romer model under the assumption of immobile technological knowledge has shown that countries which are not active in R&D can perfectly participate in the technological progress of other countries by importing their capital goods.

In general, if capital goods are differentiated, the role of international trade with capital goods is twofold: it can affect the rate of economic growth in transition towards the steady state as well as the growth rate of total factor productivity. Consequently, an empirical analysis of the effects of international trade on economic growth has to take into consideration both possibilities. Therefore, the empirical analysis in the next Chapter is based on two different estimations. First, the effect of capital good imports on the growth rate in transition towards steady state is measured. This analysis is based on a Solow–Swan model, which is modified to account for international trade with differentiated capital goods. Second, the effect of capital goods imports on total factor productivity is quantitatively estimated. This estimation is based on the same type of aggregate production function with differentiated capital goods, which has been discussed in Section B.I.2.

However, before these estimations are presented, the results of some time series estimations are given. This is necessary because some recently published empirical studies found a low temporal persistence of long-run economic growth. If these findings are correct, they would seriously question the possibility of explaining long-run economic growth by the mechanisms described by the above models. Consequently, before the effect of international trade with capital goods on long-run growth performance is measured, it is necessary to analyze the empirical characteristics of the time series behavior of economic growth.

C. Empirical Findings on Economic Growth and International Trade with Capital Goods

I. The Time Series Behavior of Economic Growth

1. Just Good Luck or Does Policy Matter?

Abstract: This section empirically analyzes the time series behavior of economic growth. First, the empirical results of Easterly et al. (1993), stating "low persistence" of economic growth rates, are analyzed. It is shown that by their measure of persistence a mean reverting growth process is compatible with "low persistence" and a random walk growth process is compatible with "high persistence." Consequently, their measure of persistence is not suitable for an analysis of the time series behavior of economic growth. It is argued that a test of the time series behavior of economic growth has to be based on an appropriate time series model. Based on such a model several tests of the null hypothesis of random walk behavior of economic growth against the alternative hypothesis of a mean reverting process are presented. Country-specific time series tests as well as a panel data test are used. The results show that economic growth is typically better described by a mean reverting process than by a random walk. Therefore, three basic conclusions are drawn. First, theories of economic growth intending to explain the first difference of real per capita GDP by stationary factors are warranted by the empirical time series behavior of economic growth. Second, cross-country regressions of long-run growth rates on stationary explanatory variables are not disturbed by an incompatible time series behavior of the variables. Third, long-run growth policies directed towards the long-run mean of the growth rate make sense. Short-run activism that intends to absorb negative shocks and generate positive shocks seems to cause only temporary effects.

Despite their differences in microeconomic details, what all models discussed in Chapter B have in common is the attempt to explain economic growth by factors that are not or, within a reasonable interpretation, not essentially stochastic by nature. Consequently, if the empirical time series behavior of economic growth were characterized by a dominance of stochastic shocks, this would seriously question the explanatory power of these theories.[111] For example, if the time series behavior of

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[111] Easterly et al. (1993) suggest that a dominance of stochastic shocks in economic growth may be compatible with the steady-state version of the Solow–Ramsey and Solow–Swan model, under the assumption that the exogenous growth rate of technological progress

economic growth (i.e., the first difference of real per capita GDP) followed a random walk, theories explaining economic growth rates by stationary factors would obviously be mistaken. In this case, theories explaining the dynamics of real per capita GDP by stationary factors had to focus on an explanation of (stationary) higher-order differences of real per capita GDP.

The time series behavior of economic growth also has implications for economic policy. A dominance of stochastic shocks in the development of real per capita GDP would question the suitability of certain policies. Growth policies intending to "get the long-run fundamentals right," such as incentives for the accumulation of physical, human, and knowledge capital, would not necessarily be appropriate. A dominance of stochastic shocks would imply that primarily growth policies dampening negative shocks and enforcing positive shocks would add to a better growth performance. Hence, discretionary activism would probably be more suitable than long-run policy designs.

Furthermore, a dominance of stochastic shocks would also have implications for the econometric analysis of economic growth. As Quah (1993b: 32) states, cross-country regressions based on growth rates averaged over time, such as those in Barro and Sala-i-Martin (1992, 1995) and Mankiw et al. (1992), are only informative if "permanent movements in income were well-described by smooth time trends, themselves largely unaffected by ongoing economic disturbances." Certainly, if the time series of economic growth displayed random walk behavior, average long-run growth rates would hardly contain information about the underlying forces of real per capita GDP development. Cross-country regressions of these growth rates on stationary explanatory variables would then result in unreliable correlations.

Taken together, these arguments suggest that an empirical study of the determinants of economic growth should be based on an analysis of the time series behavior of economic growth. Therefore, before the impact of international trade on economic growth is analyzed, this section presents a time-series analysis of economic growth.

a. *Low or High Persistence? The Easterly–Kremer–Pritchett–Summers Analysis*

Starting point of the analysis are the empirical results of Easterly et al. (1993). These authors find that "Relative growth rates of output per worker across countries are not very persistent. (...) In contrast to the growth rates themselves, the country

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primarily is driven by stochastic shocks. However, as Section C.II.1 shows, compared to the transitional version the steady-state version of this model appears to be misspecified.

characteristics which are often thought as determinants of growth rates themselves are highly persistent" (Easterly et al. 1993: 20). Hence, they conclude mainly "good luck," but not so much country-specific factors determined by policy prevail the growth process.

Figure 18 displays the finding of Easterly et al. (1993). The *x*–axis measures the growth rate of a country over the period from 1960 to 1973, while the *y*–axis measures the growth rate over the period of 1974 to 1988.[112] Given the setup of this figure, countries with similar growth performance in both periods should be placed around the 45°-line. Ostensibly, this is not the case. Most countries are placed well below the 45°-line indicating that their growth performance over the second period was lower than over the first period. However, most countries with positive growth rates in the first period displayed positive growth rates in the second period, too. Only a few countries with positive growth rates in the first period displayed negative growth in the second.

The standard correlation coefficient of period-one growth rates to period-two growth rates is 0.26, while the rank correlation coefficient is 0.25.[113] A least squares cross-country regression of period-two growth rates dependent on period-one growth rates yields a highly significant positive regression coefficient (*p*-value = 0.000) for the period-one growth rates. Their explanatory power is, however, rather small ($R^2 = 0.14$).[114] Table 2 presents the estimates of cross-country correlation coefficients of per worker GDP growth rates for the ten-year averages 1960–1970 versus 1970–1980 and 1970–1980 versus 1980–1988. They all range within the same magnitudes.

Taken together, these empirical findings suggest that the growth rates of the periods 1960–1973 and 1974–1988 display a low degree of correlation. However, this does not necessarily imply that the time series behavior of economic growth is characterized by low persistence and a dominance of stochastic shocks, as Easterly et

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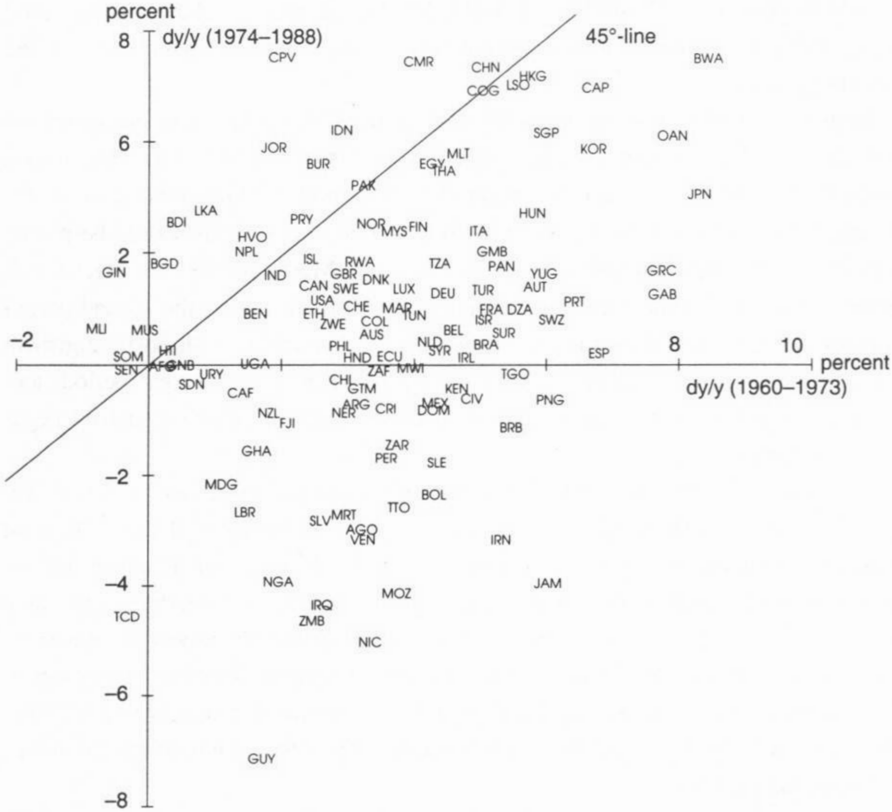
112 Instantaneous growth rates are estimated by an OLS regression of the type $\ln(GDP_t) = a + b\,t + \varepsilon$, where b is the growth rate. Following Easterly et al. (1993), conventional compound growth rates are plagued by end-point sensitivity and display an even lower persistence over both periods.

113 Easterly et al. (1993: 23) report a rank correlation coefficient of 0.21, due to a somewhat smaller country sample. (Their sample includes 115 countries; Figure 17 is based on a sample of 121 countries.)

114 Figure 18 is based on per worker GDP growth rates. Easterly et al. (1993) presume that per worker GDP is a better proxy for labor productivity than per capita GDP. Figure A.6.1 in the Appendix, shows that basically the same conclusions can be drawn from per capita GDP growth rates. However, the correlation coefficient of per capita growth rates is somewhat higher and equals 0.31.

Figure 18 — Growth Rates of Per Worker GDP, 1960–1973 versus 1974–1988[a]



[a]Least square growth rates of per worker GDP. The three-letter World Bank codes for country names are used to indicate a point (see Table A.11.3 in the Appendix). The data are taken from Summers and Heston (1991). Figure 18 corresponds to Figure 1 in Easterly et al. (1993).

Table 2 — Correlation Coefficients of Real Per Worker GDP Growth Rates, 1960–1970/1970–1980 and 1970–1980/1980–1988

Country group	Observations	Correlation coefficient	
		1st and 2nd decade	2nd and 3rd decade
All	100	0.21	0.31
Nonoil	89	0.15	0.30
OECD	22	0.73	0.07
Developing[a]	67	0.10	0.33

[a]Nonoil developing countries only.

Source: Easterly et al. (1993: Table 1).

al. (1993) suggest. The pattern of Figure 18 may as well be generated by the effects of the negative shocks, that the breakdown of the Bretton Woods system and the oil crisis at the beginning of the seventies induced to the growth process. If the adjustment of the growth process after a shock is sufficiently slow for most countries, the economic turbulences at the beginning of the seventies may be the reason for a lower growth performance measured in the second period, although the long-run average around which the growth process fluctuates has not changed. Therefore, a test for the long-run persistence of economic growth rates has not been based on a time series model that is sufficiently flexible to allow for temporal deviation from the long-run average. A simple graphical tool like Figure 18 is not appropriate for such a test.

A time series model that allows to test the null hypothesis that deviations of growth rates from their last year's realization are persistent (i.e., the random walk hypothesis) against the hypothesis that such deviations are only temporary (i.e., the mean reverting process hypothesis) in the AR(p) model. Consider for simplicity an AR(p) model with $p=1$, i.e., of autoregressive order 1:

[C.1] $\hat{y}_t = \mu + \rho \hat{y}_{t-1} + \varepsilon_t$,

where $\hat{y}_t$ is the realization of the real per capita growth rate in period t, μ and ρ are constant parameters and ε_t is white noise, $\varepsilon_t \approx N(0,1)$. A mean reverting process implies that $0<\rho<1$. In this case the constant μ "dominates" the average realization of the growth rate, while random shocks become more and more unimportant as time passes by. Since μ is "persistent," it can potentially be determined by persistent country characteristics.

If, on the contrary, $\rho=1$, the time series is a random walk. In this case the solution of [C.1] contains at least one unit root. Therefore, a test of the hypothesis $\rho=1$ is also called "unit root test." In the following the terms "unit root hypothesis" and "random walk hypothesis" are synonymously used. A random walk implies that every shock is completely transmitted into all future periods. Thus, the time series displays long-term memory concerning the shocks of its own past. Hence, if the time series behavior of economic growth followed a random walk, $\hat{y}_t$ would be primarily driven by random shocks, and the constant μ, which can be determined by country characteristics, would only play a minor role for the development of the growth rate.

To see these implications of [C.1] explicitly, consider the following transformations. Let $\bar{y}$ be the intertemporal equilibrium solution (the particular integral) of [C.1]. Then the following equation holds:

[C.2] $\bar{y} = E(y_t) = E(y_{t+1})$,

where $E(.)$ is the expectation operator. Taking the expectation value of [C.1] and inserting [C.2] yields:

[C.3] $\bar{y} = \mu/(1-\rho)$.

Solving for μ, inserting this into [C.1] and subtracting $\hat{y}_{t-1} - \bar{y}$ from both sides yields:

[C.4] $\hat{y}_t - \hat{y}_{t-1} = (\rho - 1)(\hat{y}_{t-1} - \bar{y}) + \varepsilon_t$.

Consequently, if $0<\rho<1$, a positive deviation of $\hat{y}_{t-1}$ from its intertemporal equilibrium value $\bar{y}$ is followed in the next period by an $\hat{y}_t < \hat{y}_{t-1}$. Therefore, after a shock, a correction towards the intertemporal equilibrium value takes place until $\hat{y}_t$ equals again $\bar{y}$. Hence, for $0<\rho<1$, [C.4] is a simple error correction model. If, however, $\rho=1$, no correction for a deviation of $\hat{y}_{t-1}$ from the intertemporal equilibrium value $\bar{y}$ takes place and [C.4] equals the following random walk model

[C.5] $\hat{y}_t = \hat{y}_{t-1} + \varepsilon_t$.

b. *Testing for Unit Roots — Econometric Strategies*

In this section the standard procedures of a test of the null hypothesis (H_0) of a random walk process, i.e. $\rho=1$, against the alternative hypothesis (H_1) of a mean reverting process, $0<\rho<1$, and some of their problems are described. Dickey and Fuller (1981) proposed a test based on a time series model with an autoregressive process of order *p*, AR(*p*), of the following type:

[C.6] $\hat{y}_t = \mu + \sum_{i=1}^{p} \alpha_i \, \hat{y}_{t-i} + \varepsilon_t \iff \hat{y}_t = \mu + \rho\, \hat{y}_{t-1} + \sum_{i=1}^{p} \gamma_i \; d\hat{y}_{t-i} + \varepsilon_t$,

with $\rho=1$, if $\hat{y}_t$ follows a random walk. However, time series model [C.6] is too restrictive, if the error process displays autocorrelative behavior. In this case, the appropriate estimation model is an ARIMA $(p,1,q)$ model that allows for an autocorrelated moving average of the error process of order *q*. Unfortunately, the estimation of such a highly parameterized model reduces the degrees of freedom by $p+q+1$. Given the fact that the available annual time series data on economic growth for most countries enclose about 30 to 40 observations, the quality of the test can, therefore, be seriously reduced. However, Said and Dickey (1984) showed that any ARIMA $(p,1,q)$ process can be adequately approximated by an ARIMA $(p,0,0)$ =

AR(p) process, if p is chosen large enough. The problem with this approach, however, is that the appropriate magnitude of p is unknown. As Schwert (1989) shows, this problem can seriously influence the test result. Based on a Monte Carlo study, Schwert reveals that, if the true time series process is ARIMA(1,1,1) and, hence, $p=1$, but is estimated with an AR(1), ARIMA(1,0,1), or, for instance, AR(int(12(T/100)$^{0.25}$)) model, the actual size of the test[115] for small samples (e.g., $T = 25$ or $T = 50$) is typically larger than indicated by the tabulated Dickey–Fuller distributions for a t-test and a K-test[116] of the H_0 that $\rho=1$ (Dickey and Fuller 1981; Fuller 1976).[117] Consequently, the actual probability that H_0 is rejected although H_0 is true, is higher than suggested by the Dickey–Fuller distributions.[118] To cope with this type of small sample problems two approaches are chosen in the following.

First, to determine the appropriate autocorrelation order p of the AR(p) the Hall lag-selection procedure (Hall 1990) as recommended by Campbell and Perron (1991) is used: for a given sample length T, a maximum lag order, $p_{\max}$, is chosen. Then the t-statistic of the lag coefficient (which has a standard normal distribution under both the H_0 of a unit root and the H_1 of stationarity) is used to determine whether a smaller lag can be used.[119]

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115 The size of a test is the probability of a type-one error, i.e., the probability of rejecting the H_0 although the H_0 is the true hypothesis. If the test result indicates a "small" size (conventionally $\alpha \leq 5$ percent), the H_0 can be rejected with a "high" level of significance.

116 See Table 3 for a definition of the test statistics.

117 An ARIMA(1,1,1) model equals: $\hat{y}_t = \mu + \hat{y}_{t-1} + \varepsilon_t + \theta\,\varepsilon_{t-1}$. Schwert (1989) chooses θ to take different values. A high value (0.5 or 0.8) for θ typically leads to a higher size of test, whereas a low value (0 or –0.5 or –0.8) typically leads to a lower size of the test than indicated by the Dickey and Fuller distribution tables (for t-test as well as for K-tests).

118 Beside the criticism based on the weak small sample properties of conventional Dickey–Fuller tests, Bayesians argue that unit root tests tend to be biased in favor of an acceptance of the H_0 of a random walk (see Sims 1988; Sims and Uhlig 1991). Section C.I.1.c, therefore, presents an alternative Bayesian unit root test proposed by Sims (1988) as well as a test based on the H_0 of a mean reverting process. See Appendix 8 for a discussion of these arguments and two alternative test statistics proposed by Sims (1988).

119 The Hall-lag-selection procedure (Hall 1990) is applied here in order to yield some kind of compatibility with the Levin–Lin panel data unit root test (Levin and Lin 1993), where the Hall procedure is also used. In Maurer (1995a), a Breusch–Godfrey autocorrelation test for the error process is used to determine the lag order p (Breusch 1978; Godfrey 1978). Although this leads to a somewhat higher lag order for the countries, the results do not significantly differ from those presented here.

Second, the panel data unit root test of Levin and Lin (1993) reducing small sample problems by making additional use of cross-section variety is used. This panel data test is a test of the H_0 that the time series of each panel country contains a unit root against the alternative H_1 that the time series of each panel country follows a mean reverting process. This test procedure allows for a free variation of country-specific intercepts, μ_i, and autocorrelation orders, p_i. A multiple-step estimation procedure normalizes, roughly spoken, country-specific moments such that finally a single cross-country t-test statistic can be computed. This statistic has, after a model-specific adjustment, asymptotically a standard normal distribution.

The Levin–Lin panel data unit root test succeeds in combining the favorable asymptotic properties of nonstationary time series analysis with those of stationary panel data analysis. Levin and Lin (1993) show that, on the one hand, (under the H_0) their regression estimators and test statistics display limiting normal distributions, thanks to the panel data dimension of the sample. On the other hand, (under the H_0) their regression estimators display a fast rate of conversion towards the true values (i.e., the "superconsistency" property),[120] thanks to the nonstationary character of the country-specific time series. Accordingly, Monte Carlo simulations indicate that the normal distribution very well approximates the "empirical" distribution of the test statistic even in relatively small samples (e.g., 10 countries and 25 periods). Furthermore, the simulation indicates that the test displays a significantly higher power than conventional tests for individual time series.[121] As the data used in the following allows for the computation of real per worker GDP growth rates over a time span of 25 years for 118 countries, there is good reason to believe that the Levin–Lin panel data unit roots test provides reliable results.

c. *The Results of Unit Root Tests for Individual Countries*

The unit root tests for the individual country time series as well as the Levin–Lin panel data unit root test are based on the Penn World Table (Mark 5) described in

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120 The "superconsistency" property of parameter estimators for nonstationary time series stems from the fact that estimates of parameters which do not correspond to the true parameter values yield a high variance of the residuals. If, however, the parameter estimates are close to the true parameter values, the residual variance will be low. Therefore, an estimation procedure that minimizes the sum of squared residuals, like OLS, should relatively quickly approach the true parameter values as the sample size is increased (Kennedy 1993).

121 The power of a test equals the probability of a type-two error for a given probability of a type-one error. Consequently, a "high" power implies that the test is able to discriminate fairly well between two similar hypotheses, e.g., $H_0(\rho = 1)$ and $H_1(\rho = 0.95)$.

Summers and Heston (1991). This data set provides different GDP time series at varying length from 1950 to 1988 for 138 countries. From these time series, per worker GDP in 1985 "international" prices is chosen.[122] Only test results for such countries are presented that still display a minimum sample size of 20 years after the Hall selection procedure (Hall 1990) is executed. This leaves a set of 120 countries with sample periods varying from 20 to 38 years. Two versions of the H_0 that $\rho=1$ are used for the individual country tests. Table 3 shows these test statistics. As shown by the Monte Carlo study of Dickey and Fuller (1981) the test statistics have the highest power for the combinations of H_0 and H_1 shown in Table 3.

The *t*-statistic turns out to be the most powerful test statistic for a test of the H_0: $(\mu,\rho)=(\mu,1)$ against the $H_1:(\mu,\rho)=(\mu,|\rho|<1)$. Dickey and Fuller (1981) present the cumulative probability distribution of the t-statistic under the H_0. According to this distribution, the H_0 is rejected at a significance level of 5 percent, if the *t*-statistic reaches a level of –3.0 for a sample size of $T=25$ and a level of –2.93 for a sample size of $T=50$.

Column 9 of Table A.6.1 in the Appendix presents the results of a *t*-test based on a regression model of [C.6]. These show that the H_0 cannot be rejected at a significance level of 5 percent for 26 out of the 120 countries of the Penn World Table sample.[123] Consequently, the majority of countries rejects the H_0 of a random walk based on the Dickey–Fuller *t*-test.[124] Figure 19 gives a visual impression of three paradigmatic types of time series behavior.

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122 (a) The term "international prices" refers to the special weights used to evaluate the various subaggregates of GDP. According to Summers and Heston (1991), these weights ensure cross-country compatibility of the data. Maurer (1995a) shows that the unit root test for individual countries provides similar results if applied to alternative GDP data provided by Maddison (1992). (b) The real per worker GDP growth rate (series 19 of the Penn World Table (Summers and Heston 1991)) is used for comparability with the results of Easterly et al. (1993). However, tests with other growth rates of the Summers and Heston (1991) data, such as real per capita GDP (Series 1 and Series 6), provide similar results.

123 According to Bayesian arguments stated in Sims (1988), the cumulative student distribution can be used to estimate the probability that the true parameter ρ is equal or larger than unity given the estimate ρ, if one assumes that the shape of the posterior probability function approximately equals the shape likelihood density function (see the discussion of Bayesian unit root tests in Appendix 8). Given this assumption, the estimation results imply that the probability that the true parameter of ρ is equal or higher than unity is equal or lower than 5 percent for 113 countries.

124 If the nonparametric correction proposed by Phillips and Perron (1988) is applied to the *t*-test statistic, only 5 countries reject the H_0 at a significance level of 5 percent (Column 8 of Table A.6.2 in the Appendix). As a Monte Carlo study of Handa and Ma (1989) shows the Phillips–Perron *t*-test has a higher power than the Dickey–Fuller *t*-test, if the errors of the regression equation are autocorrelated. However, the price one has to pay

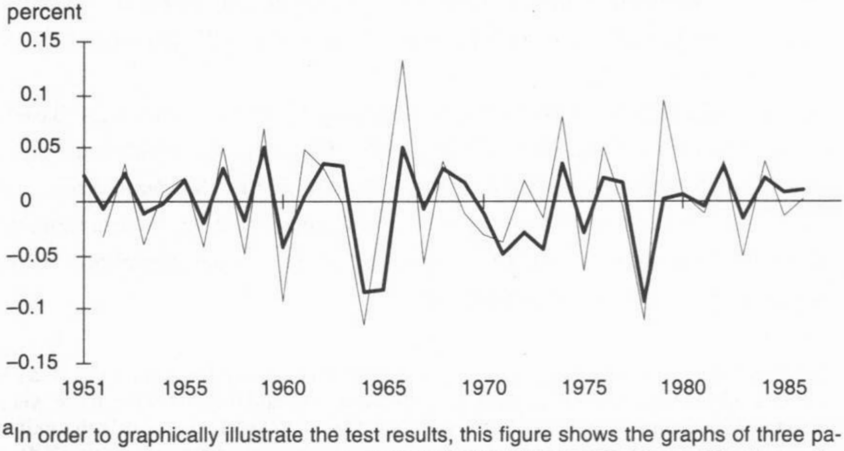
Table 3 — Test Statistics for the Country-Specific Unit Root Tests[a]

H_0	H_1	Test statistic
$H_0 :(\mu, \rho) = (\mu, 1)$	$H_1 :(\mu, \rho) = (\lvert \mu, \rho \rvert < 1)$	$t = (\hat{\rho} - 1)/\sigma_{\hat{\rho}}$
$H_0 :(\mu, \rho) = (0,1)$	$H_1 :(\mu, \rho) = (\mu, \rho \neq 1)$	$K = T(\hat{\rho} - 1)$ and $t = \hat{\mu} / \sigma_{\hat{\mu}}$

[a]Variables as defined in [C.1]. The variables $\sigma_{\hat{\rho}}$ resp. $\sigma_{\hat{\mu}}$ represent the estimated standard deviations of $\hat{\rho}$ and $\hat{\mu}$. T is the sample size.

Figure 19 — Paradigmatic Types of Time Series Behavior of Economic Growth, 1951–1985

a. Mean and Lag Deviation of Real Per Worker GDP Growth of India[a]



[a]In order to graphically illustrate the test results, this figure shows the graphs of three paradigmatic cases of the time-series behavior of economic growth. Figure 19a shows the deviation of the real per worker GDP growth rate of India from the time series mean (bold line). India is one of the 94 countries where the Dickey–Fuller t-test rejects the unit root hypothesis. The t-value is –6.37 and the estimated ρ is –0.11. As the figure shows, a positive deviation from the time series mean (estimated by the compound growth rate) is typically followed by a smaller negative deviation from the mean in the next period and vice versa, as implied by the estimated value of ρ. Consequently, mean deviations are not persistent, as they would be in case of a random walk, but run out in the course of time. The thin line represents the one-year lag deviation of the growth rate (i.e., this year's growth rate minus last year's growth rate). In case of a random walk, the lag deviation is smaller than the mean deviation. The relation between the squared sum of the lag deviations to the squared sum of the mean deviation is measured by the von Neuman-ratio test for unit roots (Dickey and Fuller 1981). As the figure shows, the one-year lag deviation is in most years significantly higher than the mean deviation. This, again, reflects the strong mean reverting behavior of India's per worker GDP growth rate.

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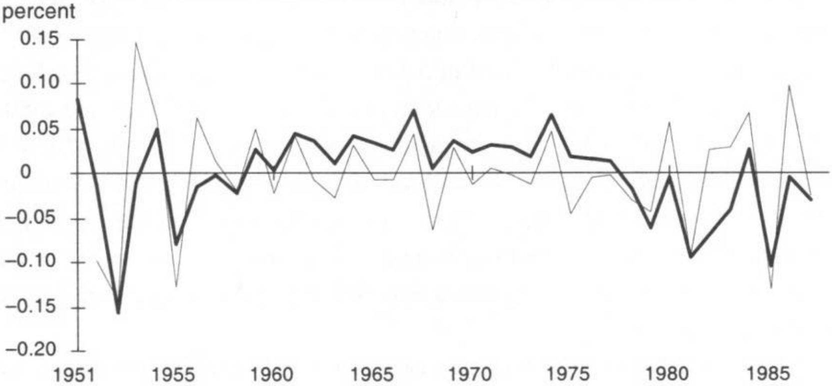
for this better performance is, according to Handa and Ma (1989), its relative poor small-sample quality.

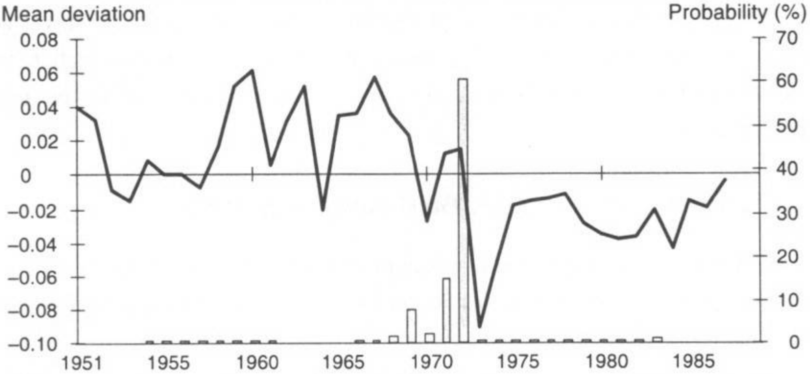
Figure 19 continued

b. Mean and Lag Deviation of Real Per Worker GDP Growth of Bolivia[b]



[b]Figure 19b displays the time series behavior of real per worker GDP growth of Bolivia. Bolivia is one of the 26 countries, where a Dickey–Fuller t-test does not reject the random walk hypothesis at the 5 percent significance level. (The t-value equals −1.26, the estimated ρ is 0.76.) Figure 19b shows that the deviations from the mean imply only a temporary persistence over the period 1961–1977. As a consequence, the one-year lag deviations are smaller than the mean deviations during this period. All in all, it is at least questionable, whether the time series behavior illustrated in Figure 19b is actually driven by a random walk. Instead, there seems to be a positive time trend in the growth rates in the period 1951–1967 and a negative time trend afterwards.

c. Mean Deviation and Structural Break Probability of Per Worker GDP Growth of Japan[c]



[c]Figure 19c shows the time series behavior of real per worker GDP growth of Japan. Japan is one of those 16 countries, where Kim's posterior probability indicates a structural break. The columns present the estimated posterior probabilities for each year. They peak at the year 1972 with a value of 61 percent pointing at a strong structural break. As the bold line indicates, the mean of the growth rates in the period 1951–1972 appears to be significantly higher than the mean of the growth rates from 1973 to 1985.

The Dickey–Fuller *K*-test, $K=T(\rho-1)$, provides similar results. As the Monte Carlo study of Dickey and Fuller (1981) shows, this test has the highest power of their statistics, if the H_0 implies a random walk without drift (Table 3). According to the cumulative probability distribution presented by Dickey and Fuller (1981) the H_0 is rejected at a significance level of 5 percent if the *K*-statistic reaches a level of –12.5 for a sample size of $T = 25$ and a level of –13.3 for a sample size of $T = 50$.

Column 7 of Table A.6.1 in the Appendix presents the results of the *K*-test. The H_0 cannot be rejected at a significance level of 5 percent for 5 of the 120 countries of the Penn World Table sample. To sum up, the tests for separate country time series indicate that the overwhelming majority of countries rejects the H_0 of a unit root. Nevertheless, based on the *t*-test, a remarkable group of countries (22 percent) does not reject the H_0.[125]

However, as follows from Bayesian criticism of classical unit root tests, these tests may be biased in favor of an acceptance of the unit root hypothesis, due to the discontinuity of classical asymptotic theory in the presence of unit roots (see Appendix 8 for an explicit description of this argument). Consider, therefore, the estimates for the prior probability in favor of a unit root, necessary to equate the estimated posterior probability of a unit root to the estimated posterior probability of the absence of a unit root (see Appendix 8 for an intuition of this test statistic). As Column 10 in Table A.6.2 in the Appendix, the prior probability in favor of a unit root has to be at least 95 percent for 121 countries in order to equalize the posterior probabilities. Only 3 countries (Algeria, Bolivia, Sweden) reach an equalization of the posterior probabilities with a prior probability in favor of a unit root lower than 80 percent (but still higher than 70 percent). Hence, a Bayesian researcher, who wants to interpret the test results in favor of the H_0, needs strong subjective priors in favor of the H_0.

d. The Results of the Levin–Lin Panel Data Unit Root Test

The Levin–Lin panel data unit root test is applied to all countries of the Penn World table data set that provide data on per worker GDP in international prices over the period 1960–1985. This leaves a maximum country set of 118 countries. Several subsamples are tested in order to check the sensitivity of the results. The tests are based on the $AR(p)$ time series model of [C.6]. Country-specific intercepts, μ_i, and lag orders, p_i, are allowed for. Since intercepts are included, the resulting

125 If the nonparametric correction proposed by Phillips and Perron (1988) is applied to the *K*-test statistic, 5 countries reject the H_0 at a significance level of 5 percent (Column 9 in Table A.6.2 in the Appendix).

t-statistic of the H_0 that $\rho=1$ has to be adjusted by the mean and standard deviation adjustment factors for "model 2" presented in Levin and Lin (1993: Table 2). This yields the adjusted t-statistics of Column 3 in Table 4. According to the recommendation of Levin and Lin, the individual lag lengths are determined following the Hall (1990) selection procedure. Column 6 in Table 4 reports the average lag length that results under this procedure.

The p-values presented in Column 4 are close to zero.[126] Thus, no matter what country sample is chosen, the H_0 that the growth rates of each individual country display a unit root can be rejected with a very high level of significance against the H_1 that the growth rate of each country is a stationary mean reverting process. Hence, the Levin–Lin panel data test firmly supports the results of the separate country-specific unit root tests that per worker GDP growth rates typically follow a mean reverting process.

Table 4 — Levin–Lin Panel Data Unit Root Test for GDP Per Worker Growth Rates, 1960–1985

Sample of countries	Panel-ρ	Adjusted t-value	p-value	Average lags	Average periods	Number of countries
All available	0.099	–31.018	0.000	0.70	22.3	118
Barro and Sala-i-Martin	0.087	–28.137	0.000	0.76	22.2	95
OECD	0.108	–15.895	0.000	0.29	22.7	24
Africa	–0.023	–20.203	0.000	0.89	22.1	39
Latin-America	0.083	–15.600	0.000	0.21	22.8	24
Asia	0.148	–7.726	0.000	1.00	22.0	9

e. Do Structural Breaks Explain the Differences of Subperiod Growth Rates?

Taken together, the results from the time series tests indicate that the pattern of economic growth illustrated by Figure 18 is caused by the error correction mechanism of a mean reverting process. However, one may argue that, although economic growth typically follows a mean reverting process, exogenous shocks, like the first oil crisis and the breakdown of the Bretton Woods exchange rate system, cause "singular" structural breaks. These singular breaks could potentially be strong enough to

126 The p-value of a test equals the probability level of a type-2 error at which the H_0 can be rejected.

dominate the long-run growth performance, even in the presence of a mean reverting process.

This argument, however, neglects the impact of structural breaks on the result of unit root tests: structural breaks tend to bias unit root tests in favor of an acceptance of the H_0, although, actually, the time series displays no unit root (Perron 1988; Maddala 1988). Intuitively spoken, this is the case, because structural breaks reduce the "predictive power of the mean" in favor of the "predictive power of last year's realization." Consequently, a strong influence of structural breaks on the time series behavior of economic growth would have biased the above unit root tests towards an acceptance of the H_0. Therefore, the fact that the unit root hypothesis is rejected by most tests implies also that structural breaks did not have a strong influence on the time series behavior of economic growth in most countries.

This is also indicated by explicit tests for structural breaks. Column 14 of Table A.6.1 in the Appendix shows the result of a test (Nyblom 1989) for an unknown structural break in a stationary time series based on the $AR(p)$ model of [C.1]. Following this test, the H_0 of the absence of a structural break at some unknown point in time is rejected at a significance level of 5 percent, if the test statistic is higher than 0.461 (0 lags) or 1.686 (5 lags). Accordingly, the H_0 of no structural break can be rejected in 22 cases.

One problem of the Nyblom test (Nyblom 1989) is its relatively poor small-sample performance. Kim (1991) proposes a Bayesian test for an unknown structural break that reveals, according to a Monte Carlo study, a rather good small-sample performance, even in the presence of multiple structural breaks (Kim 1991: Figures 1–10). Furthermore, the test yields reliable results in the presence of stationary as well as nonstationary time series and accounts for structural breaks in μ as well as in ρ (see [C.1]).

Kim's (1991) test statistic computes the posterior probability of a structural break for each point in time based on the assumption that the prior probability of a structural break is equal at each point in time ("flat prior" assumption; for an explicit discussion of the test statistic see Section C.I.2, [C.12]). As Kim's Monte Carlo study indicates, in the presence of a structural break at a certain year the posterior probability typically reaches a peak between 40 percent and 50 percent. As Column 14 in Table A.6.2 in the Appendix reveals, the posterior probability reaches a level higher than 40 percent in 18 cases.[127] The years of the potential structural breaks, as

[127] These are: Ghana (1969), Côte d'Ivoire (1979), Liberia (1977), Canada (1958), Mexico (1981), Nicaragua (1979), Trinidad and Tobago (1981), Peru (1975), Suriname (1978), Indonesia (1981), Iran (1980), Japan (1972), Sri Lanka (1976), Belgium (1974), Greece

indicated by the peak of the posterior probability, are not concentrated at the beginning of the 1970s.

Therefore, taken together, these test results indicate that structural breaks cannot be the predominant cause for the pattern displayed by Figure 17. Rather, the results are compatible with the notion that this pattern is primarily determined by the error correction mechanism of the mean reverting time series behavior of economic growth.

f. Mean Reversion to What Mean?

Consider, finally, the results of the individual country unit root tests concerning the intercept, μ. As follows from [C.3], in case of a stationary AR(1) process, i.e., lags = 0, the long-run equilibrium growth rate, i.e., the value, around which the growth rate fluctuates, equals: $\bar{y}=\mu/(1-\rho)$. Consequently, if the intercept is close to zero, the long-run equilibrium growth rate is close to zero, too.[128]

The cumulative probability distribution of a *t*-test in the presence of a stationary time series corresponds to the student distribution. Based on the student distribution the H_0 is rejected at a significance level of 5 percent if the *t*-statistic reaches a level of 1.71 for a sample size of T = 25 and a level of 1.68 for a sample size of T = 50. Given these critical values, the H_0 of $\mu=0$ is rejected at a significance level of 5 percent by 42 countries (see Table A.6.2, in the Appendix, Column 4). Consequently, there appear to be two broad categories of countries: one large group with a long-run growth rate close to zero, and another group with a significantly positive long-run growth rate. This indicates that the distribution of per worker income across countries is diverging over the sample period (see Section C.II.1.b for further discussion of these aspects).[129]

(1973), Italy (1958), Sweden (1958), Papua New Guinea (1970). Since the estimator for the posterior probability tends to be biased at the beginning and the end of a time series, only those countries where the maximum probability is reached outside the first and the last five years of the sample are taken into consideration.

128 There are 47 countries in the sample, which show a higher lag order. For these, the formula holds only approximately.

129 This is compatible with the findings of Quah (1994). A diverging distribution of per worker or per capita GDP is called sigma divergence (e.g., Barro and Sala-i-Martin 1995). Following the implications of the Solow–Swan growth model, sigma divergence can be caused by different steady-state parameters of the countries. As Quah (1993a) shows, sigma divergence is compatible with beta convergence as well as beta divergence. For an explicit definition of beta and sigma convergence see Section C.II.1.b.

Furthermore, Columns 5 and 6 in Table A.6.2 in the Appendix show that the value of the intertemporal equilibrium solution, $\bar{\hat{y}}$, is always close to the compound growth rate, $\tilde{\hat{y}}$.[130] A t-test based on the time series standard deviation of the compound growth rate reject the $H_0: \tilde{\hat{y}} = \bar{\hat{y}}$, at the 5 percent significance level for one country only (Kuwait).[131] Consequently, cross-country regressions, such as those by Barro (1991), Barro and Sala-i-Martin (1992, 1995) and Mankiw et al. (1992), who use the compound growth rate as dependent variable, use indeed a good proxy for the intertemporal equilibrium value, around which growth rates fluctuate: a simple averaging across the growth rates eliminates most of the autocorrelated fluctuations.

g. *Lessons from the Time Series Behavior of Economic Growth*

Taken together, this empirical analysis revealed several pronounced characteristics of the time series behavior of economic growth: economic growth, measured here as the growth rate of per worker income,[132] is best characterized by a mean reverting process. Stochastic shocks do not play a long-run role. Furthermore, the intertemporal equilibrium value, around which growth rates fluctuate, is not significantly different from the compound growth rate.[133]

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130 The compound growth rate over T periods is given by the following formula: $\ln(\hat{y}_{t+T} / \hat{y}_t)/T$.

131 Since, for simplicity, the time series standard deviation of the compound growth rate is used, this corresponds to a t-test of the null hypothesis that the compound growth rate is the true growth rate.

132 Alternative tests with per capita growth rates basically yield the same result.

133 From this result, of course, no conclusion can be drawn whether the mean around which growth rates fluctuate is the drift parameter of a random walk of the level per worker GDP or the deterministic trend of the level per worker GDP. This leads to the controversy whether there is a unit root in real GDP or not. As real per worker (as well as per capita) GDP typically shows a time trend, the question is whether the level of per capita GDP fluctuates around this trend (i.e., whether real per worker GDP is trend stationary) or whether this trend is only the drift parameter of a random walk (i.e., whether real per worker GDP is difference stationary). If the mean, around which growth rates fluctuate, is the drift parameter of a difference stationary model, it cannot be excluded that this mean plays only a minor role in the development of the level per worker GDP. In a sense, the controversy on this question ended with a stalemate: as Christiano and Eichenbaum (1990) argue, it is hardly possible to empirically discriminate between both types of time series behavior. Nevertheless, Appendix 7 presents a Levin–Lin panel test of the H_0 that the level of per worker GDP follows a random walk with a drift against the H_1 that the level of per worker GDP follows a deterministic trend. It is argued that the Levin–Lin test making use of time series as well as cross-sectional variation may be less hampered by the Christiano–Eichenbaum identification problem. For the results and their interpretation see Appendix 7.

This leads to the following conclusions: The intention of growth theories to explain the first difference of real per capita GDP makes sense. It is not necessary to explain higher-order differences, as would be the case if economic growth followed some kind of random walk.

However, the fact that growth rates of most countries are stationary and show no time trend questions those versions of endogenous growth models where the per capita growth rate is determined by factors that show a time trend in most countries. Typically, such factors are human capital and labor force. However, since scale-dependent steady-state growth rates are not a necessary implication of endogenous growth models, the empirical evidence does not question models of endogenous growth in general.[134]

The results furthermore indicate that there are two broad categories of countries: Those that display a long-run mean significantly different from zero and those that do not. From Table A.6.2, Column 4, in the Appendix follows that most industrialized and most newly industrialized countries display a long-run mean significantly different from zero, while many developing countries, especially most African and most Latin American countries display a long-run mean not significantly different from zero. These findings correspond to those of Quah (1993b: 433), who finds, based on a Markov chain transition analysis, that there is a "tendency towards a two-camp world, divided between haves and have-nots, where escaping from the poverty trap is a low probability proposition, either over short or long runs."

In principle, this result is compatible with the hypothesis that there is no convergence of per worker GDP, in the sense that per worker GDP of countries with a low level of per worker GDP grows not faster than that of countries with a high level of per worker GDP. It does, however, not necessarily imply the absence of conditional convergence of per worker GDP. Conditional convergence means that countries far away from their steady state grow with higher rates than countries close to their

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[134] Actually, most models of endogenous growth show such scale-dependent steady-state growth rates. One of the few models that do not is the fiscal spending model of Barro (1990). Scale-dependent steady-state growth rates are not a necessary implication of endogenous growth models. It is straightforward to design endogenous growth models where the resulting steady-state growth rate is not scale-dependent: the function that includes the accumulating production factor with constant marginal returns must not include nonaccumulating production factors (such as nonaccumulating labor or nonaccumulating human capital).Consequently, an R&D model of endogenous growth without scale-dependent steady-state growth rates has to be based on R&D production function which includes, for example, accumulating human capital (instead of nonaccumulating human capital or nonaccumulating raw labor). In this case, only the structural parameters of the economy appear in the steady-state growth rate.

steady states. Hence, if the steady-state level of per capita GDP of African and Latin American countries is typically very low, perhaps due to a poor performance of economic policy, their growth performance may be rather poor, although conditional convergence holds in general.

Taken together, the significantly different time series means of the countries suggest that there are country-specific factors that determine the long-run growth performance. Therefore, policy designs directed towards the long-run mean, around which growth rates fluctuate, make sense. Short-run activism that intends to absorb negative shocks and generates positive shocks appears to cause only temporary effects. In this sense, it is long-run growth policy that matters.

The results also indicate that for most countries there is no empirical evidence in favor of strong structural breaks in the time series behavior of economic growth. The next section discusses on the question whether this also holds for those countries that implemented major trade reforms in the postwar period.

2. Do Trade Reforms Cause Structural Breaks in the Time Series Behavior of Economic Growth?

Abstract: This chapter analyzes the influence of trade reforms on the time series behavior of economic growth. Several econometric approaches are applied: tests for known structural breaks of the time series behavior as well as tests for unknown structural breaks. The empirical results indicate that most postwar trade liberalization episodes had neither a significant positive nor a significant negative effect on economic growth. Several explanations for these findings are considered. For example, the observed trade liberalizations may typically have been too weak to affect long-run growth. Alternatively, there may be a selection bias in the sample of trade reform countries: countries engaging in trade reforms may typically be more concerned about trade policy and therefore practice already a relatively free trade regime. Perhaps, most likely, trade liberalization episodes may have affected relative commodity prices in a way that growth performance was not influenced. Taken together, the conclusion is drawn that exploring the cross-country variation of trade regimes and taking special care of the potential effects of capital goods trade may provide more substantial insights.

a. Trade Liberalization Episodes and Growth Performance — The Results of a World Bank Study

The preceding chapter has shown that the growth rates of most countries typically fluctuate around a persistent mean. This chapter raises the question whether observed trade reforms did affect this mean. The information about trade reform episodes is taken from a World Bank research project.[135] In this project a team of 32 authors analyzed the trade liberalization experiences of 19 countries. All countries engaged in trade liberalization episodes in the postwar period are included in this sample. "Trade liberalization" is defined as "any change, which leads a country's trade system towards neutrality in the sense of bringing its economy closer to the situation, which would prevail, if there were no governmental interference in the trade system. Put in words, the new trade system confers no discernible incentives to either the importable or the exportable activities of the economy" (Michaely et al. 1991: 37).

Hence, if the trade regime is described by an *n*-dimensional vector that contains the deviations of domestic prices and quantities of all goods from their free trade values, this definition implies that "trade liberalization" is an unequivocal shift of the *n*-dimensional trade regime vector towards the zero vector. Following this definition a transition from an import substitution system to an export promotion system solely achieved through a compensation of the anti-export bias via export subsidies is no trade liberalization episode:[136] the export subsidies may drive the domestic prices of the subsidized goods away from their free trade level. However, a transition from an import substitution system to an export promotion system achieved through a reduction of import tariffs and quotas is a trade liberalization episode.[137]

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135 The results of this project are summarized in Michaely et al. (1991).

136 The usual definition of anti-export bias is the protection of the domestic manufacturing industry by import tariffs and quotas at the expense of domestic primary sector production. This kind of protection is called anti-export bias, because it regularly refers to developing countries, which typically have a comparative advantage in primary production. See Maurer (1994: 21, 63) for a discussion of various trade regime measurement approaches.

137 There are some hints that trade regime changes which Michaely et al. (1993) classify as trade liberalization episodes were in fact characterized by significant usage of export subsidies. The most apparent case is Korea. The author of the Korea study in the World Bank project, Kwang Suk Kim, does not report the usage of direct or indirect export subsidies in Korean trade policy. However, in Helleiner (1994: 322–323) the same author reports in a detailed way on a broad set of different export subsidy instruments used in Korean trade reform 1965–1967.

Table 5 — Annual Real GDP Growth Rate Before and After a Trade Liberalization Period[a]

Episode		*PtL*	*T*	*T* + 1	*T* + 2	*T* + 3	*AVG-T*	*AVG*
Argentina	(1966–1970)	7.90	1.40	5.00	0.90	3.50	3.13	2.70
Argentina	(1976–1980)	6.70	2.60	4.40	8.50	5.40	6.10	5.23
Brazil	(1965–1973)	2.90	–0.60	6.50	–3.10	6.90	3.43	2.43
Chile	(1956–1961)	3.23	2.70	5.10	4.80	9.30	6.40	5.48
Chile	(1974–1981)	2.30	1.20	7.90	2.80	0.53	3.74	3.11
Colombia	(1968–1982)	–1.50	8.50	–12.90	3.50	9.86	0.15	2.24
Greece	(1953–1955)	3.87	2.67	4.93	6.59	6.50	6.01	5.17
Greece	(1962–1982)	4.90	13.06	3.10	6.81	8.70	6.20	7.92
Indonesia	(1966–1972)	6.13	0.58	10.07	7.54	9.25	8.95	6.86
Israel	(1962–1968)	0.80	2.72	1.41	10.89	6.83	6.38	5.46
Israel	(1969–1977)	9.80	10.10	11.40	9.80	9.10	10.10	10.10
Korea	(1965–1967)	5.77	12.60	7.90	11.00	12.30	10.40	10.95
Korea	(1978–1979)	6.97	5.80	12.70	6.60	11.30	10.20	9.10
New Zealand	(1962–1981)	13.80	3.31	6.36	–6.20	6.36	2.17	2.46
New Zealand	(1982–1984)	4.02	5.84	6.57	5.54	–2.16	3.32	3.95
Pakistan	(1959–1965)	4.32	4.66	0.48	2.78	3.29	2.18	2.80
Pakistan	(1972–1978)	2.15	1.47	4.34	5.23	5.92	5.16	4.24
Peru	(1979–1980)	5.48	1.61	7.53	7.71	4.11	6.45	5.24
Philippines	(1960–1965)	0.30	3.78	3.07	3.14	0.74	2.32	2.68
Philippines	(1970–1974)	5.37	0.90	4.90	4.50	6.30	5.23	4.15
Portugal	(1970–1974)	5.32	4.84	5.72	5.23	8.48	6.48	6.07
Portugal	(1977–1980)	5.88	7.55	6.39	9.49	11.48	9.12	8.73
Singapore	(1968–1973)	1.60	5.30	3.20	4.50	4.90	4.20	4.48
Spain	(1970–1974)	10.10	14.27	13.50	13.65	12.61	13.25	13.51
Spain	(1977–1980)	6.67	4.89	5.54	8.59	8.06	7.40	6.77
Sri Lanka	(1968–1970)	3.30	3.72	2.50	0.16	1.48	1.38	1.97
Sri Lanka	(1977–1979)	3.57	7.57	4.25	3.50	–0.52	2.41	3.70
Turkey	(1970–1973)	2.80	4.87	8.69	6.28	5.47	6.81	6.33
Turkey	(1980–1984)	5.69	5.28	9.00	6.00	4.10	6.37	6.10
Uruguay	(1974–1982)	2.90	–1.07	4.10	4.64	3.25	4.00	2.73
Yugoslavia	(1965–1967)	–4.96	3.37	5.28	1.62	2.75	3.22	3.26
Average GDP		4.45	4.69	5.45	5.26	6.00	5.57	5.35
Average industry		6.75	5.31	6.93	6.92	7.97	7.27	6.78
Average agriculture		2.79	2.91	5.48	2.83	3.95	4.09	3.80

[a]Abbreviations: *PtL* = average of three years up to liberalization; *T* = year of implementation of the liberalization episode; *AVG-T* = average of three years after *T*; *AVG* = average of *T* plus three years after liberalization.

Source: Michaely et al. (1991: 89).

Based on this definition the authors find 31 trade liberalization episodes in developing countries in the postwar period.[138] For each episode they present the be-

[138] Trade liberalization episodes of countries with an insufficient data base are excluded from the sample.

havior of macroeconomic variables that refer to, inter alia, exports, production and GDP growth, before and after the year of trade reform implementation. Table 5 is taken from the summary volume of this World Bank study (Michaely et al. 1991: 89) and shows the annual real GDP growth rates in the years before and after the year of the implementation. It shows that only 8, out of 31, trade reform episodes were followed by a three-year GDP growth rate (*AVG-T*) that was lower than the three-year growth rate before the episode (*PtL*).

b. Time Series Tests for the Long-Run and Short-Run Impact of Trade Liberalization Episodes on Economic Growth

According to Table 5, the impact of trade liberalization episodes in the postwar period on real GDP was overwhelmingly positive. However, the three-period comparisons of Table 5 are somewhat ad hoc. Why is it exactly a three-period comparison that measures the true effect of trade liberalization on growth performance? To avoid this kind of arbitrariness in the following two formal tests of the impact of liberalization episodes on the time series behavior of economic growth are used. These tests are based on the same *AR*(*p*)-time series model that was used in the preceding section ([C.6]).[139] To test for the long-run effect of trade liberalization episodes a dummy variable is introduced from the year of implementation to the end of the sample period. The estimated model equals then:

$$[C.7] \quad \hat{y}_t = \mu + \theta_1 + \theta_2 + \theta_3 + \rho\,\hat{y}_{t-1} + \sum_{i=1}^{p} \gamma_i \; d\hat{y}_{t-i} + \varepsilon_t ,$$

where θ_i is the trade liberalization episode dummy. After the start of the first trade liberalization period θ_1 takes the value 1, after the start of the second trade liberalization period θ_2 takes the value 1, after the start of the third trade liberalization period θ_3 takes value 1. In all other cases $\theta_1, \theta_2, \theta_3$ are zero (for the other variables see [C.6]).[140] Hence, the null hypothesis of a long-run impact of trade liberalization on the process of economic growth corresponds to a *t*-test of the marginal significance of the dummy coefficient. Annual real per worker GDP growth rates from the Summers and Heston data set (Summers and Heston 1991) are used for the estimation of [C.7]. Table 6 shows the results.

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139 See Section C.I. for an interpretation of this model.

140 No more than a maximum of three trade liberalization episodes per country are observed.

Table 6 — Tests for the Long-Run Impact of Trade Liberalization Episodes on the Time Series Behavior of Real Per Worker GDP Growth Rates $\hat{y}_{t-1}$ [a]

Country	Mean	Const.	Reform1		Reform2		Reform3		$\hat{y}_{t-1}$	F	Lag	SEE	DW	Obs.
Argentina	0.008	0.011	1966	0.017	1976	–0,059	–	–	–0.82	5.11	0	0.037		36
		(0.02)		(0.29)		(0.00)			(0.00)	(0.00)			2.19	
Brazil	0.041	0.047	1965	–0.016	–	–	–	–	0.09	0.45	0	0.069		36
		(0.03)		(0.51)					(0.58)	(0.64)			1.98	
Chile	0.011	0.11	1956	0.004	1974	–0.013	–	–	0.154	0.47	0	0.059		37
		(0.72)		(0.91)		(0.56)			(0.39)	(0.70)			1.93	
Colombia	0.019	0.005	1964	0.019	1968	0.001	–	–	–0.003	2.485	2	0.027		35
		(0.62)		(0.23)		(0.97)			(0.98)	(0.05)			2.19	
Greece	0.039	0.038	1953	–0.007	1962	–0.014	–	–	0.149	1.5	0	0.037		37
		(0.46)		(0.36)		(0.31)			(0.04)	(0.22)			1.92	
Indonesia	0.039	0.002	1966	0.032	–	–	–	–	0.205	1,67	0	0.042		25
		(0.94)		(0.34)					(0.29)	(0.21)			1.01	
Israel	0.034	0.035	1962	–0.004	1969	–0.017	–	–	0.321	2.24	0	0.038		34
		(0.05)		(0.86)		(0.32)			(0.07)	(0.01)			2.00	
Korea	0.057	0.025	1965	0.067	1978	–0.026	–	–	–0.307	1.69	5	0.043		29
		(0.23)		(0.03)		(0.18)			(0.50)	(0.16)			2.33	
New Zealand	0.016	0.026	1951	–0.047	1962	–0.019	1982	–0.006	–0.087	0.585	0	0.040		37
		(0.16)		(0.31)		(0.24)		(0.73)	(0.63)	(0.68)			2.07	
Pakistan	0.024	–0.014	1959	0.047	1972	–0.015	–	–	0.052	1.19	5	0.041		32
		(0.63)		(0.19)		(0.41)			(0.89)	(0.34)			2.19	

Table 6 continued

Country	Mean	Const.	Reform1		Reform2		Reform3		$\hat{y}_{t-1}$	*F*	Lag	SEE	DW	Obs.
Peru	0.014	0.041	1979	–0.058	–	–	–	–	–0.648	3.89	2	0.047		35
		(0.00)		(0.01)					(0.04)	(0.01)			2.066	
Philip-pines	0.022	0.024	1960	–0.009	1979	–0.006	–	–	0.351	6.73	1	0.028		36
		(0.06)		(0.53)		(0.61)			(0.04)	(0.00)			2.15	
Portugal	0.040	0.041	1970	0.005	1977	–0.021	–	–	0.091	0.81	0	0.057		37
		(0.01)		(0.78)		(0.39)			(0.64)	(0.49)			1.94	
Singapore	0.058	0.22	1968	0.014	–	–	–	–	0.424	3.12	0	0.038		24
		(0.21)		(0.53)					(0.12)	(0.06)			1.72	
Spain	0.033	0.026	1960	0.027	1970	–0.022	1977	–0.023	0.109	2.53	0	0.045		37
		(0.11)		(0.14)		(0.24)		(0.23)	(0.49)	(0.05)			1.94	
Sri Lanka	0.014	0.013	1968	–0.006	1977	0.035	–	–	–0.467	3.70	0	0.041		36
		(0.20)		(0.72)		(0.07)			(0.00)	(0.02)			2.37	
Turkey	0.023	0.043	1970	0.12	1980	–0.037	–	–	–0.56	1.56	2	0.048		35
		(0.00)		(0.56)		(0.14)			(0.07)	(0.20)			1.90	
Uruguay	0.003	–0.001	1974	0.01	–	–	–	–	0.102	0.33	0	0.055		37
		(0.91)		(0.65)					(0.91)	(0.71)			1.59	
Yugo-slavia	0.034	0.69	1965	–0.038	–	–	–	–	–0.024	1.03	0	0.043		26
		(0.02)		(0.16)					(0.91)	(0.37)			1.89	

[a]Underlined years mark the start of a "sustained" liberalization episode (see Table 7).

Source: Own calculations.

Out of a sample of 34 trade liberalization episodes only three reveal a significant impact on the long-run growth rate: the Argentinean trade reform of 1976 and the Peruvian trade reform of 1979 coincided with a significant (at the 5 percent level) reduction of the long-run growth rate; only the Korean trade reform of 1965 coincided with a significant increase of the long-run growth rate. Consequently, there seems to be no long-run effect, neither positive nor negative, of the observed trade liberalizations on the growth performance of most countries.

A potential explanation of this result would be the low sustainability of liberalization episodes. Table 7 shows a classification of liberalization episodes according to their degree of sustainability. Three classes are formed: (1) sustained, (2) partially sustained, and (3) collapsed episodes. Michaely et al. (1991: 35) define these classes in the following way:

A liberalization episode that, for its duration, has either kept progressing or, at least, not been reversed is classified as '*sustained*'; others, more tentatively included in the category, are episodes that are still in progress (Uruguay (1974–82), New Zealand (1982–84), Turkey (1970–73)). In several cases policy has been reversed, but even so the trade regime has remained significantly more liberalized than before the attempt to liberalize. These episodes are classified as '*partially sustained*'. Where policy reversals have led liberalization back to, or below, its pre-episode level, the episode is described as '*collapsed*'.

According to this definition, 14 episodes are "sustained," 9 episodes are "partially sustained," and 10 liberalization episodes are "collapsed." Hence, a large fraction of all episodes is classified as "sustained" and the overwhelming majority is at least classified as "partially sustained." Consequently, if one takes this classification

Table 7 — Sustainability of Liberalization Episodes

Sustained	Period	Partially sustained	Period	Collapsed	Period
Chile	1974–1981	Colombia	1968–1982	Argentina	1966–1970
Greece	1953–1955	Pakistan	1959–1965	Argentina	1976–1980
Greece	1962–1982	Pakistan	1972–1978	Brazil	1965–1973
Indonesia	1966–1972	Philippines	1960–1965	Chile	1956–1961
Israel	1962–1968	Philippines	1970–1974	Colombia	1964–1966
Israel	1969–1971	Portugal	1977–1980	Peru	1979–1980
Korea	1965–1967	Spain	1960–1966	Portugal	1970–1974
Korea	1978–1979	Spain	1970–1974	Sri Lanka	1968–1970
New Zealand	1962–1981	Spain	1977–1980	Turkey	1970–1973
New Zealand	1982–1984			Yugoslavia	1965–1967
Singapore	1968–1973				
Sri Lanka	1977–1979				
Turkey	1980–1984				
Uruguay	1974–1982				

Source: Michaely et al. (1991: 35).

scheme for reliable, the degree of sustainability had no influence on the long-run growth process.

Given these results on the long-term impact of trade liberalization episodes, it is natural to ask whether there was at least a short-term impact. Therefore, [C.7] is estimated using now a dummy from the start to the end of the trade liberalization episode. Hence, θ_i is set equal to 1 during a trade liberalization episode, and 0 else. Table A.9.1. in the Appendix shows the results of this estimation. Now five trade reforms turn out to coincide with a significant shift (at the 5 percent level) of growth performance during their implementation phase: Pakistan (1959–1965), Portugal (1970–1974), Spain (1960–1966), and Turkey (1980–1984) experience a positive shift, Israel (1969–1977) a negative shift. Consequently, the overwhelming majority of countries does not exhibit a significant immediate impact of trade liberalization episodes.

Taken together, the results indicate that most of the postwar trade liberalization episodes had typically no impact on economic growth, neither in the long run nor in the short run. However, so far the date of the trade liberalization episodes as determined by Michaely et al. (1991) was taken for granted. Yet, it is possible that the date of the liberalization episode and the impact of the episode on the growth process do typically not coincide. In this case the impact of the liberalization episode may follow the start of the episodes with a certain time lag. Furthermore, it is also possible that the estimated date of the liberalization period is mistaken. In this case, it may even be possible that the impact of the liberalization period may precede the estimated date. Consequently, in both cases, the above dummy regressions would yield no reliable results.

c. Test for an Unknown Structural Break

In order to take care of the problems that may emerge from misspecified dates of the liberalization episodes a test for an unknown structural break of a time series is used in the following. One problem that emerges with this type of tests is typically their poor small-sample performance. For example Monte Carlo simulation show that tests for an unknown structural break for stationary time series based on classical inference, such as the CUSUM test of Brown et al. (1975), the Kontrus–Kramer–Ploberger test (Kontrus et al. 1989) or the Nyblom test (Nyblom 1989), have typically low power against local shifts of parameters in small samples. Kim (1991) therefore proposed a Bayesian flat prior test for an unknown structural break that turns out to have relatively good small-sample properties (see also Section C.II.1). A Monte Carlo simulation for a sample of $T = 50$ shows that the test detects structural breaks, i.e., changes of the intercept, μ, as well as changes of ρ (see [C.18]), reasonably well. This holds also, if there are several structural breaks within one sample (see Kim 1991: Figure 10). Another favorable property of this test is its immunity against stationary or nonstationary time series. However, by construction of the test statistic the reliability of the test is poor at the sample border. The Monte Carlo simulation shows that the test performance near the sample borders is low.

The Kim test is based on the assumption that the probability of a structural break before the data are observed (i.e., the prior, or unconditional, probability of a structural break) is equal at every point in time (this is the Bayesian flat prior assumption). Note that this implies the assumption that the prior probability of at least one structural break at any point in time of the sample period equals 100 percent. Based on this assumption and Bayes' theorem it is possible to compute the posterior probability, i.e., the probability of a structural break at a certain point in time after the data are observed.[141] In other words, the Kim test starts with the (nonpartisan) assumption that the probability of a structural break is equal at any point in time and computes whether this assumption has to be changed given the realization of the data. Hence, if trade liberalization episodes cause structural breaks, a Kim test should reveal this by a concentration of probability mass around the trade liberalization periods.

Kim shows that the marginal posterior probability of a structural break at a certain point in time m follows from a normalization of the following marginal posterior mass function:

$$[C.8] \quad P\left(m \middle| X_{(1,T)}\right) = \left(\left|X'_{(1,m)}X_{(1,m)}\right|\left|X'_{(m,T)}X_{(m,T)}\right|\right)^{-0.5}\left(\left|\varepsilon'_{(1,m)}\varepsilon_{(1,m)} + \varepsilon'_{(m,T)}\varepsilon_{(m,T)}\right|\right)^{-(T-2k)}.$$

Here, $X_{(1,T)}$ is the regressor matrix of the period $t=1$ to $t=T$, $X_{(i,j)}$ is the partitioned regressor matrix of the period $t=i$ to $t=j$, $\varepsilon_{(i,j)}$ is the residuum of a regression of [C.7] over the period $t=i$ to $t=j$. This formula has a simple intuition: Its value is the higher, the lower the sum of the squared residuals of a regression over the period $t=1$ to $t=m$ and of a regression over the period $t=m$ to $t=T$. Consequently, if at point $t=m$ the time series contains a structural break, the fit of both regressions will be optimal at this point such that the sum of the squared residuals will be minimal. Hence, the value of the marginal posterior probability will peak at $t=m$.

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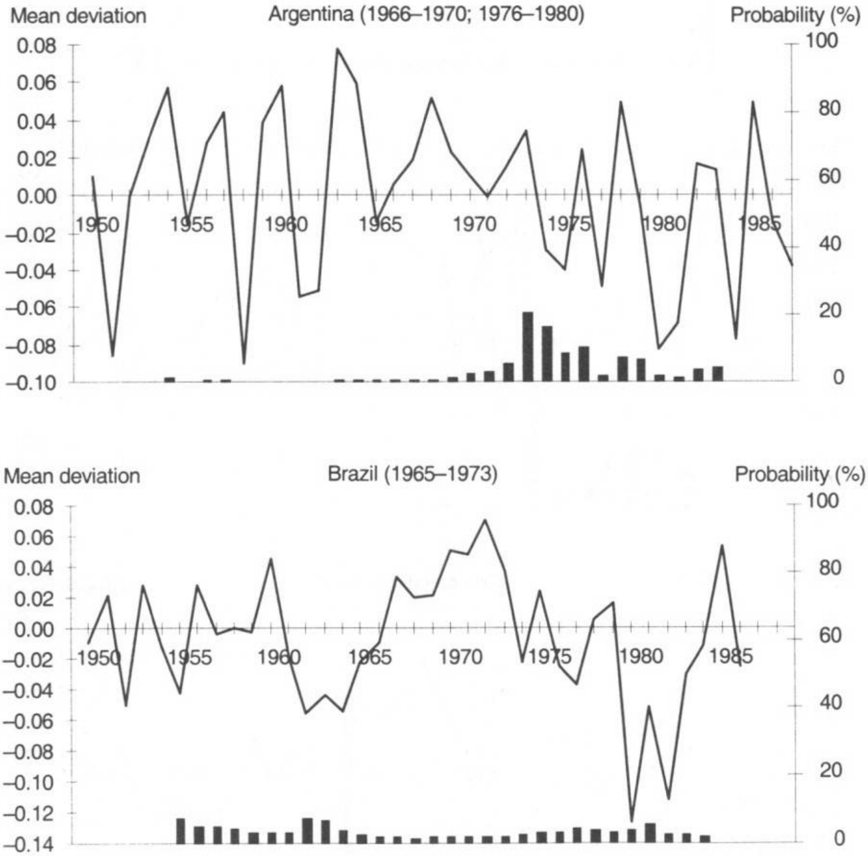
141 For a presentation of Bayes' theorem and a discussion of Bayesian inference see Appendix 8.

The results of Kim's posterior probability test are displayed in Figure 20. The time series regression model given by [C.6] is used for the estimation; the lag structure is chosen according to the Hall selection procedure.[142] The columns indicate each year's posterior probability of a structural break. The line indicates the deviation of each year's real per worker GDP growth rate from the time series mean.[143]

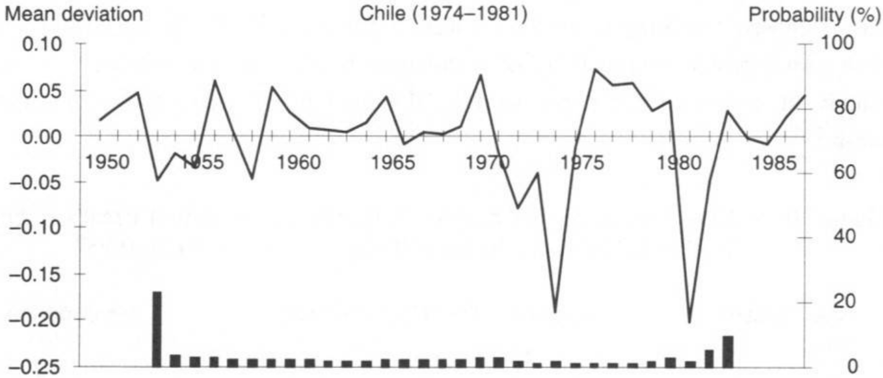
Figure 20 — Mean Deviaton and Posterior Probability of Structural Breaks in Per Worker GDP Growth in Trade Reform Countries, 1950–1985[a]

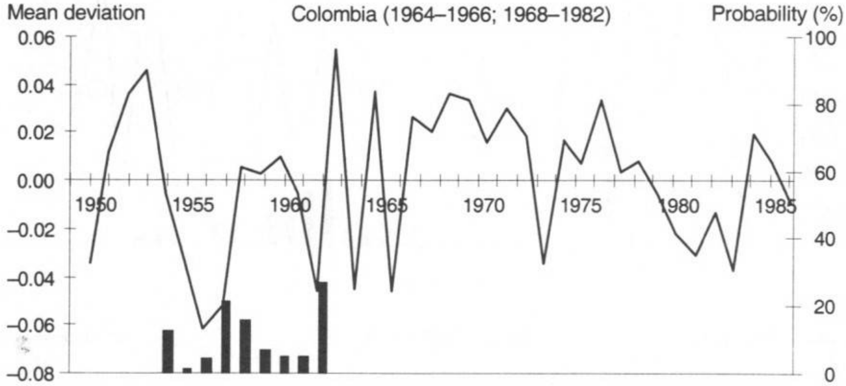


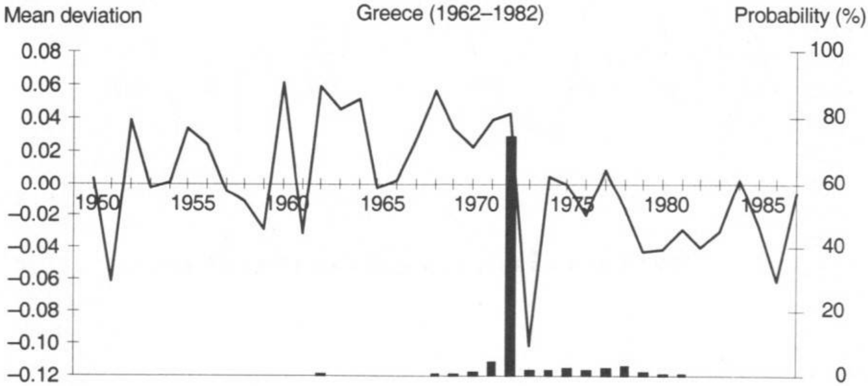
[142] See Chapter C.I.1 for a description of the Hall selection procedure (Hall 1990).

[143] The data are taken from Summers and Heston (1991).

Figure 20 continued







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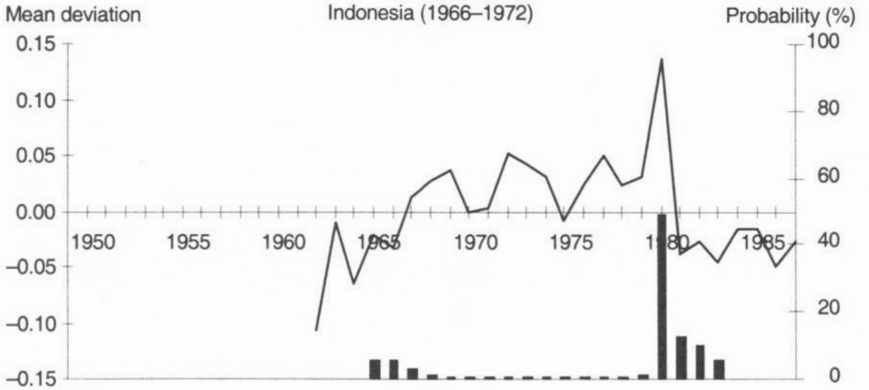

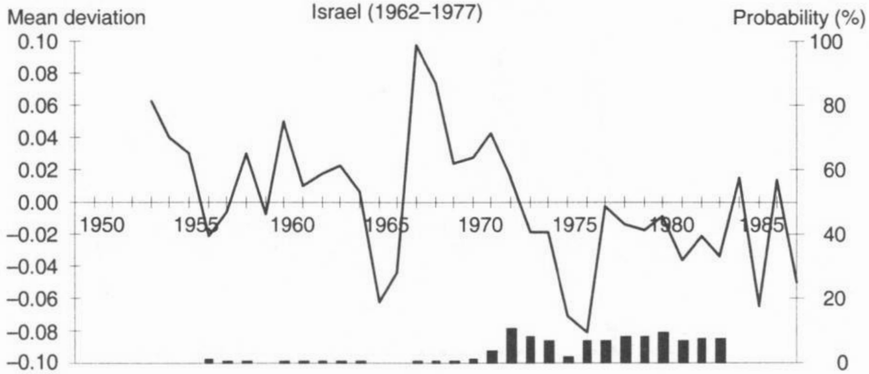

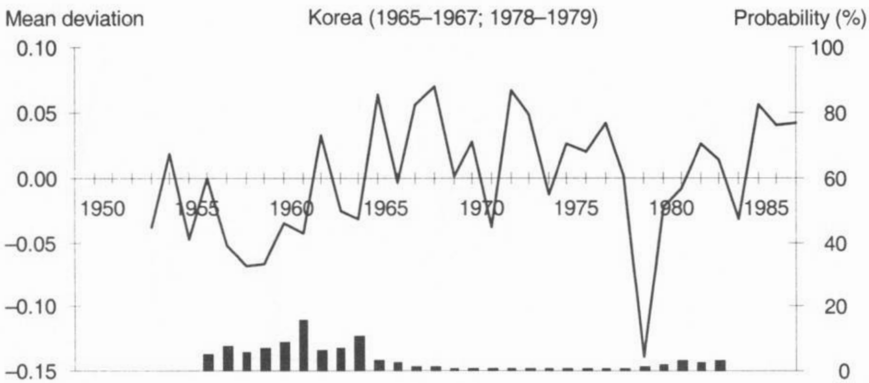

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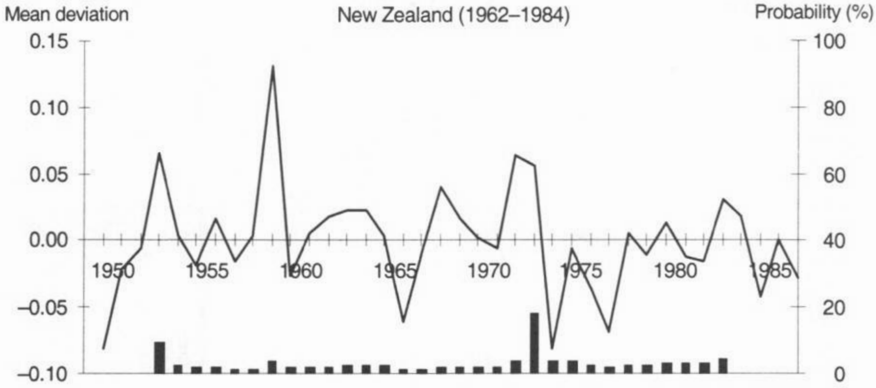

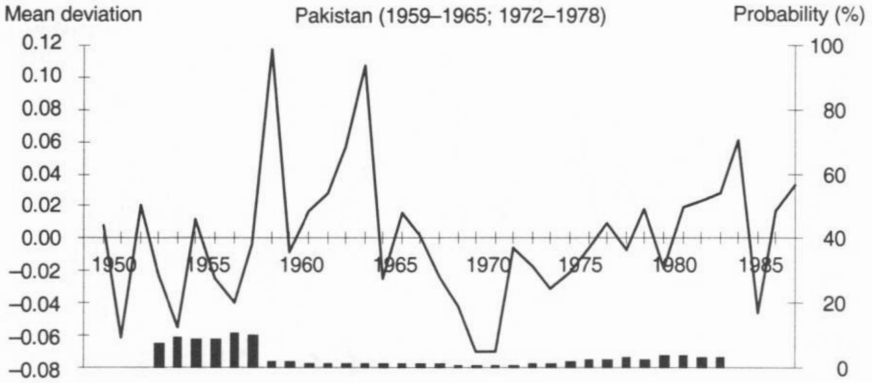

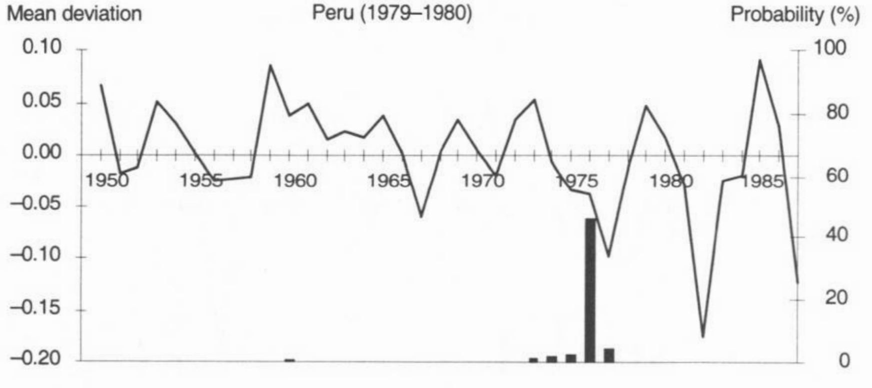

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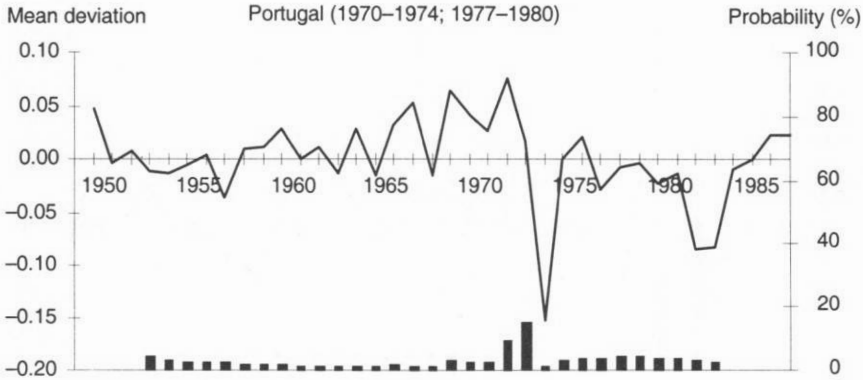
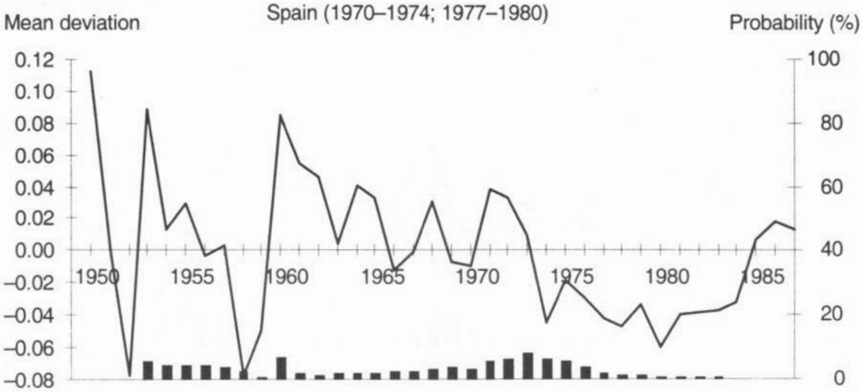




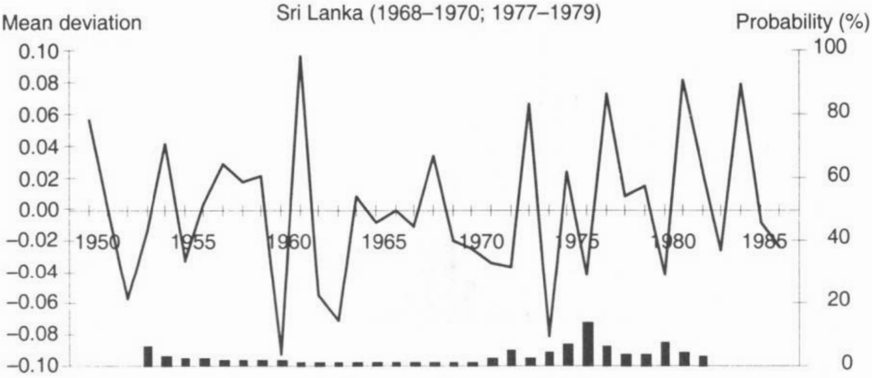
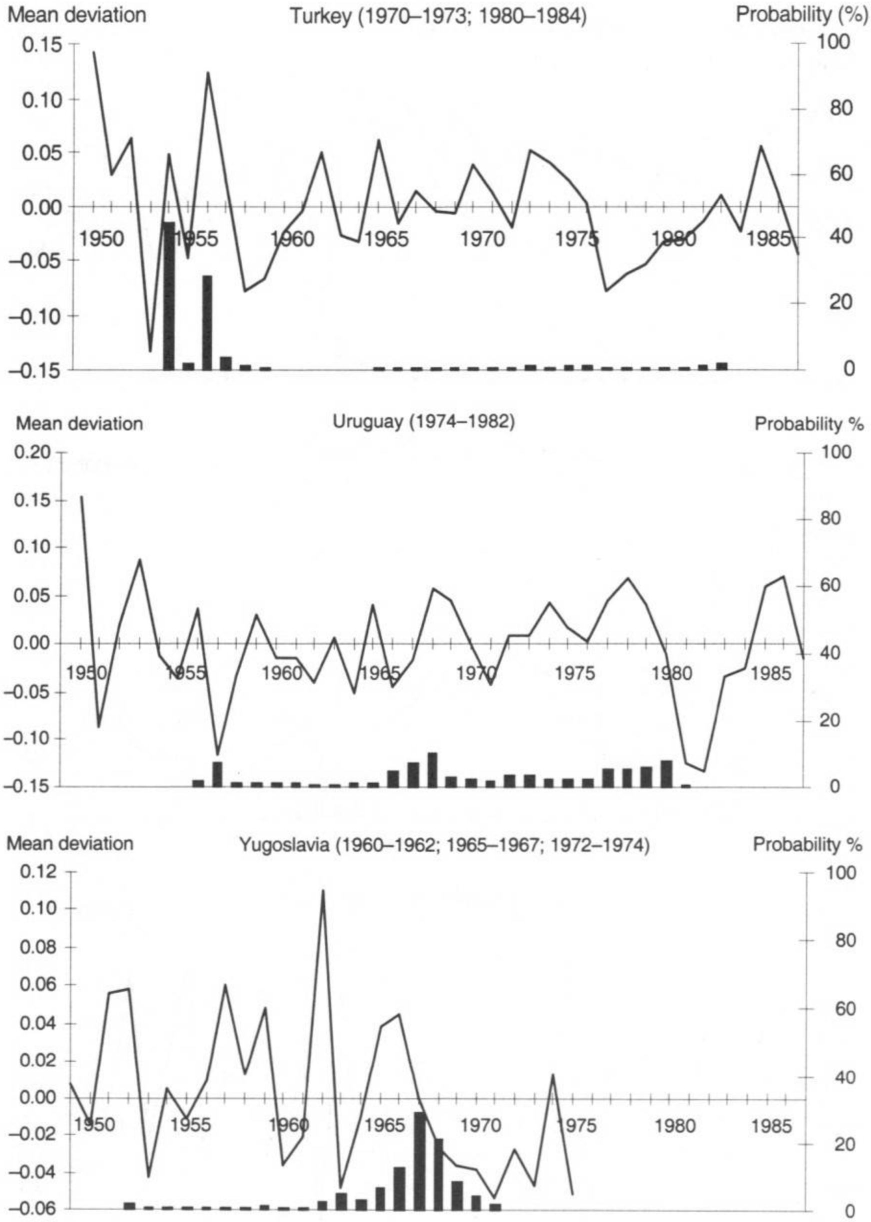


Figure 20 continued



[a]The columns indicate the posterior probability of a structural break for each year. The line indicates the deviation of each year's real per worker GDP growth rate from the mean. The brackets behind the country name present the trade liberalization episodes. The scale of the *y*–axis differs from country to country.

If the dates of the trade liberalization episodes are misspecified by the Michaely et al. (1991) study, the posterior probability of a structural break should peak some years before or behind the estimate of Michaely et al. (1991). In this case a reestimation of the time series regression [C.7] with correspondingly adjusted dummies would be necessary. However, if the posterior probability does peak far beyond the estimated date of the liberalization episode or if it does not peak at all, this indicates that trade liberalization episodes did not affect the time series behavior of economic growth.

Argentina shows a peak of the posterior probability at 1974, pointing at a probability of a structural break of around 20 percent. Hence, there is a slight possibility that the 1976–1980 liberalization episode started two years before the date given in the Michaely et al. (1991) study. However, as the mean deviations indicate this implies (if anything) that a structural break, so it occurred, reduced the growth performance. Brazil shows no significant peak of the structural break probability. However, as the mean deviations indicate, the liberalization period (1965–1973) exactly coincides with a positive trend of the growth rate. This is compatible with the interpretation that the reduction of the growth rate after 1973 was caused by the collapse of the Brazilian trade reform (Table 7). Perhaps the most interesting result represents Chile. Although the Chilean liberalization (1973–1980) was the most radical and was sustained according to the Michaely et al. (1991) study,[144] the probability of a structural break does not peak at any point.[145] Colombia is the only country where the peak of the probability of a structural break (about 25 percent) exactly coincides with the beginning of a liberalization period (1964–1966). However, as Table 6 shows, the dummy of this episode is not significant. The country that reaches the highest probability for a structural break (80 percent in the year 1973) is Greece. However, this peak lies more or less in the middle of the trade liberalization period (1962–1982). The most reliable interpretation for this break seems to be the first oil crisis, which particularly affected the Greek supertanker fleet. The mean deviations of the growth rates suggest that these turbulences had a long-run negative effect on the Greek growth performance.[146] Indonesia provides only data for a relatively small times series (1962–1988). Hence, the effect of the trade liberalization

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144 The Chilean trade (1974–1981) liberalization episode is the only episode which the authors of the Michaely et al. (1991) study characterize as resulting in a nearly free-trade regime.

145 Remember that peaks on the sample borders are not reliable according to the Monte Carlo investigation of Kim's posterior probability test.

146 In a sense, Greece is an example for the good small-sample performance of Kim's posterior probability test for an unknown structural break.

episode (1966–1972) is probably not correctly reflected by the test. A peak at 1981 points at a structural break beyond the trade episode. Korea is one of the world's best postwar growth performers. The posterior probability for a structural break exhibits a certain concentration before the 1965–1967 liberalization period. The probability that a structural break happened at any point within the 1960–1965 period equals about 55 percent. However, since the estimates are close to the sample border, they are less reliable.

The concentration of probability mass at the end of the second Israeli liberalization episode (1969–1977) suggests the possibility of a structural break coinciding with the end of the episode. However, according to the Michaely et al. (1991) study, Israel sustained its trade liberalization (Table 7). Hence, the lower growth performance, as indicated by the mean deviations, cannot be attributed to the end of the episode. New Zealand performed three liberalization episodes: 1951–1956, 1962–1981, and 1982–1984. However, the posterior probability peaks at 1974 in the middle of the second episode indicating a probability of a structural break of about 16 percent. Pakistan is one of the countries where the start of a trade liberalization episode (1959–1965) coincides with a concentration of probability mass in the preceding years. (The probability of a structural break at any point in time in the 1955–1960 period equals about 50 percent.) The fact that this episode was only "partially sustained" (Table 7) is compatible with the reduction of growth performance after the episode. Nevertheless, the sample-border effect reduces the reliability of the estimation. Peru is a similar case. Here, the probability of structural break peaks two years before the chosen date for the start of the trade liberalization episode (1979–1980) reaching a value of about 45 percent in the year 1977. As the mean deviations (and, approximately, the regression estimate in Table 6) show, the growth performance decreased after 1977. Hence, if there were an impact of the liberalization episode, it would be negative. The Philippines experienced two trade liberalization episodes. However, as the relatively flat probability estimates reveal (with the exception of the less reliable sample border), there seems to have been no structural break in growth performance. Portugal exhibits a relatively low peak (15 percent) at the year 1974. This indicates a slight possibility of a structural break, leading to a poorer growth performance after the collapse (Table 7) of the 1970–1974 episode. Spain exhibits no discernible probability peak. The weak growth performance in the decade after the second liberalization episode was not persistent, as indicated by the mean deviations. Sri Lanka, on the contrary, exhibits a certain concentration of probability mass around its second liberalization episode (1977–1979). The probability of a structural break in any of the years from 1976 to 1978 equals roughly 25 percent. Nevertheless, this is no strong evidence for a structural break. With the exception of the (not reliable) sample border, Turkey shows a relatively stable growth performance, not indicating any structural breaks. The same holds for Uruguay, though the volatility was somewhat larger. Yugoslavia exhibits a notable concentration of probability mass around 1968, indicating a structural break towards a lower growth performance after 1968. This coincides with the collapse of the 1965–1967 liberalization episode (Table 7). Nevertheless, it may also be due to a sample-border effect.

Taken together, this check for structural breaks, based on Kim's posterior probability measure, does not indicate a systematic mismeasurement of the impact of trade liberalization episodes on the time series behavior of economic growth by the liberalization episode dates in the Michaely et al. (1991) study. The results fit reasonably well with the dummy regressions, indicating no regular impact of trade liberalization episodes on the time series behavior of economic growth. There are some potential exceptions, such as Argentina (1976–1980), Israel (1969–1977), Pakistan (1959–1965) and Portugal (1970–1974), but the evidence is by no means strong. To sum up, these results question the long-run effect of trade liberalizations on economic growth. However, they do of course not necessarily imply that there is no link between trade and growth. There are several alternative explanations which have to be taken into consideration. *First*, the observed trade liberalizations typically may have been too weak to affect long-run growth. As indicated by the trade liberalization indices of the Michaely et al. (1991) study, only four countries experienced a liberalization episode with a change in the liberalization index by at least 10 points, while only 5 countries out of 19 (Chile, Greece, Israel, Korea, Portugal) ever reached an index value well above 15. The only country that reached an index value of 20, pointing to a "nearly free trade" regime, is Chile. *Second,* there may as well have been a selection bias in the trade reform country sample: countries that have political forces strong enough to bring about a trade liberalization episode, whether sustained or not, may already have a more liberal trade regime than countries never engaged in trade liberalizations. For example, no African country joined the trade liberalization club. Consequently, the observed trade liberalizations typically took place on the basis of already liberalized trade regimes. *Third*, trade liberalization episodes may have affected the price of capital goods in a similar way as the price of other goods such that the relative price of capital goods was not changed by the liberalization. Hence, there may have been no effect of trade liberalization episodes on capital accumulation. Therefore, the next section is directed towards the special effect of the capital goods trade regime on economic growth within a cross section of countries.

It is clear that the results of this paragraph do not support the case against trade liberalizations. On the contrary, as trade liberalizations may increase welfare through a better supply of consumption goods, the fact that trade liberalizations in general did not significantly reduce growth performance may be considered as an argument in favor of trade liberalizations.

II. The Impact of International Trade with Capital Goods on Economic Growth

1. The Impact of Capital Goods Import Tariffs on Capital Accumulation

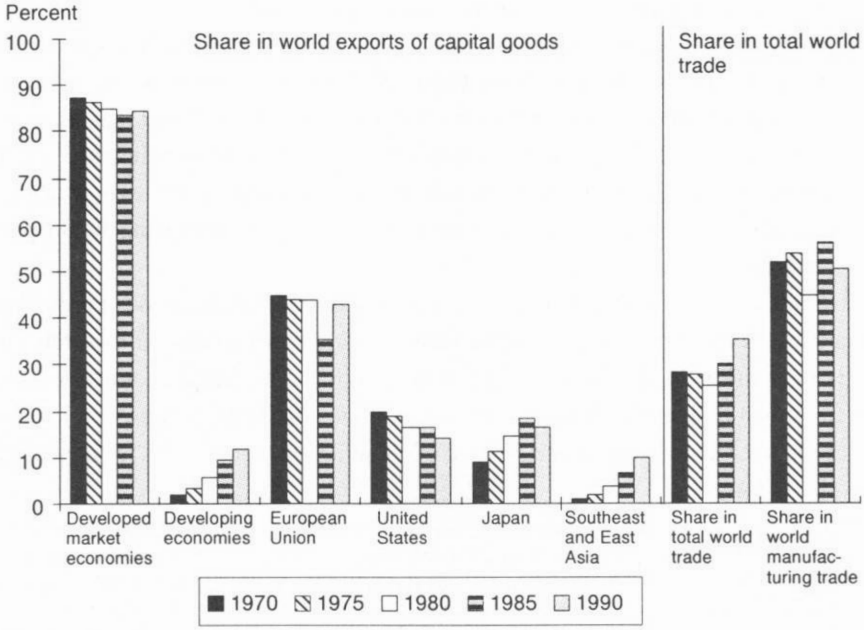
Abstract: This chapter empirically analyzes the impact of capital goods import restrictions on the process of capital accumulation and real per worker GDP growth. International trade with capital goods plays a dominant role in world trade. Capital accumulation in most developing countries strongly depends on capital goods imports from a relatively small group of developed countries. In order to estimate the influence of capital goods import restrictions on economic growth, a Solow–Swan model is modified to account for international trade with differentiated capital goods. As a result of this modification, the model predicts that restrictions on capital goods reduce the transitional growth rate of real per capita GDP via their impact on capital accumulation. The tests indicate that the steady-state version of the model is misspecified, but not so the transitional version. A test of the transitional version cannot reject the hypothesis that restrictions on capital goods imports negatively affect growth performance.

a. Stylized Facts on International Trade with Capital Goods

The basic result of the last chapter was the indifference of the time series behavior of economic growth to observed trade liberalization episodes. However, trade liberalization episodes may be very different. For example, given the definition of trade liberalization by Michaely et al. (1991), trade liberalization episodes can be directed towards investment goods only or towards investment goods and consumption goods. In the first case only the (absolute) domestic price of investment goods may decline inducing a decrease of the domestic relative price for investment goods. In the latter case the (absolute) domestic price of investments goods as well as the (absolute) price of consumption goods may decline leaving the relative price of capital goods unchanged. Growth theories, however, can have very different implications for trade policies affecting the relative prices of capital goods and those affecting not. Therefore, this chapter pays special attention to the effects of different capital goods trade regimes on the growth performance of countries.[147]

International trade with capital goods plays an important role in world trade. Figures 21–25 presenting some "organ-pipe" graphs illustrating the basic patterns of international trade with capital goods. Figure 21 shows that about 30 percent of world

Figure 21 — Structure of World Trade with Capital Goods, 1970–1990[a]



[a]Exports of machinery and transport equipment (SITC 7) measured in current US-dollars. Regions defined according to UNCTAD (1992).

Source: UNCTAD (1992: Table A.9).

147 There exists a large empirical literature on the relation between economic growth and export performance. The theory behind this literature goes back to a simple model of Feder (1982), who states that the export sector exhibits positive externalities to the other sectors of an economy. Most empirical tests on the relation between economic growth and export growth yielded a significant positive correlation (for an overview see Maurer 1994: Table A5). However, as revealed by Sheehey (1990), all these estimations are flawed by the same problem: since exports themselves are a component of GDP all estimations are biased in favor of a positive correlation between the GDP growth and export growth. Therefore, this study does not follow this approach. See Maurer (1994) for an explicit discussion of the export-oriented growth debate.

trade and about 50 percent of world manufacturing trade is trade with capital goods (defined as machinery and transport equipment (SITC 7)). At the same time more than 80 percent of world exports of capital goods is concentrated on the group of developed market economies.[148] In this group the European Union (France, Italy, Germany and the United Kingdom in particular), Japan and the United States hold a world market share of about 75 percent. Only a slight decrease of this market share is recognizable due to the increasing share of the South and Southeast Asian countries (Hong Kong, Singapore, Taiwan and South Korea in particular). Consequently, although trade with capital goods plays an important role in international trade, only a small number of countries dominate the world export market.

This structure of international trade with capital goods basically reflects the structure of capital goods world production. Figure 22 shows that over 80 percent of capital goods world production is concentrated on the group of developed market economies. Again, within this group the European Union, the United States and Japan hold a major share of about 75 percent. Corresponding to their world export market share, South and Southeast Asian countries also display an increasing world production share.

It is interesting to note that this strong concentration of capital goods production remarkably coincides with the concentration of world expenditures on research and development (R&D). As Figure 23 shows the developed market economies account for more than 80 percent of total world expenditures on R&D. North America and the European Union alone reach a share of about 65 percent.[149] This is compatible

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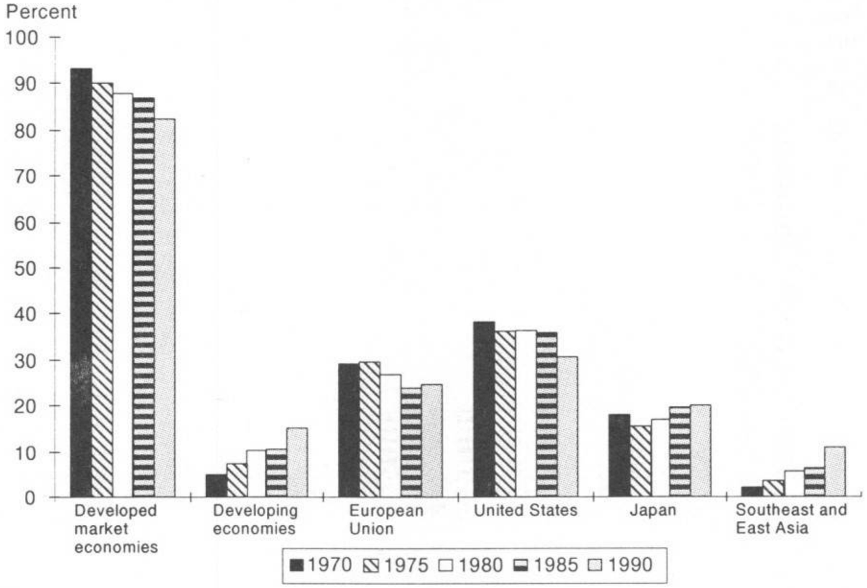
[148] The definition of "developed market economies" according to UNCTAD (1992) includes the following 24 countries: Canada, United States, Belgium, Luxembourg, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, United Kingdom, Austria, Finland, Iceland, Norway, Sweden, Switzerland, Israel, Japan, Australia, New Zealand. The group of South East and South East Asian countries includes here Brunei, Indonesia, Malaysia, Philippines, Singapore, Thailand, Bangladesh, India, South Korea, Sri Lanka, Cambodia, Hong Kong, Macao, Maldives, Myanmar, Taiwan. If not indicated otherwise, the group of "developing countries" includes all other countries minus former (and present) socialist economies.

[149] Of course, R&D expenditures represent only the "top of the iceberg" of total innovation expenditures. A panel survey for German manufacturing firms reveals that R&D expenditures comprise about 30 percent of total innovation expenditures. Other important components of innovation activity are construction and product design (25 percent), and training on the job (15 percent) (Harhoff and Licht 1995). For a definition of these innovation activities see the Oslo Manual (OECD 1992). Unfortunately, data on these types of innovation activities are not collected on an internationally comparable base. Consequently, up to now, international comparisons of innovation activities have to be based on R&D expenditure data. There is, however, some empirical evidence that the "top of the iceberg" may contain some information about the "rest" of the iceberg, too: as the results for German manufacturing show, the share of new goods in total production is sig-

Figure 22 — Structure of World Production of Capital Goods, 1970–1990[a]



[a]Production of capital goods (ISIC 382, 383, 384, 385) measured in PPP-US-dollars. Regions defined according to UNCTAD (1992).

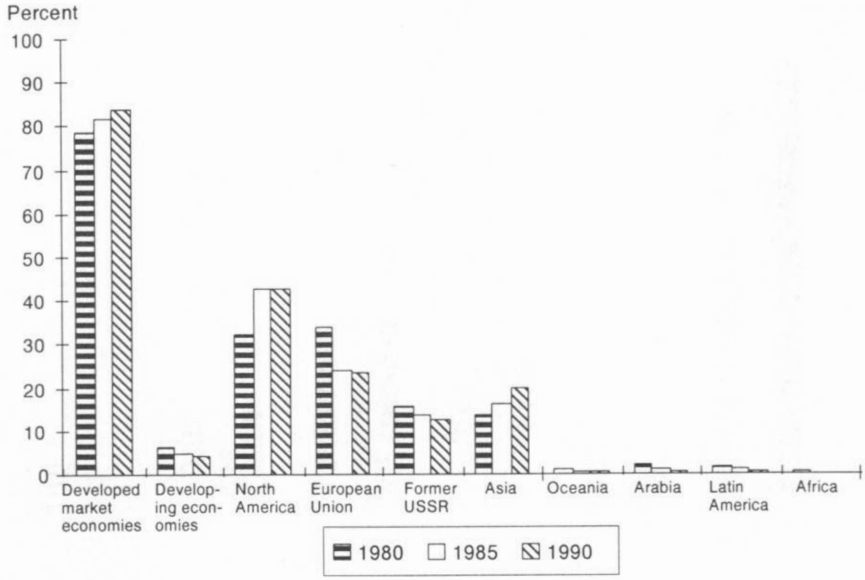
Source: UNIDO (1995).

with the view that there are strong vertical integration links between capital goods production and R&D. This interpretation is supported by the fact that the world R&D share of Asia, which includes those Southeast and East Asian countries that succeeded in establishing a domestic capital goods production base, has significantly increased. If there were actually a vertical link between R&D and capital goods production, only those developing countries that succeed in establishing a domestic R&D sector would be able to implement a domestic capital goods industry. However, as it is most likely that developing countries have a comparative disadvantage in innovation activities, it is most likely that they have a comparative disadvantage in the production of capital goods, too.

In a sense, this stylized pattern of capital goods production and R&D activities remind to the Rivera-Batiz–Romer model with international immobility of technological knowledge, where the North performs R&D and produces capital goods,

nificantly correlated with the share of total R&D expenditures in total production (Harhoff and Licht 1995). Hence, there is some reason to believe that Figure 23 at least roughly describes the worldwide concentration of innovation activities.

Figure 23 — Shares of World R&D Expenditures, 1980, 1985, and 1990[a]



[a]Measured in US-dollars. The official exchange rate was used to convert the R&D expenditures of the former USSR to US-dollars (see UNESCO 1993: Appendix C).

Source: UNESCO (1993: Table 5.1).

while the South completely depends on capital goods imports from the North (Section B.III.3.b). However, the fact that the Southeast and East Asian countries have succeeded in establishing a domestic production base for capital goods as well as a domestic R&D sector indicates that technological knowledge is not as immobile as assumed by this model. The world structure of capital goods production may be rigid to some extent. However, it seems not to be perfectly immovable.[150]

Nevertheless, given the weak domestic production base, accumulation of physical capital in many developing countries strongly relies on capital goods imports from developed market economies. The average share of net domestic imports (i.e., domestic imports minus exports) in domestic capital goods absorption (Figure 24) reveals this:[151] On average developing countries import nearly 80 percent of their

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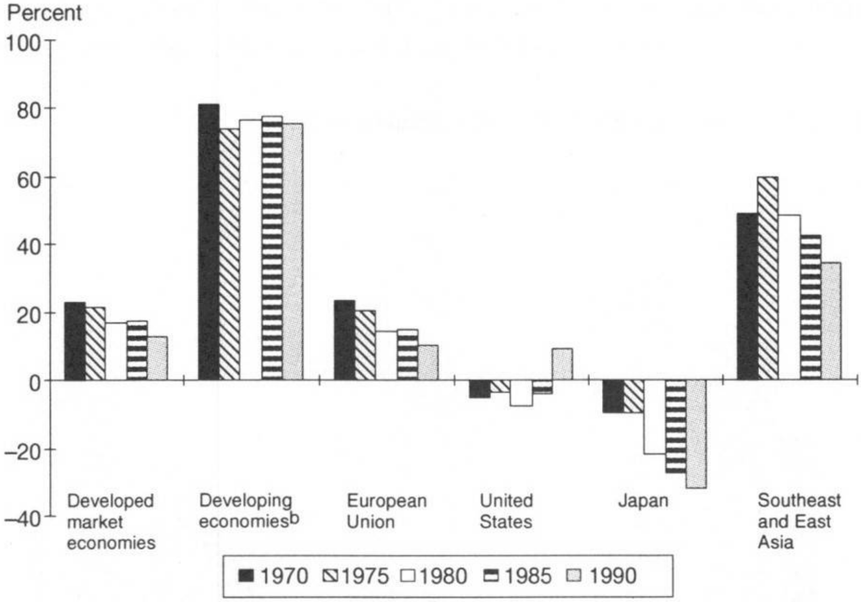
150 Following a study of the World Bank (1993) the success of the East Asian newly industrialized economies mainly depends on their ability to establish favorable conditions for the accumulation of physical and human capital.

151 The country group numbers in Figure 24 are computed by arithmetically averaging across the shares of net capital goods imports in domestic capital goods absorption of all countries belonging to the same country group.

domestic capital goods absorption, while the "average" developed market economy imports less than 20 percent of its domestic absorption.[152] Hence, if accumulation of physical capital is important for real per capita GDP growth, import restrictions on capital goods should have a significant impact on growth performance in developing countries.

Figure 24 — Average Shares of Capital Goods Net Imports in Domestic Capital Goods Absorption, 1970–1990[a]



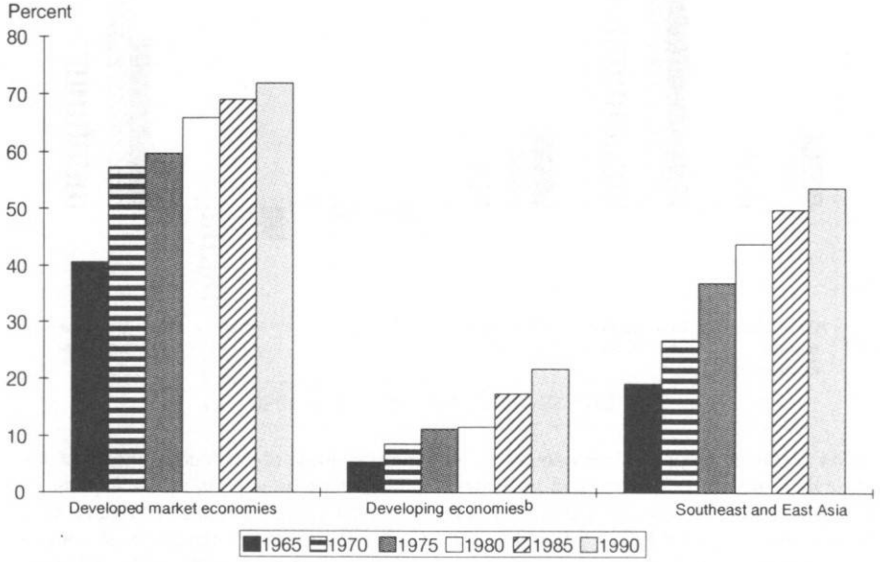
[a]For each country group the index equals the arithmetic average of the country shares of imports minus exports (= net imports) in domestic production plus imports minus exports (= domestic absorption). Exports and imports data on capital goods correspond to machinery and transport equipment (SITC 7) from UNCTAD (1992). Production of capital goods corresponds to nonelectrical machinery (ISIC 382), electrical machinery (ISIC 383), transport equipment (ISIC 384), professional and scientific equipment (ISIC 384) from UNIDO (1995). All values measured in current dollars. Regions defined according to UNCTAD (1992). — [b]Without Southeast and East Asian countries.

Source: UNCTAD (1992), UNIDO (1995).

[152] Of course, the fact that "on average" even developed market economies are net importers implies that there is at least one economy that must be a net capital goods exporter. As it turns out Japan (see Figure 24), Germany, Italy but also Korea and Taiwan form the small group of world capital goods net exporters.

The strong dependence of developing countries on capital goods imports is also reflected by the Grubel–Lloyd index of intraindustry trade.[153] Figure 25 exhibits relatively low values for developing countries. The high shares of net imports in total domestic capital goods absorption imply that these low intraindustry trade values stem from a deficit of the trade balance with capital goods. It is astonishing that the index values for the developed market economies are that high despite the low values for developing countries. As the capital goods trade balance deficit of developing countries implies that other countries must have a trade balance surplus with capital goods (and, hence, relatively low intraindustry trade index values), the high values for developed market economies imply that intraindustry trade between devel-

Figure 25 — Intraindustry Trade with Capital Goods, 1965–1990[a]



[a]The index for each country group equals the arithmetic average of the Grubel–Lloyd intraindustry trade index. The Grubel–Lloyd index equals: (export+import–abs(export–import))/(export+import). The data are taken from UNCTAD (1992: Table A.9). — [b]Without Southeast and East Asian countries.

Source: UNCTAD (1992: Table A.9).

[153] The Grubel–Lloyd index equals: (export+import–abs(export–import))/(export+import). See Grubel and Lloyd (1975). In principle, the Grubel–Lloyd index should refer to be used for the total trade imbalance of a country. However, as the above indices are averaged across countries, trade imbalance effects should more or less net out.

oped market economies alone must be even higher than indicated by Figure 25. Furthermore, it is interesting to note that the group of Southeast and East Asian countries has increased its index values since 1965 at a remarkably faster pace than developed market economies. This seems to indicate that countries reaching a higher level of economic development typically engage more and more in intraindustry trade. Consequently, the stylized facts indicate that North–South trade with capital goods is typically interindustry trade, while North–North trade with capital goods is typically intraindustry trade.

b. A Simple Solow–Swan Model with Differentiated Capital Goods

In order to estimate the impact of capital goods import restrictions on the process of capital accumulation and real per worker GDP growth this section derives a modified version of the Solow–Swan model. The modification allows for international trade with capital goods and provides, therefore, an additional restriction for the regression equation derived by Mankiw et al. (1992). This restriction can be used to estimate the impact of the capital goods trade regime on growth performance. Given the stylized facts presented in the preceding section, allowing for international trade with capital goods should add to the empirical performance of the Solow–Swan model.

The basic difference between the Solow–Swan model used by Mankiw et al. (1992) and the modified version derived in the following is the aggregate production function. Instead of the Cobb–Douglas function with homogenous capital goods used by Mankiw et al. (1992), here a Cobb–Douglas function with differentiated capital goods is employed similar to that discussed in Section B.I.2 ([B.3]):

$$[C.9] \quad Y_t = L_t^{\alpha} H_t^{\beta} \left(\sum_{i}^{A_D} X_{i,t}^{\gamma} + \sum_{j}^{A_F} X_{j,t}^{\gamma} \right) \text{ where } \alpha+\beta+\gamma=1, \; 0<\alpha,\beta,\gamma<1 .$$

Here, Y_t is GDP, L_t is the labor force, H_t is the stock of human capital, $X_{i,t}$ is a domestic capital good, $X_{j,t}$ is a foreign capital good, A_D is the set of domestically produced differentiated capital goods, A_F is the set of foreign-produced differentiated capital goods. As discussed in Section B.I.2, this way of modeling the stock of physical capital implies that total factor productivity is the higher, the larger the available set of capital goods, $A_D + A_F$. Given the above stylized facts, the set of domestic capital goods, A_D, should typically be small in most developing countries, reflecting their dependence on capital goods imports from developed countries. Hence, using statistical proxies for A_D the model provides some flexibility to account for different specialization patterns of countries. Assuming τ to represent the "effective tariff" (i.e., the deviation of the domestic price for foreign capital goods from its free trade value caused by import restrictions on capital goods) in market equilibrium, [C.9] can be rewritten in the following way (for an explicit derivation see Appendix 10.1):

$$[C.10] \quad Y_t = L_t^{\alpha} \; H_t^{\beta} \; K_t^{\gamma} \; \Psi_t^{1-\gamma} \quad \text{with } \Psi_t := \left(A_{D,t} + A_{F,t} \left(1+\tau\right)^{\frac{-\gamma}{1-\gamma}} \right).$$

Here K_t equals the market value of the capital stock. The variable Ψ_t represents a kind of "conversion factor" that converts the market value of the capital stock into the "real effective capital stock" (see Appendix 10.1). The real effective capital stock is the higher, the larger the set of diversified capital goods, $A_{D,t} + A_{F,t}$, and the lower the effective import tariff, τ. As Ψ_t is inversely related to the effective import tariff, it is called the "openness indicator" in the following. The openness indicator has a plain intuition: As implied by the "love for capital goods variety" implication of production function [C.9] a larger set of diversified capital goods increases the productivity of the stock of accumulated capital (see the discussion of [B.3] in Chapter B.I.2). The effective import tariff, however, reduces this productivity effect of capital variety for two reasons: a "substitution effect" and an "income effect."

The substitution effect stems from the fact that both domestic and foreign capital goods are characterized by diminishing marginal returns, i.e., $0<\gamma<1$. Consequently, to reduce the negative productivity effect of diminishing marginal returns, it is output maximizing to use the same quantities of both types of capital goods. However, a profit maximizing firm reduces the input of foreign capital goods relatively to the input of domestic capital goods, if the price of foreign capital goods is increased by import restrictions (see [A.10.7] in Appendix 10.1). As a result, import restrictions on foreign capital goods lead to an inefficient composition of the domestic stock of physical capital: too much use of domestic capital goods and too little use of foreign capital goods is made. Therefore, the output level decreases as τ increases. The substitution effect of import tariffs stems from the "love for capital goods variety" assumption implied by the aggregate production function. Following this assumption, different capital goods are imperfect substitutes, i.e., $1/(1-\gamma)<\infty$.[154] One consequence of this assumption is that domestic capital goods are only imperfect substitutes for foreign capital goods. Hence, there is a com-

154 See Appendix 1 for a derivation.

plementary relation between domestic and foreign capital goods. Empirical evidence in favor of this assumption is presented by Hentschel (1992). Explicit estimations of the elasticity of substitution indicate a strong complementary relationship between domestically produced production factors and imported production factors for a set of twelve developing countries.[155]

The income effect of import restrictions on capital goods stems from the fact that the reduction of the input quantity of foreign capital goods is not totally offset by the increase of the input quantity of domestic capital goods. As the effective import tariff increases the domestic price for foreign capital goods, on average less capital goods can be bought with a given market value of accumulated capital, K_t. Consequently, import tariffs reduce the total input quantity of capital. Tentative empirical evidence in favor of a negative effect of import restrictions on the quantity of accumulated capital is provided by Levine and Renelt (1992). This study shows that there is a robust and significant positive relation between the share of imports in GDP and the share of investment in GDP.[156]

In order to derive an equation which can be linearly estimated the model is kept simple. According to the Solow–Swan model used by Mankiw et al. (1992), it is assumed that technological progress, i.e., total factor productivity growth, is exogenous. The assumption of endogenous technological progress typically leads to rather complex nonlinear expressions for the transitional growth rate, which have not necessarily a general solution.[157] Exogenous technological progress enters the model via the growth of the set of diversified capital goods. For simplicity it is assumed that the growth rate of the set of diversified capital goods equals g for the domestic and for the foreign stock of capital goods. This implies the assumption that countries engaged in R&D are, in relation to their accumulated stock of technological knowledge $A_{D,t}$, on average equally successful in the invention of new capital goods ($A_{D,t} / A_{D,t} = e^g$). This assumption does not imply that all countries are engaged in R&D: countries not engaged in R&D realize a rate of tech-

[155] Hentschel (1992) finds that, because of these complementaries, the problems of financing the imports of production factors, caused by the debt crisis of the eighties, gave rise to a significant slackening of economic growth within a group of twelve highly indebted countries.

[156] Of course, as the share of imports in GDP is not only determined by import restrictions but also by other country-specific factors (like country size), it is a rather imperfect measure of import restrictions. Therefore, a cautious interpretation of this result of Levine and Renelt (1992) is necessary.

[157] See Mulligan and Sala-i-Martin (1992) for an analysis of the transitional dynamics of multi-sector endogenous growth models.

nological progress equal to g via capital goods imports.[158] Using the standard assumptions of the Solow–Swan model (see Appendix 10.1), the steady-state solution for the level of real per worker GDP of country i can now be determined (see Appendix 10.1 for the explicit derivation):

$$\text{[C.11]} \quad \left(\frac{Y}{L}\right)^{*}_{i,t} = e^{g\vartheta t}\left(n_i + d + g\vartheta\right)^{\frac{-\beta-\gamma}{\alpha}} s_{i,k}^{\frac{\gamma}{\alpha}} s_{i,h}^{\frac{\beta}{\alpha}} \Psi_{i,0}^{\vartheta} \qquad \text{with}$$

$$\Psi_{i,0} = \left(A_{i,D,0} + A_{i,F,0}\left(1+\tau\right)^{\frac{-\gamma}{1-\gamma}}\right) \qquad \text{and } \vartheta := \frac{1-\gamma}{\alpha},$$

where $s_{i,k}$ equals the share of GDP used for physical capital investments, $s_{i,h}$ equals the share of GDP used for human capital investments, d is the rate of depreciation of physical and human capital and n_i is the growth rate of the labor force. Taking the first derivation of the right-hand side of [C.11] with respect to time yields g. Consequently, in steady state the level of per worker GDP grows with a rate equal to the rate of technological progress. Given the assumptions of the model, ad valorem tariffs and nondiscriminatory quantitative import restrictions on capital goods "only" affect the steady-state level of per worker GDP but not the steady-state growth rate. If, however, a country is not engaged in the production of technological knowledge for capital goods, i.e., if $A_{D,0} = 0$, and prohibits imports of new differentiated capital goods from abroad, it will face zero growth in steady state.

A cross-country estimation of [C.11] has to be based on the assumption that all countries of the sample are close to their steady states. If, however, the countries are out of their steady states, the level of per capita GDP in the Solow–Swan model is determined by a weighted average of the steady-state level of per capita GDP and the initial level of per capita GDP. This relation is given by the following equation:[159]

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158 The model assumes that the domestic growth rate of technological progress is either zero (if $A_{D,0} = 0$) or identical to the foreign growth rate of technological progress (if $A_{D,0} > 0$). As a consequence, tariffs and quantitative restrictions which are not prohibitive and do not discriminate between old and new capital goods do not affect the steady-state growth rate of total factor productivity. See the end of Section C.II.1.d for a discussion of a more general case.

159 For a derivation see Barro and Sala-i-Martin (1995: 37, 53).

$$\text{[C.12]}\quad \ln\left(\frac{Y_{i,t}}{L_{i,t}}\right)=\left(1-e^{-\lambda t}\right)\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right)^{*}+e^{-\lambda t}\ln\left(\frac{Y_{i,0}}{L_{i,0}}\right)$$
$$\text{with }\ \lambda=\left(1-\beta-\gamma\right)\left(n+d+g\vartheta\right),$$

where $\left(Y_{i,0}\,/\,L_{i,0}\right)$ is the initial level of per capita GDP. As follows from [C.12], λ determines the speed of the transition from the initial level of per capita GDP to its steady-state level. The higher λ, the faster the transition from the initial level of per capita GDP to its steady-state level is. For a hypothetical $\lambda=0$ no convergence towards the steady state takes place $\left(\ln(y_t)=\ln(y_0)\right)$, while for a hypothetical $\lambda=\infty$ the economy is always in its steady state $\left(\ln(y_t)=\ln(y_t^*)\right)$. Furthermore, [C.12] implies that the weight of the initial level of per capita GDP is the higher, the "younger" the economy (the lower t). By the same argument [C.12] implies that the weight of the steady-state level of per capita GDP is the higher, the "older" the economy (the higher t) is. Inserting [C.11] in [C.12] and taking logs yields:

$$\text{[C.13]}\quad \ln\left(\frac{Y_{i,t}}{L_{i,t}}\right)=\omega g\vartheta t-\omega\frac{\beta+\gamma}{\alpha}\ln\left(g\vartheta+d+n_i\right)+\omega\frac{\gamma}{\alpha}\ln\left(s_{i,k}\right)$$
$$+\omega\frac{\beta}{\alpha}\ln\left(s_{i,h}\right)+\omega\frac{1-\gamma}{\alpha}\ln\left(\Psi_{i,0}\right)+e^{-\lambda t}\ln\left(\frac{Y_{i,0}}{L_{i,0}}\right)\quad\text{with }\omega=\left(1-e^{-\lambda t}\right).$$

[C.13] determines the level of per worker GDP in transition to steady state. Subtracting the log of base year level of per worker GDP, $Y_{i,0}/L_{i,0}$, from both sides of [C.13] yields the growth rate of per worker GDP in transition to steady state. This subtraction only changes the coefficient of the base year level of per worker GDP from $e^{-\lambda t}$ to $e^{-\lambda t}-1$. As the beta convergence implication of the Solow–Swan model implies $\lambda>0$ such that $e^{-\lambda t}<1$, the coefficient thereby changes its sign.[160] All other predictions of the model concerning the coefficients of explanatory variables are not changed by this subtraction. Hence, the model implies that the open-

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160 Conditional beta convergence implies that countries far away from their steady states grow with higher rates than countries close to their steady states. Beta convergence has to be distinguished from sigma convergence. Conditional sigma convergence implies that the conditional cross-section variance of the level of per capita GDP decreases in the course of time. Although both concepts of convergence have to be distinguished from each other, they are closely related. Maurer (1995b: Lemma 1 and Lemma 2) proves that sigma convergence implies necessarily beta convergence and beta divergence implies necessarily sigma divergence. However, as shown by Quah (1993a) beta convergence is compatible with sigma convergence as well as sigma divergence. For an analytical discussion of OLS estimation problems of conditional and unconditional sigma and beta convergence see also Maurer (1995b).

ness indicator, $\Psi_{i,0}$, positively affects the level as well as the growth rate in transition to steady state. Stated in another way, import restrictions on capital goods imports negatively affect the level as well as the growth rate in transition to steady state. Allowing for some country-specific deviations, ε_i, which are assumed to be uncorrelated with the explanatory variables, [C.13] can be rewritten in form of the following cross-section linear regression model:

$$[C.14] \quad \ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) = a - b_1 \ln(g + d + n_i) + b_2 \ln(s_{i,k})$$
$$+ b_3 \ln(s_{i,h}) + b_4 \ln(\Psi_{i,0}) + b_5 \ln\left(\frac{Y_{i,0}}{L_{i,0}}\right) + \varepsilon_i .$$

The parametric assumptions of the Cobb–Douglas production function imply $\alpha+\beta+\gamma=1$ and $0<\alpha,\beta,\gamma<1$ to hold. As is well known and shown in Appendix 10, this assumption is essential to ensure a decentralized market solution of the Solow–Swan model. Hence, in order to test whether the data support this assumption or not, it is necessary to restrict the regression coefficients. From [C.13] and [C.14] follow that $\alpha+\beta+\gamma=1$ implies $b_2 + b_3 - b_1 = 0$ to hold. This is the restriction used by Mankiw et al. (1992) to estimate their version of the Solow–Swan model. However, the version used here includes $\Psi_{0,t}$ as an additional explanatory variable. Therefore, in order to ensure that the regression coefficient of $\Psi_{0,t}$ (which equals $\omega(1-\gamma/\alpha)$) is compatible with the values for γ and α implied by the first restriction, a second restriction has to be imposed. As follows from [C.13] and [C.14] this second restriction equals $b_4 - b_3 + b_0 = 1$.

c. *Measures of Import Restrictions on Capital Goods*

To test [C.14] and its restrictions an appropriate proxy for the effective import tariff on capital goods, τ, has to be chosen. The effective import tariff corresponds to the deviation of the domestic price for foreign capital goods from its free trade value caused by import restrictions on capital goods. Most countries use two types of import restrictions: ad valorem import tariffs and quantitative restrictions.[161] Both types of restrictions drive the domestic price above its free trade value. Table 8 presents the results of an OLS regression of the relative capital goods price index (*RCGP*) on the import tariffs (*IT*) and coverage ratios of quantitative restrictions (*IQ*) on capital goods. The *RCGP* of country *i* corresponds to:

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161 For a survey see Erzan et al. (1988) and Maurer (1994).

$$[C.15] \quad RCGP_i = \frac{p_{X,i}}{p_{X,us}} \left(e_{us,i}^{PPP}\right)^{-1}, \text{ with } e_{us,i}^{PPP} = \frac{p_{GDP,i}}{p_{GDP,us}},$$

where $p_{X,i}$ is the price index for a basket of capital goods of country *i* in domestic currency, $p_{X,us}$ is the price index for the same basket of capital goods of the United States in dollars, $p_{GDP,i}$ is the GDP deflator of country *i* in domestic currency, and $p_{GDP,us}$ is the GDP deflator of the United States in dollars. Consequently, the relative capital goods price index equals the ratio of the domestic price level of capital goods (converted by the purchasing power parity exchange rate) to the United States price level of capital goods.

The price indices for capital goods are taken from the International Comparison Program (ICP) of the United Nations Statistical Bureau (UNSTAT) and the Statistical Office of the European Union (EUROSTAT).[162] The data on import tariffs and coverage ratios of quantitative restrictions on capital goods are taken from Barro and Lee (1993). They are collected for a sample of 104 countries (resp. 102 countries for the coverage ratios) over the period 1980–1985.[163]

As Table 8 shows (based on a cross-country OLS regression) the import tariffs (*IT*) as well as the quantitative restrictions (*IQ*) are positively correlated with the relative capital goods price index (*RCGP*). However, only import tariffs exhibit always a significant coefficient (the *p*-value is always 0.000) and explain most of the variation (as indicated by the $\overline{R}^2$). This indicates that the data on import tariffs (*IT*) contain more information on the capital goods trade regime than the data on quantitative restrictions (*IQ*).

This conclusion is also supported by an OLS regression of the relative input mix indicator (*RIM*) on import tariffs and quantitative restrictions. Contrary to the relative

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162 (1) Unfortunately, prices of the ICP project are only published in relation to US prices and the absolute values of US prices are not published. Nevertheless, as can be analytically shown, this normalization does not change cross-country correlation coefficients. (2) Phase IV of the ICP provides price indices for 60 countries (UNSTAT and EUROSTAT 1987) collected for 1980 and phase V of the ICP provides price indices for 64 countries collected for 1985 (UNSTAT and EUROSTAT 1994). The price level index for producer durables of Phase IV is based on a precisely defined commodity basket of 150 "nonelectrical machinery and equipment" products, 55 "electrical equipment and appliances" products and 70 "transport equipment" products. To guarantee a high degree of international comparability of the data, engineers and material scientists were consulted. These specialists were asked to decide over the equivalence of the definitions of the products with the real products found on the local markets. Consequently, there is good reason to believe that the price level indices for producer durables of the ICP are internationally comparable.

163 Table A.11.3 in the Appendix surveys these data.

Table 8 — Cross-Country OLS Regression of Relative Capital Goods Price Index (*RCGP*) on Import Tariffs (*IT*) and Quantitative Restrictions (*IQ*)[a]

	*RCGP*80			*RCGP*85		
Const.	1.306	1.234	0.85	1.04715	1.033	0.687
p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
IT	0.254	0.261	—	0.247	0.265	—
p-value	(0.000)	(0.000)	—	(0.000)	(0.000)	—
IQ	0.0325	—	0.073	0.011	—	0.106
p-value	(0.000)	—	(0.079)	(0.797)	—	(0.046)
$\overline{R}^2$	0.432	0.434	0.044	0.435	0.46	0.068
p-value(*F*)	0.004	0.000	0.025	0.000	0.000	0.023
Obs.	48	50	49	45	49	45

[a]Variables as defined in the text. The number behind *RCGP* denotes the year; e.g., *RCGP*85 indicates that the data for the construction of the *RCGP* value are taken from the year 1985. Numbers in parenthesis are *p*-values of corresponding *t*-values of regression coefficients. *p*-value(*F*) = *p*-value of an *F*-test of the null hypothesis that all regression coefficients are jointly zero. $\overline{R}^2$ = adjusted *R*-squared value. Obs. = number of observations.

capital goods price index, the relative input mix indicator is based on quantitative variables only. As derived in Appendix 10.2. the Solow–Swan model with diversified capital goods implies that the following relation holds between the effective import tariff and the input ratio of the domestic to foreign capital goods:

$$\text{[C.16]} \quad \left(1+\tau_t\right)^{\frac{\gamma}{1-\gamma}} = \frac{\dot{K}_{D,t}}{\dot{K}_{F,t}} \Big/ \frac{A_{D,t}}{A_{F,t}},$$

where $\dot{K}_D$ equals the aggregate investment of domestic capital goods in period t. It is empirically measured here by the domestic production of capital goods minus exports of domestic capital goods. Similarily, $\dot{K}_F$ equals the aggregate investment of foreign capital goods in period t. It is empirically measured here by the domestic imports of foreign capital goods. A_D is the number of the domestic varieties of capital goods. A_F is the number of the foreign varieties of capital goods. The relative input mix indicator is constructed under the assumption that the ratio of A_D/A_F can be approximated by the ratio of exports of domestic capital goods to the total foreign production of capital goods. Introducing this in [C.16] yields a variable that has the following dimension:

$$\text{[C.17]} \quad \frac{\dot{K}_D}{\dot{K}_F} \Big/ \frac{A_D}{A_F} = \frac{\text{ratio of domestic capital goods to foreign capital goods in } \textit{domestic} \text{ production}}{\text{ratio of domestic capital goods to foreign capital goods in } \textit{world} \text{ production}}.$$

[C.16] and [C.17] imply that given an effective tariff on capital goods equal to zero, $\tau = 0$, the ratio of domestic capital goods to foreign capital goods in domestic production should equal the ratio of domestic capital goods in world production, i.e., the relative input mix value should equal unity. This implication of the Solow–Swan model with diversified capital goods follows from production function [C.9]. Given this type of technology it is profit-maximizing for enterprises all over the world to use the same "input mix" of capital goods varieties in the absence of import restrictions. If, however, a country increases the domestic price of foreign capital goods by introducing import restrictions, the profit maximizing "input mix" changes and countries use relatively more domestic goods. Thus, the relative input mix indicator reaches a value above unity.[164] Of course in a world with transportation costs and other kind of transaction costs, the relative input mix indicator will typically reach a value significantly higher than unity. However, as these transaction costs should be similar for most countries, the cross-country variation of the relative input mix indicator should contain information about import restrictions on capital goods.

Table 9 displays the results of a cross-country OLS regression of the relative input mix value on the import tariffs (*IT*) and coverage ratios of quantitative restrictions (*IQ*) on capital goods.[165] The results indicate that import tariffs are significantly positively correlated with the relative input mix values (the *p*-values are always close to 0.000). The regression coefficients for the coverage ratios *IQ* show no significant correlation in a joint regression of *IT* and *IQ* (the *p*-values are higher than the 0.05 significance level).[166] Also, the $\overline{R}^2$ values indicate that import tariffs explain more cross country variation of the relative input mix values than quantitative restrictions. Table 9 shows furthermore that this holds for relative input mix values over the whole period 1965–1985. As the data for the capital goods import tariffs are collected over the period 1980–1985, this indicates that capital goods trade regimes had been relatively invariant over the period 1965–1985.

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164 This holds, strictly speaking, only if other countries introduce no import restrictions on capital goods. If other countries use import restrictions, too, the ratio of domestic to foreign capital goods in world production is downward biased. However, if import restrictions do not discriminate between countries exporting capital goods, this downward bias hits all countries in the same way. Therefore, the cross-country variation of the relative input mix value should nevertheless contain the information wanted.

165 The relative input mix value is based on data on capital goods production and trade taken from UNCTAD (1992) and UNIDO (1995). Table A.11.3 in the Appendix shows the data for the relative input mix values of the years 1965, 1970, 1975, 1980, and 1985.

166 The relatively high values of the regression constant indicate that transaction costs and the existence of nontradable capital goods increase the level of the relative input mix value of most countries considerably above unity.

Table 9 — Cross-Country OLS Regression of Relative Input Mix Value (*RIM*) on Import Tariffs (*IT*) and Quantitative Restrictions (*IQ*), 1965–1985[a]

	*RIM*65			*RIM*70			*RIM*75			*RIM*80			*RIM*85		
Const.	13.203	13.806	11.505	14.752	14.277	11.65	12.851	12.815	9.746	13.047	12.769	9.955	12.581	12.749	8.926
p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
IT	1.012	1.504	–	1.749	1.947	–	1.845	1.869	–	1.725	1.823	–	2,030	1.988	–
p-value	(0.032)	(0.002)		(0.000)	(0.000)		(0.000)	(0.000)		(0.000)	(0.000)		(0.000)	(0.000)	
IQ	0.489	–	0.865	0.408	–	0.875	0.036	–	0.522	0.24	–	0.631	–0,122	–	0.308
p-value	(0.171)		(0.011)	(0.000)		(0.002)	(0.855)		(0.025)	(0.366)		(0.023)	(0.534)		(0.221)
$\overline{R}^2$	0.239	0.202	0.149	0.527	0.503	0.168	0.487	0.497	0.071	0.374	0.377	0.076	0.53	0.54	0.010
p-value (*F*)	0.004	0.002	0.011	0.000	0.000	0.002	0.000	0.000	0.025	0.000	0.000	0.023	(0.000)	(0.000)	(0.221)
Obs.	36	39	36	48	49	48	57	58	58	54	55	55	51	52	52

[a]Variables as defined in text. The number behind *RIM* denotes the year; e.g., *RIM*65 indicates that the data for the construction of the *RIM* value are taken from the year 1965. Numbers in parenthesis are *p*-values of corresponding *t*-values of regression coefficients. *p*-value(*F*) = *p*-value of an *F*-test of the null hypothesis that all regression coefficients are jointly zero. $\overline{R}^2$ = adjusted *R*-squared value. Obs. = number of observations.

Taken together, the results indicate that import tariffs on capital goods contain more information about capital goods trade regimes than the coverage ratios on quantitative restrictions. This suggests that the construction of coverage ratios is not appropriate to capture the actual restrictiveness of trade regimes.[167] Figures 26 and 27 give a visual impression of these correlations for the year 1985.[168] The *x*-axis measures the import tariff on capital goods, while the *y*-axis measures the relative capital goods price index (Figure 26) resp. the relative input mix value (Figure 27). The three-letter World Bank country code is used to mark a point (see Table A.11.3 in the Appendix for the key). Given this relatively close relationship between the import tariff data and both the price indices and the quantitative indices, the estimation of [C.14] will be based on the import tariff data as an empirical proxy for the effective import tariff.[169]

Besides their importance for the selection of an empirical proxy for the effective import tariff, these estimation results are remarkable from another point of view. The results reveal that the trade regime has a significant impact on the relative price of capital goods and, as a consequence, on the relative input quantities of foreign and domestic capital goods. In their exploratory study on the empirical relationship between equipment investment and economic growth DeLong and Summers (1992, 1993) suggest, based on a cross-country estimation, the following causal chain:[170] relative equipment prices are negatively correlated with the share of real capital goods investment in GDP; the share of real capital goods investment in GDP in turn is positively correlated with per worker GDP growth. Combining these empirical findings with the findings presented here indicates that it is the capital goods trade regime which mainly determines the relative price of capital goods and, hence, affects per worker GDP growth via the causal chain found by DeLong and Summers.

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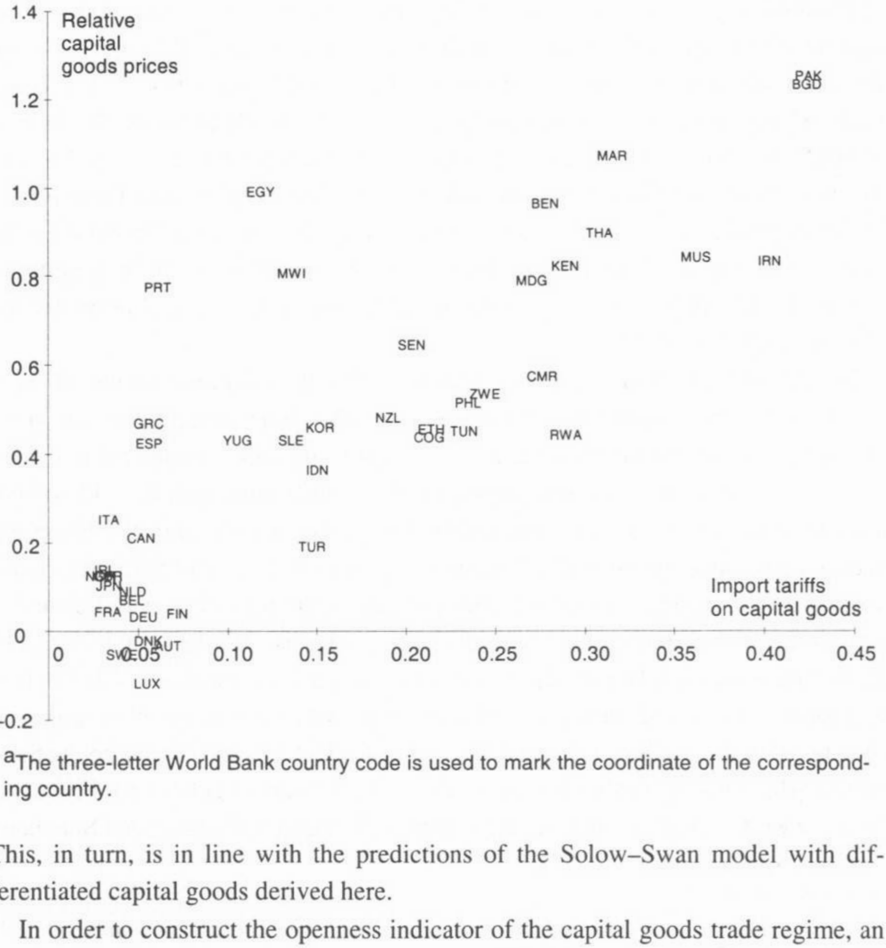
167 Presumably, this is due to the fact that coverage ratios measure only the number of capital goods affected by any quantitative restriction but not the strength of the quantitative restriction itself, while the data on the average import tariff measure (at least approximately) the average strength of the import tariffs. Hence, the latter is likely to contain more information on the real effect of import restrictions.

168 Figures A.11.1–A.11.5 in the Appendix show the corresponding relations for earlier years.

169 Maurer (1995c) alternatively uses the relative capital goods price index (*RCGP*), the relative input mix indicators (*RIM*), and the import tariffs for capital goods to estimate [C.25]. The estimates are not qualitatively different from those presented in the following.

170 (a) The definition of "equipment goods" by DeLong and Summers (1992, 1993) is basically equivalent to the definition of "capital goods" used here. (b) A similar relationship between the relative price of capital and economic growth is reported by Jones (1994).

Figure 26 — Import Tariffs on Capital Goods and Relative Capital Goods Prices, 1985[a]



[a]The three-letter World Bank country code is used to mark the coordinate of the corresponding country.

This, in turn, is in line with the predictions of the Solow–Swan model with differentiated capital goods derived here.

In order to construct the openness indicator of the capital goods trade regime, an empirical proxy for the number of domestic capital goods, $A_{D,0}$, and the number of foreign capital goods, $A_{F,0}$, has still to be determined.[171] Doing this, it is important

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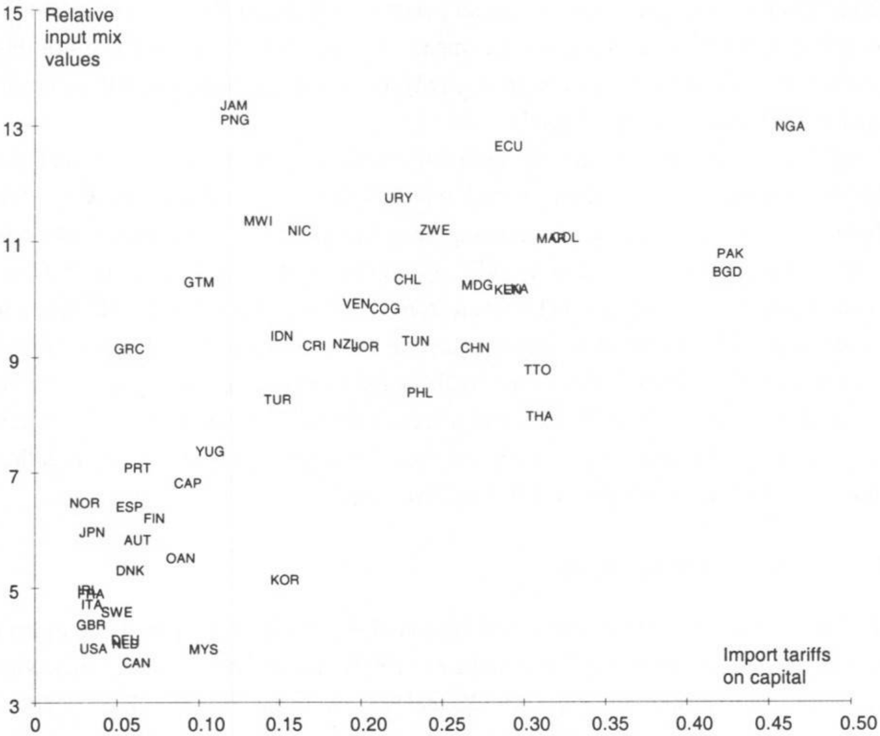
[171] Recall that the indicator of the capital goods trade regime openness equals $\Psi_{i,0} = (A_{i,D,0} + A_{i,F,0}(1+\pi)^{(-\gamma/(1-\gamma))})$. The power to the effective import tariff, $-\gamma / 1-\gamma$, cannot be estimated simultaneously within an OLS estimation. Therefore, it is assumed that it equals –1.0, which is equivalent to the assumption that $\gamma = 0.5$. As the results show under this assumption, the parameter estimates for γ tend to fall in the interval [0.5, 0.6]. This implies a value of the power $-\gamma / (1-\gamma)$ between [–1.0, –1.5]. A sensitivity analysis shows that the estimation results, especially the estimates for γ, are not essentially affected if –1.5 is chosen instead of –1.0.

Figure 27 — Import Tariffs on Capital Goods and Relative Input Mix Values, 1985[a]



[a]The three-letter World Bank country code is used to mark the coordinate of the corresponding country.

to note that in a cross-country regression the formula of the openness indicator attaches a higher weight to an effective import tariff of a country that owns only a small domestic set of differentiated goods, A_D, than to the same import tariff of a country that owns a larger set of differentiated goods. To see this remember that for country i the number of foreign capital goods equals $A_F = A_{world} - A_D$. Consequently, a country with a large stock of domestic capital goods exhibits a smaller A_F than a country with a small stock of domestic capital goods. Inserting $A_F = A_{world} - A_D$ into the formula of Ψ_0 and taking the first derivation with respect to A_D yields $((1-(1+\tau)^{(-\gamma/(1-\gamma))})$ that is strictly larger than zero for all nonnegative import tariffs, τ. Hence, countries with a larger domestic set of differentiated capital goods show a larger value of Ψ_0 for the same effective import tariff than a country with a smaller domestic set of differentiated capital goods.

This weighting scheme of the effective import tariff has a plain intuition: Given production function [C.9] a country with a larger domestic stock of differentiated capital goods is less dependent on capital goods imports from abroad. Consequently, an effective import tariff has a smaller impact on the total factor productivity of this country than on the total factor productivity of a country with a small domestic stock of differentiated capital goods.

As A_D and A_F are not directly observed, empirical proxies have to be used. As the model implies that a country with a relatively high A_D holds a relatively high share of world capital goods production, the domestic share in world production is used as a proxy for A_D. Consequently A_F equals $1-A_D$. Unfortunately, data on world production of capital goods (taken from UNIDO 1995) are available only for a relatively small sample of countries such that the maximum cross-country sample is reduced to 59 countries. Therefore, to allow for a sensitivity test of this reduction of sample size, $A_D = A_F = 0.5$ is used as a second proxy. This allows for a maximum cross-country sample of 74 countries. For simplicity, the first proxy of Ψ_t is called "microversion," the second is called "macroversion."

d. The Estimation Results

All data are taken from Summers and Heston (1991) with exception of the human capital data, which are from Barro and Lee (1993). To achieve comparability with the estimations of Mankiw et al. (1992), real per capita GDP is used as dependent variable. The explanatory variables, $s_{k,i}$, $s_{h,i}$, and n_i, are annual averages over the 1960–1985 period. The investment quota of physical capital, $s_{k,i}$, is the share of nominal investments in nominal GDP, because the stock of physical capital, $K_{i,t}$, in [C.10] corresponds to the market value of the capital stock.[172] Following Mankiw et al. (1992) the investment quota of human capital, $s_{h,i}$, is the percentage of the working-age population in secondary school. Three subsamples are used for the estimation in order to take care for a potential neglect of subsample-specific explanatory variables. The sample called "all countries" includes all countries of the Summers and Heston (1991) data set with exception of small islands economies, major oil exporters and former (and present) socialist countries (see Table A.11.3 in the Appendix). This leaves a set of 98 countries. Due to missing explanatory variables, this set

[172] Remember that Ψ_t represents a "conversion factor" that converts the market value of the capital stock into the "real effective capital stock" (see the discussion of [C.10] and Appendix 10.1). However, as a sensitivity analysis shows, using the share of real investments (i.e., nominal investments deflated by an investment price index) in real GDP (i.e., nominal GDP deflated by an GDP price index) does not essentially change the results.

is reduced by the macroversion of Ψ_0 to 74 countries and by the microversion of Ψ_0 to 59 countries.

Tables A.11.1 and A.11.2 in the Appendix show the estimation results for the steady-state specification of the Solow–Swan model with differentiated capital goods ([C.11]). Although the estimations typically yield significant results (for the separate explanatory variables as well as for the total regression) and the imposed restrictions are not rejected, the standard errors are generally 2 to 4 times larger than those for the transitional version of the model. Similarly, the adjusted R^2 are notably lower for the steady-state version. Furthermore, the Durbin–Watson coefficient indicates that the null hypothesis of negative first-degree autocorrelation of the residuals cannot be rejected in most cases (the sample is ranked according to the 1985 level of per capita GDP), while the transitional version performs much better in terms of the Durbin–Watson coefficient. These results suggest that the steady-state version is misspecified. Most countries of the sample seem to be not in the steady state but in transition to the steady state. Consequently, the base year per capita GDP must not be omitted as an explanatory variable. The omission of a variable that belongs to the true model may bias estimates of the other regression coefficients in an OLS estimation. Hence, the estimates of the steady-state version of the Solow–Swan model are not reliable.

Tables 10 and 11 present the estimation results for the transitional version ([C.13]). The overall impression is that the modified version of the Solow–Swan model is not rejected by the data, no matter whether the microversion or macroversion of Ψ_0 is chosen and no matter what country subsample is used. An F-test of the null hypothesis that all regression coefficients (other than the intercept) are zero is always rejected at conventional significance level (the p-value are always close to 0.000). The estimates for the single explanatory variables are, as a rule, significant at conventional levels. The signs of the variables correspond to the predictions of the model. The adjusted R^2 values generally fall between 0.8 and 0.9. This indicates that the model has explanatory power.

Adding the indicator of the openness of the capital goods trade regime, Ψ_0, improves the estimation result in terms of the adjusted R^2 value as well as in terms of the standard error of the estimate (SEE). Imposing the double restrictions of this version of the Solow–Swan model (as described in the preceding section: $b_4 - b_3 + b_0 = 1$ and $b_2 + b_3 - b_1 = 0$) does not significantly deteriorate the estimation results. The null hypothesis that the model performs better without the restrictions is rejected at conventional levels, with exception of the OECD countries (for the microversion of Ψ_0 at the 5 percent level and for the macroversion at the 10 percent level). However, due to the very small sample sizes (21 and 20 countries) the OECD

Table 10 — Cross-Country OLS Estimation Results for the Transitional Version of a Solow–Swan Model Based on the Macro-version of Ψ_t [a]

	All countries[b]				All non-OECD countries[c]				OECD countries			
	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]
Const.	1.799	1.614	3.213	1.896	3.695	1.846	4.487	2.070	2.381	2.867	4.421	3.051
$p(b=0)$	0.141	0.003	0.016	0.001	0.074	0.010	0.032	0.005	0.132	0.004	0.009	0.002
$\ln(y_{1960})$	0.710	0.708	0.664	0.678	0.663	0.671	0.639	0.650	0.635	0.649	0.644	0.628
$p(b=0)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$p(b=1))$	0.000	0.000	0.000	0.000	0.002	0.003	0.001	0.001	0.005	0.004	0.002	0.002
$\ln(n+g+d)$[e]	–0.907	–0.974	–0.560	–0.967	–0.353	–0.981	–0.170	–0.974	–0.703	–0.512	–0.016	–0.511
$p(b=0)$	0.035	0.000	0.199	0.000	0.608	0.000	0.803	0.000	0.181	0.006	0.975	0.004
s_K	0.759	0.751	0.696	0.725	0.775	0.747	0.312	0.722	0.367	0.413	0.412	0.399
$p(b=0)$	0.000	0.000	0.000	0.000	0.002	0.002	0.002	0.003	0.078	0.016	0.025	0.017
s_h	0.228	0.223	0.266	0.242	0.279	0.234	0.702	0.252	0.099	0.098	0.087	0.112
$p(b=0)$	0.003	0.002	0.001	0.001	0.005	0.007	0.004	0.004	0.289	0.282	0.281	0.208
Ψ			2.281	0.564			1.982	0.602			5.617	0.483
$p(b=0)$			0.017	0.000			0.085	0.000			0.017	0.015
α	0.242	0.231	0.375	0.250	0.488	0.251	0.681	0.264	0.342	0.407	0.956	0.421
β	0.191	0.176	0.297	0.188	0.405	0.179	1.322	0.190	0.093	0.114	0.234	0.127
γ	0.635	0.593	0.777	0.562	1.124	0.570	0.589	0.545	0.344	0.479	1.107	0.452
$\alpha+\beta+\gamma$	1.067	1.000	1.449	1.000	2.017	1.000	2.591	1.000	0.779	1.000	2.297	1.000
λ	0.017	0.016	0.027	0.018	0.036	0.019	0.051	0.020	0.020	0.024	0.056	0.025
F(restr.)		0.029		1.766		0.940		1.312		0.160		2.874

Table 10 continued

	All countries[b]				All non-OECD countries[c]				OECD countries			
	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]
$p(F)$		0.865		0.179		0.337		0.279		0.695		0.088
$\overline{R}^2$	0.890	0.892	0.898	0.895	0.795	0.795	0.804	0.801	0.847	0.855	0.887	0.863
F	137.9	140.1	113.9	111.2	46.6	46.6	36.8	36.3	22.2	23.6	23.7	18.8
$p(F)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SEE	0.138	0.136	0.129	0.132	0.176	0.176	0.169	0.171	0.027	0.026	0.020	0.024
DW	1.919	1.918	1.913	1.910	1.598	1.593	1.664	1.602	2.113	2.163	2.424	2.188
Obs.	74	74	74	74	53	53	53	53	21	21	21	21

[a]Variables are defined in the text. $p(b{=}0)$ $[p(b{=}1)]$ is the p-value of a t-test of the H_0 that the regression coefficient in the row above the p-value equals zero [one]. $p(F)$ is the p-value of the F-value in the row above the p-value. $\overline{R}^2$ is the adjusted R-squared value. SEE is the standard error of the regression. DW is the Durbin–Watson test of first-order serial correlation of the regression errors. (The sample is ranked according to the 1985 level of per capita GDP.) According to the Savin–White tables the upper (resp. the lower) bound for a rejection (resp. acceptance) of the H_0 of a negative first-order autocorrelation of the residuals are 1.739 (resp 1.515) for 4 explanatory variables and 74 observations, 1.770 (resp 1.487) for 5 explanatory variables and 74 observations, 1.724 (resp. 1.414) for 4 variables and 55 observations, 1.768 (resp. 1.374) for 5 variables and 55 observations, 1.812 (resp. 0.927) for 4 variables and for 21 observations and 1.964 (resp. 0.829) for 5 variables and 21 observations. The corresponding numbers for the H_0 of a positive first-order autocorrelation of the residuals equals 2.188 (resp. 3.023) for 21 observations and 4 variables and 2.036 (resp. 3.171) for 21 observations and 5 variables. F(restr.) is the F-value of a test of the H_0 that the restricted model is false and the unrestricted model is true. — [b]The country sample corresponds to the "big sample" (98 countries) of Barro and Lee (1993). This sample excludes all small islands economies, the major oil exporters and the former socialist countries. — [c]All "big sample" countries minus OECD countries. — [d]The restrictions urge the sum of the implicit values of the production elasticities to equal unity (i.e., $\alpha+\beta+\gamma=1$). — [e]$(g+d) = 0.05$ is assumed.

Table 11 — Cross-Country OLS Estimation Results for the Transitional Version of a Solow–Swan Model Based on the Micro-version of Ψ_t [a]

	All countries[b]				All non-OECD countries[c]				OECD countries			
	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]
Const.	1.656	1.407	2.999	2.211	2.582	1.471	3.478	2.240	2.345	2.261	5.036	2.677
$p(b=0)$	0.213	0.025	0.029	0.002	0.300	0.120	0.158	0.029	0.122	0.022	0.000	0.006
$\ln(y_{1960})$	0.715	0.710	0.632	0.628	0.672	0.676	0.609	0.605	0.720	0.716	0.778	0.668
$p(b=0)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$p(b=1)$)	0.003	0.001	0.000	0.000	0.015	0.015	0.004	0.003	0.036	0.019	0.013	0.005
$\ln(n+g+d)$[e]	–1.044	–1.134	–0.775	–1.072	–0.909	–1.280	–0.737	–1.188	–0.518	–0.554	0.490	–0.555
$p(b=0)$	0.027	0.000	0.088	0.000	0.271	0.000	0.357	0.000	0.310	0.002	0.222	0.001
$\ln(s_K)$	0.949	0.926	0.777	0.816	1.086	1.052	0.295	0.915	0.499	0.489	0.641	0.458
$p(b=0)$	0.000	0.000	0.001	0.000	0.002	0.002	0.017	0.005	0.025	0.005	0.000	0.006
$\ln(s_h)$	0.214	0.207	0.254	0.256	0.258	0.228	0.889	0.273	0.064	0.065	0.028	0.096
$p(b=0)$	0.014	0.010	0.003	0.001	0.038	0.031	0.010	0.008	0.482	0.461	0.635	0.237
$\ln(\Psi)$			1.179	0.628			1.047	0.668			3.574	0.428
$p(b=0)$			0.009	0.000			0.065	0.002			0.000	0.022
α	0.215	0.204	0.322	0.258	0.265	0.202	0.347	0.249	0.351	0.339	–0.832	0.375
β	0.161	0.146	0.222	0.177	0.209	0.142	0.789	0.172	0.081	0.078	–0.106	0.109
γ	0.714	0.650	0.680	0.565	0.878	0.656	0.261	0.578	0.625	0.584	–2.400	0.517
$\alpha+\beta+\gamma=1$	1.089	1.000	1.224	1.000	1.352	1.000	1.397	1.000	1.056	1.000	–3.339	1.000
λ	0.015	0.014	0.023	0.018	0.020	0.015	0.026	0.019	0.020	0.020	–0.049	0.022
F(restr.)		0.046		0.972		0.239		0.407		0.006		8.684

Table 11 continued

	All countries[b]				All non-OECD countries[c]				OECD countries			
	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]
$p(F)$		0.831		0.385		0.628		0.669		0.940		0.004
$\overline{R}^2$	0.870	0.873	0.884	0.884	0.736	0.742	0.755	0.763	0.865	0.873	0.943	0.889
F	87.3	89.1	76.2	76.3	22.3	23.0	18.5	19.3	19.2	20.7	33.2	16.0
$p(F)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SEE	0.136	0.134	0.122	0.122	0.191	0.187	0.178	0.172	0.025	0.023	0.010	0.020
DW	1.900	1.895	1.807	1.839	1.645	1.626	1.642	1.622	2.053	2.045	2.461	2.029
Obs.	59	59	59	59	39	39	39	39	20	20	20	20

[a]Variables are defined in the text. $p(b=0)$ [$p(b=1)$] is the p-value of a t-test of the H_0 that the regression coefficient in the row above the p-value equals zero [one]. $p(F)$ is the p-value of the F-value in the row above the p-value. $\overline{R}^2$ is the adjusted R-squared value. SEE is the standard error of the regression. DW is the Durbin–Watson test of first-order serial correlation of the regression errors. (The sample is ranked according to the 1985 level of per capita GDP.) According to the Savin–White tables the upper (resp. the lower) bound for a rejection (resp. acceptance) of the H_0 of a negative first-order autocorrelation of the residuals are 1.739 (resp 1.515) for 4 explanatory variables and 74 observations, 1.770 (resp 1.487) for 5 explanatory variables and 74 observations, 1.724 (resp. 1.414) for 4 variables and 55 observations, 1.768 (resp. 1.374) for 5 variables and 55 observations, 1.812 (resp. 0.927) for 4 variables and for 21 observations and 1.964 (resp. 0.829) for 5 variables and 21 observations. The corresponding numbers for the H_0 of a positive first-order autocorrelation of the residuals equals 2.188 (resp. 3.023) for 21 observations and 4 variables and 2.036 (resp. 3.171) for 21 observations and 5 variables. F(restr.) is the F-value of a test of the H_0 that the restricted model is false and the unrestricted model is true. — [b]The country sample corresponds to the "big sample" (98 countries) of Barro and Lee (1993). This sample excludes all small islands economies, the major oil exporters and the former socialist countries. — [c]All "big sample" countries minus OECD countries. — [d]The restrictions urge the sum of the implicit values of the production elasticities to equal unity (i.e., $\alpha+\beta+\gamma=1$). — [e]$(g+d) = 0.05$ is assumed.

results are less reliable. It is notable that the significance of the regression coefficients generally is increased by imposing the restrictions.

The estimates of the model parameters α, β, γ, and λ are similar to those of the Mankiw et al. (1992) paper, although the values for γ are somewhat higher. The parameter estimates of the restricted regressions can be used to compute the quantitative impact of the import restrictions on capital goods on growth performance. The following GDP component shares are computed based on the parameter estimates for the restricted regression of the microversion of Ψ_0:

[C.18]

$$\boxed{\text{Steady-state component}} = \left(\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) - e^{-\lambda t} \ln\left(\frac{Y_{i,0}}{L_{i,0}}\right) \right) \Big/ \ln\left(\frac{Y_{i,t}}{L_{i,t}}\right)$$

$$\boxed{\text{TFP component}} = (\omega g \vartheta t) \Big/ \left(\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) - e^{-\lambda t} \ln\left(\frac{Y_{i,0}}{L_{i,0}}\right) \right)$$

$$\boxed{\text{Physical capital}} = \left(\omega \frac{\gamma}{\alpha} \ln\left(s_{i,k} / (g + d + n_i)\right) \right) \Big/ \left(\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) - e^{-\lambda t} \ln\left(\frac{Y_{i,0}}{L_{i,0}}\right) \right)$$

$$\boxed{\text{Human capital}} = \left(\omega \frac{\beta}{\alpha} \ln\left(s_{i,h} / (g + d + n_i)\right) \right) \Big/ \left(\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) - e^{-\lambda t} \ln\left(\frac{Y_{i,0}}{L_{i,0}}\right) \right)$$

$$\boxed{\text{Import-tariff component}} = \left(\omega \frac{1-\gamma}{\alpha} \ln\left(\Psi_{i,0}\right) \right) \Big/ \left(\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) - e^{-\lambda t} \ln\left(\frac{Y_{i,0}}{L_{i,0}}\right) \right)$$

For each of the three country groups the cross-section average of the explanatory variables are used to determine the country-group average estimate of 1985 per capita GDP and its components. Following the definitions of [C.18], the steady-state component equals the share of GDP that is not determined by the base year per capita GDP but by the steady-state variables inclusive total factor productivity growth. As Figure 28 shows this share equals about 40 percent of the estimate of 1985 per capita GDP. Consequently, the largest part of 1985 GDP, namely 60 percent, is explained by the base-year per capita GDP of 1960. In order to adjust the estimates for the base-year effect, the definitions of the other GDP components refer to the 1985 GDP estimate minus the base-year component.[173]

[173] Consequently, the import-tariff component, the physical-capital component, the human-capital component and the TFP component sum up to unity.

Figure 28 — Estimates of the 1985 GDP Components Based on the Average Actual Capital Goods Import Tariff

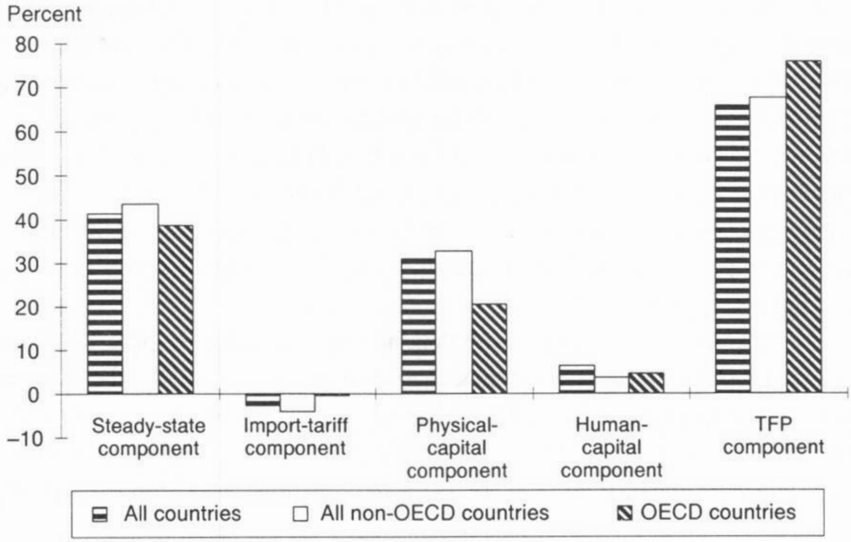


Figure 28 shows that the largest component is the TFP component. It reaches about 76 percent for the OECD countries and about 65 percent for the non-OECD countries. Thus, the largest part of the change of per capita GDP from 1960 to 1985 is "explained" by total factor productivity growth, i.e., the regression constant, $\omega g \vartheta t$. The physical capital component ranges around 20 percent for OECD countries and 33 percent for non-OECD countries. Hence, compared to non-OECD countries, the accumulation of physical capital seems to be less important for OECD countries, while TFP growth seems to be more important.

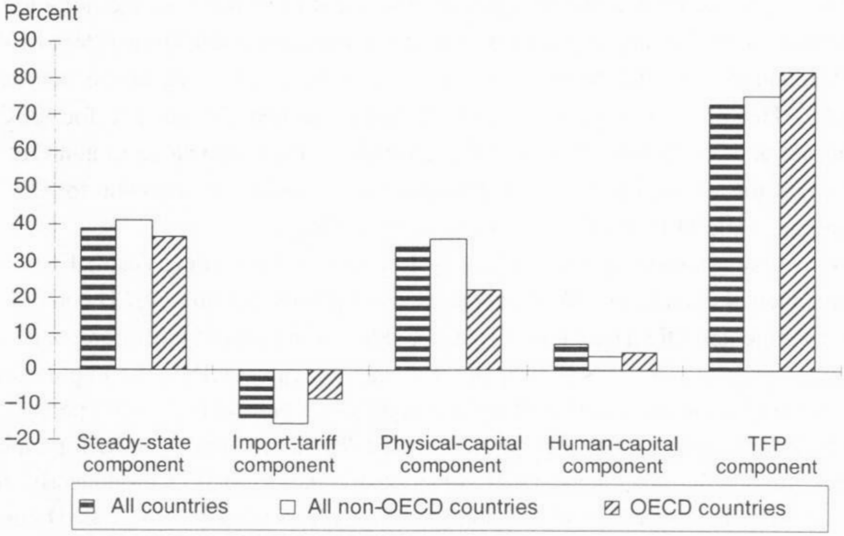
Somehow astonishing is the relatively low value of the human capital components (about 4 percent for OECD countries and 3 percent for non-OECD countries). The average non-OECD country displays a value of the import tariff component of about –4 percent (i.e., –1.8 percent of 1985 total per capita GDP); the import-tariff component for the average OECD country equals –0.7 percent (i.e., –0.02 percent of 1985 total per capita GDP). By construction of Ψ_0, a zero import tariff for capital goods implies that the import-tariff component equals zero.[174] Consequently, the average import tariff of the three country groups (22 percent for non-OECD countries, 4 percent for OECD countries) induces a relatively small negative impact on

174 For positive nonzero tariffs the log of Ψ_0 is negative; for zero tariffs the log of Ψ_0 equals zero.

the level of 1985 per capita GDP. Nevertheless, for non-OECD countries the absolute value of the import tariff component is larger than the human-capital component. Inserting a hypothetical import tariff of 100 percent for all country groups shows that high import tariffs on capital goods can potentially have a significant negative impact. In this case, the import-tariff component equals about –9 percent (i.e., –3.5 percent of total per capita GDP) for OECD countries, and –17 percent (i.e., –7.5 percent of total per capita GDP) for non-OECD countries (Figure 29). Hence, following these estimates, especially countries of the non-OECD country group, i.e., developing countries with high import tariffs on capital goods can significantly increase their per capita GDP by reducing the tariffs on capital goods (see Table A.11.3 in the Appendix).[175]

Taken together, the results indicate that the import tariffs on capital goods have explanatory power for the development of real per capita GDP. The estimated quantitative impact of import tariffs on capital goods is, however, not very strong. This relatively small magnitude of the import tariff effect is in line with an estimation of Lee (1993), who finds over the 1965–1985 period that a distortionary trade

Figure 29 — Estimates of 1985 GDP Components Based on a Hypothetical 100 Percent Capital Goods Import Tariff



[175] Following Table A.11.3 in the Appendix four countries have capital goods import tariffs above 40 percent: Burkina Faso (48.2 percent), Paraguay (46.3 percent), Peru (40.9) and Bangladesh (40.9 percent).

regime, as measured by an interaction term based on import tariffs, black market premia and an estimated free trade import share, lowers the annual growth rate of an average developing country by only 1.4 percent of the magnitude of the growth rate (Lee 1993: 325). All in all, the estimates presented here suggest that for OECD countries as well as for non-OECD countries the most important component in GDP growth is total factor productivity growth.

However, it is argued here that these results do not imply that trade with capital goods has only a minor impact on real per capita GDP growth. As the discussion of the Solow–Swan model with differentiated capital goods has shown, import tariffs on capital goods reduce the transitional growth rate. As long as import restrictions on capital goods are not prohibitive, total factor productivity growth, although essentially dependent on capital goods imports, is not necessarily affected by import tariffs. Intuitively spoken, this is due to the fact that (nonprohibitive) import restrictions, although lowering the quantity of foreign capital goods imported per period, do not prevent imports of new capital goods. New capital goods, however, incorporate new technological knowledge produced abroad, and therefore increase total factor productivity. Consequently, if import restrictions on capital goods lower the level of total factor productivity by the same factor as the per period increase of total factor productivity, the growth rate of total factor productivity (i.e., the per period increase of total factor productivity divided by the level of total factor productivity) is not affected by import tariffs on capital goods.

As it turns out, import restrictions on capital goods lower the level of total factor productivity by the same factor as the per period increase of total factor productivity only if either the growth rate of domestic and foreign technological knowledge is identical, i.e., $\dot{A}_D / A_D = \dot{A}_F / A_F$, or if the domestic stock of technological knowledge does not grow, i.e., $\dot{A}_D = 0$. To see this within the framework of the above model, consider the formula of total factor productivity, following from [C.10]:

$$[C.19] \quad TFP_t = Y_t \Big/ \left(L_t^{\alpha} \; H_t^{\beta} \; K_t^{\gamma} \right) = \left(A_{D,t} + A_{F,t} \left(1+\tau\right)^{\frac{-\gamma}{1-\gamma}} \right)^{1-\gamma} .$$

Following this formula, import tariffs on capital goods, τ, negatively affect the level of total factor productivity. Deriving from [C.19] the formula for total factor productivity growth and taking from this formula the first derivation with respect to the import tariff for capital goods, τ, yields the following formula:[176]

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176 For derivation see Appendix 11.

$$\text{[C.20]} \quad \frac{\delta\left(T\dot{F}P/TFP\right)}{\delta\tau} = \frac{(1+\tau)^{1-\gamma}\left(A_{D,t}\,A_{F,t}\left(\frac{\dot{A}_{D,t}}{A_{D,t}}-\frac{\dot{A}_{F,t}}{A_{F,t}}\right)\right)}{\left(A_{D,t}+A_{F,t}\,(1+\tau)^{\frac{-\gamma}{1-\gamma}}\right)^{2}}.$$

Obviously, there are two cases where total factor productivity growth is not affected by capital goods import tariffs. The first case emerges, if the domestic and foreign stock of technological knowledge grow with the same rate, i.e., $\dot{A}_D/A_D=\dot{A}_F/A_F$. The second emerges, if no domestic research and development is performed such that $A_D=0$. In both cases the right-hand side of [C.20] equals zero.[177]

As Figure 23 reveals, most research and development activities are concentrated on a small group of developed countries such that $A_D\approx 0$ approximately holds for most developing countries. On the other hand, countries performing research and development, i.e., primarily the group of OECD countries, are likely to be on average equally successful in relation to their absolute effort such that for these countries the domestic growth rate of the stock of technological knowledge should be approximately equal to the foreign growth rate such that $\dot{A}_D/A_D\approx\dot{A}_F/A_F$ holds.

Consequently, as most countries belong to one of both groups (i.e., developing countries with $A_D\approx 0$ and developed countries with $\dot{A}_D/A_D\approx\dot{A}_F/A_F$), there is good reason to believe that the estimated effect of capital goods import tariffs, presented in Tables 10 and 11, does not account for the total effect of foreign capital goods imports on total factor productivity growth. Thus, the estimated effect of import tariffs on capital goods are likely to underestimate the total effect of capital goods imports on economic growth.[178] Therefore, in order to estimate the effect of foreign capital goods imports on total factor productivity growth, the next chapter uses an estimation procedure that directly measures the effect of trade with capital goods on total factor productivity growth.

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177 This corresponds to the assumptions made for the derivation of the estimation equation [C.14].

178 Remember that, although the estimation equation [C.14] is based on the level version of the solution of the modified Solow–Swan model, the estimation results for the single steady-state components (i.e., import-tariff component, physical-capital component, human-capital component and TFP component), as presented in Figure 28, refer to the change of the level of per capita GDP from the base year 1960 to the final year 1985. Consequently, the import-tariff component measures only the effect of the import tariff on the total per capita GDP growth from the base year 1960 to the final year 1985. The effect of the import tariff on the level of per capita GDP in the base year 1960 is not measured by the import-tariff component.

2. The Impact of International Trade with Capital Goods on Total Factor Productivity

Abstract: This chapter empirically analyzes the impact of international trade with capital goods on the development of total factor productivity. The basic finding is that trade with capital goods (primarily, imports of electrical and nonelectrical machinery plus transport equipment) seems to be closer related to the development of total factor productivity than total trade with goods and services. This suggests that, corresponding to models of economic growth through R&D, trade with capital goods is an important transmission channel of embodied new technological knowledge. The countries with the largest impact of domestic R&D activities on total factor productivity of foreign countries are the United States, Japan and Germany: a one-percent increase of R&D expenditures in the United States (Japan, Germany) induces an average increase of total factor productivity in foreign countries by 0.71 percent (0.80 percent, 0.70 percent).

a. Theoretical Framework and Empirical Implementation

According to the type of Solow–Swan model, derived in the preceding chapter, total factor productivity depends on the set of available differentiated capital goods. Following [C.10] in a market equilibrium, the relation between total factor productivity and the set of domestic and foreign capital goods is given by the following equation:[179]

$$[C.21] \quad TFP_t = Y_t \Big/ \left(L_t^{\alpha} \; H_t^{\beta} \; K_t^{\gamma} \right) = \left(A_{D,t} + A_{F,t} \left(1+\tau\right)^{\frac{-\gamma}{1-\gamma}} \right)^{1-\gamma} .$$

In order to derive a simple linear regression equation, the assumption was made that the sets of domestic and foreign differentiated capital goods, i.e., $A_{D,t}$ and $A_{F,t}$ grow with the same exogenous rate, g. In the following this assumption is dropped. In models of endogenous growth, the set of differentiated capital goods is proportional to the accumulated investments in research and development (see Appendix 4, [A.4.19]). Therefore, following Coe and Helpman (1995), the following empirical implementation of [C.21] is chosen:[180]

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179 See [C.9] for the notation.

180 Coe and Helpman (1995) show that [C.22] can be interpreted as an empirical implementation of the relation between total factor productivity and research and development investments for a model of horizontal as well as vertical product differentiation.

[C.22] $\ln(TFP_{i,t}) = a_i + b_1 \ln(A_{F,i,t}) + b_2 \ln(A_{D,i,t})$.

Coe and Helpman (1995) proxy $A_{D,i,t}$ by the stock of accumulated domestic real investments in research and development in country *i*. This is based on the idea that new technological knowledge is a positive function of R&D expenditures. Similarly, the proxy for $A_{F,i,t}$ equals the stocks of accumulated investments in research and development of the trade partners of country *i*, weighted by their share in total imports of country *i*. As the shares of the weights used for the construction of the proxy for $A_{F,i,t}$ add up to unity, this proxy does not reflect the possibility that total factor productivity grows, if a country increases its foreign imports. Therefore, Coe and Helpman (1995) compute the interaction term between the proxy for $A_{F,i,t}$ and the import quota $m_{i,t}$.[181]

Coe and Helpman (1995) use total imports of goods and services for the construction of the proxy for $A_{F,i,t}$ and the import quota, $m_{i,t}$. However, following the assumptions of endogenous growth models (and the above version of the Solow–Swan model as well), capital goods play the major role in the transmission of foreign technological progress. Thus, if this assumption correctly describes the actual transmission channel of technological progress, the estimates of Coe and Helpman (1995) should be improved using imports of capital goods instead of total imports of goods and services. Therefore, the following analysis compares the estimates using total imports of goods and services with the estimates using imports of various aggregates of capital goods.

b. Data and Estimation Procedure

[C.22] is estimated using the data of 16 and 22 OECD countries over the 1970–1990 period. The data on total factor productivity[182] and R&D capital stocks[183] are taken

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181 Within the framework of [C.21], $m_{i,t}$ can be interpreted as a rough measure of the openness of country *i*, $(1+\tau)^{-\gamma/(1-\gamma)}$.

182 Total factor productivity is computed based on the Cobb–Douglas function $TFP = Y_t / (K^{\beta} L^{1-\beta})$, where Y_t is value added in the business sector, K_t is the stock of business sector capital and L_t is employment in the business sector. The coefficient β is the average share of capital income from 1987–1989. Y_t, K_t and L_t are taken from the OECD Analytical Data Base in Coe and Helpman (1995). For a detailed description, see the Appendix in Coe and Helpman (1995).

183 The real R&D capital stock of a country is estimated by Coe and Helpman (1995) in the following way: a weighted average of the deflator for business sector output and an index of average business sector wages is used to deflate nominal R&D expenditures yield-

Table 12 — Levin–Lin Panel Data Unit Root Tests for all Variables[a]

Variables[b]	Adjusted t-value[c]	Adjusted t-value[c]
TFP	6.01*	1.34*
SDOM	1.20*	–1.984*
SFOR(g&s)	7.92*	3.76*
SFOR(m)	16.33*	
SFOR(m+c)	24.40*	
SFOR(m–t)	31.26*	
SFOR(m+c–t)	23.84*	
SFOR(manuf–m)	26.87*	
IMP(g&s)	4.77*	16.45*
IMP(m)	3.52*	
IMP(m+c)	4.00*	
IMP(m–t)	5.83*	
IMP(m–t+c)	4.89*	
IMP(manuf–m)	8.01*	
SFORIMP(g&s)	4.61*	3.95*
SFORIMP(m)	27.27*	
SFORIMP(m+c)	30.45*	
SFORIMP(m–t)	20.18*	
SFORIMP(m–t+c)	22.90*	
SFORIMP(manuf–m)	32.05*	

[a]An * indicates that the null hypothesis of non–stationarity cannot be rejected at a 5 percent significance level. In the case of *SDOM* the p-value reached is slightly below 5 percent (i.e., 4.792). — [b]The variables are defined as follows: TFP=log of total factor productivity of the business sector; SDOM=log of domestic real R&D capital stock. *SFOR(g&s)*=log of the sum of the real R&D capital stocks of the other countries weighted by the bilateral import share of goods and services in GDP. *SFOR(x)*=log of the sum of the real R&D capital stocks of the other countries weighted by the share of bilateral industry x imports in gross domestic production of industry x. *IMP(g&s)*=log of the total import share of goods and services in GDP. *IMP(x)*= the share of total industry x imports in gross domestic production of industry x. *SFORIMP(g&s)*=log of the sum of the real R&D capital stocks of the other countries weighted by the bilateral import share of goods and services in GDP times the share of total import of goods and services in GDP. *SFORIMP(x)*=log of the sum of the real R&D capital stocks of the other countries weighted by the share of bilateral industry x imports in gross domestic production of industry x times the share of total industry x imports in gross domestic production of industry x. x corresponds to: electrical and nonelectrical machinery plus transport equipment (m), electrical and nonelectrical machinery plus transport equipment plus industrial chemicals (m+c), electrical and nonelectrical machinery (m–t), electrical and nonelectrical machinery plus industrial chemicals (m+c–t), industrial chemicals (c) and total manufacturing minus m (*manuf–m*). — [c]Adjusted ADF is the adjusted augmented Dickey–Fuller t-test statistic of the Levin–Lin panel data unit root test. The country-specific lag is chosen according to the Hall (1990) selection procedure.

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ing real R&D expenditures, R_t. Based on these deflated values, the real R&D capital stock, S_t, is computed using the perpetual inventory model, $S_t = (1-\delta)S_{t-1} + R_{t-1}$. The depreciation rate δ was assumed to be 0.05. Experimental regressions with $\delta = 0$ and $\delta = 0.1$ yielded similar results. The depreciation rate δ captures the idea that the emergence of new knowledge may substitute old knowledge. For a detailed description of the construction of the real R&D capital stock see the Appendix in Coe and Helpman (1995).

from Coe and Helpman (1995). The data on import shares of goods and services are taken from the World Bank (1994). The data on import shares of capital goods of various subaggregates are taken from OECD (1994a, 1994b). To select the appropriate estimation procedure for [C.22], an analysis of the time series behavior of the data is necessary. To check for potential nonstationarity, a Levin–Lin panel data unit root test (Levin and Lin 1993) is used. Table 12 presents the results.[184] The first column gives the results for the 16 OECD countries, where data on import shares of capital goods (OECD 1994b) are available, the second column gives the results for the 22 OECD countries of the original estimation in Coe and Helpman (1995).[185]

c. *Estimation Results*

Following Coe and Helpman (1995), [C.22] was first estimated on the basis of a simple Engle–Granger cointegration regression (Engle and Granger 1987).[186] The Bhargava–Franzini–Narendranathan panel data Durbin–Watson test statistic (BFN–DW) indicates a strong positive first-degree autocorrelation of the residuals.[187] Since in the presence of autocorrelated residuals the variance of the OLS estimator is inflated, a simple cointegration regression does not provide reliable significance values. Therefore, contrary to Coe and Helpman (1995), the error correction model (ECM) version of [C.22] is estimated. An ECM is able to eliminate autocorrelation in the residuals by an appropriate lag structure. Written as an ECM [C.22] equals:

$$
\text{[C.23]}\quad \mathrm{d}\ln(TFP_{i,t}) = a_i + b_0 \ln(TFP_{i,t}) + b_1 \ln\left(A_{D,i,t-1}\right) + b_2 \ln\left(A_{F,i,t-1}\right) - \sum_{j}^{p-1} b_3 \,\mathrm{d}\ln(TFP_{i,t}) - \sum_{j}^{q-1} b_4 \,\mathrm{d}\ln\left(A_{D,i,t-j}\right) - \sum_{j}^{r-1} b_5 \,\mathrm{d}\ln\left(A_{F,i,t-j}\right) + u_t .
$$

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184 The estimated t-values differ numerically more or less from those of Coe and Helpman (1995). This is due to the fact that Coe and Helpman use an earlier version of the Levin–Lin panel data unit root test.

185 The 16 OECD countries of the first set are Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, United Kingdom and the United States. The second set is the countries of the first set plus Austria, Belgium, Greece, Ireland, Israel, and Switzerland.

186 Column (1) in Table 13 is equivalent to equation (4) in Coe and Helpman (1995).

187 The critical value for a rejection of the null hypothesis of positive first-degree autocorrelation at the five percent significance level is BFN–DW < 1.842 for three explanatory variables.

Column (2) in Table 13 presents the results of an estimation of [C.23] for $p=q=r=2$.[188] The coefficients in Table 13 are the coefficients of the steady-state equilibrium relation between the variables. They are computed based on the estimated regression coefficients of [C.23]. The standard errors and the *p*-values of the steady-state coefficients are taken from an estimation of the Bewley transformation of [C.23].[189] The BFN-DW statistic does now reject a test of the null hypothesis of first-degree autocorrelation.[190] The Levin–Lin panel data unit root test statistic (adj-ADF) indicates that the estimated steady-state linear combination of the variables is stationary.[191]

Table 13 — Pooled Panel Cointegrating Regressions for 22 OECD Countries[a]

	(1)	(2)
SFORIMP(g&s)	0.084	0.058
p-value	0.000	0.314
SDOM	0.042	0.059
p-value	0.000	0.046
*SDOM*G7*[b]	0.170	0.167
p-value	0.000	0.019
adj ADF[c]	–4.904	–6.800
p-value(ADF)	0.000	0.000
BFN-DW	0.552	1.887
adj R^2	0.576	0.084
SEE	0.003	0.001
Obs.	396	396

[a]The dependent variable is the log of total factor productivity. For each country a dummy is introduced. In most cases this dummy is significant. — [b]G7 is a dummy that equals 1, if a country belongs to the group of G7 countries, and zero otherwise. This allows the regression coefficient of *SDOM* to diverge for the G7 countries from the estimate for the other countries. If the coefficient of *SDOM* is urged to be identical for all countries, the estimate is typically not significant. — [c]Adjusted ADF is the adjusted augmented Dickey–Fuller *t*-test statistic of the Levin–Lin panel data unit root test. The country-specific lag is chosen according to the Hall selection procedure (Hall 1990). For the ECM (Column (2)) the test is executed for the estimated linear combination of the integrated variables (see Footnote 192).

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188 The lag structure of the ECM was chosen such that the BFN–DW statistic approaches 2 as close as possible.

189 For each country a dummy, which allows for country-specific fixed effects, was introduced in the regression. In most cases this dummy is significant.

190 The critical value for a rejection of the null hypothesis of positive first-degree autocorrelation at the five-percent significance level is BFN–DW > 1.877 for five explanatory variables.

191 The steady-state linear combination of the integrated variables equals

$$w_{D,t} = -b_0\left(\ln(TFP_{D,t}) - \frac{b_1}{-b_0}\ln(A_{D,t}) - \frac{b_1}{b_0}\ln(A_{F,t}) \right).$$

Contrary to the results of Coe and Helpman (1995), the steady-state value of the foreign research and development activities on domestic total factor productivity growth is not significant at the five percent level.[192] Since the theory, however, predicts that foreign technological knowledge is primarily transferred to the domestic economy via capital goods imports, the bad performance of the proxy for the foreign R&D capital stock may be due to the usage of the "wrong" imports. This is analyzed in the following.

Table 14 presents the results of an estimation of the ECM version of [C.23] based on those OECD countries, where data on bilateral capital goods imports are available.[193] Six types of import shares are used to construct the proxy for the foreign R&D capital stock:[194] the share of total imports of goods and services in GDP $(g+s)$

Table 14 — Pooled Panel Cointegrating Regressions for 16 OECD Countries[a]

	(1)	(2)	(3)	(4)	(5)	(6)
	$g+s$	mf	$m+c$	m	$m-t+c$	$m-t$
SFORIMP(x)	0.010	0.094	0.179	0.164	0.147	0.147
p-value	0.896	0.299	0.027	0.034	0.103	0.087
SDOM	0.062	0.051	0.044	0.043	0.047	0.044
p-value	0.149	0.235	0.242	0.260	0.244	0.266
*SDOM*G7*	0.186	0.156	0.126	0.135	0.133	0.138
p-value	0.032	0.065	0.083	0.063	0.092	0.072
adj ADF	–6.973	–6.904	–6.857	–6.862	–6.882	–6.876
p-value(ADF)	0.000	0.000	0.000	0.000	0.000	0.000
BFN–DW	1.869	1.856	1.839	1.845	1.848	1.851
adj R^2	0.092	0.093	0.110	0.113	0.101	0.112
SEE	0.001	0.001	0.001	0.001	0.001	0.001
Obs.	288	288	288	288	288	288

[a]For the definition of the variables see the footnotes in Table 12. — [b]Adjusted ADF is the adjusted augmented Dickey–Fuller t-test statistic of the Levin–Lin panel data unit root test. The country-specific lag is chosen according to the Hall selection procedure (Hall 1990). The test is executed for the residuum of the steady-state relation of the variables.

192 In the estimations shown in Table 13 the specification of the domestic stock of R&D capital is modified compared to [C.23]: since the domestic stock of R&D capital exhibits no significant regression coefficient for all countries, the effect of the domestic stock of R&D capital in the G7 countries only is measured by the *SDOM*G7* variable (for a definition, see the footnotes in Table 12).

193 A simple Engle–Granger OLS cointegration regression yielded, once again, residuals where the hypothesis of absence of first-degree autocorrelation was strongly rejected. (The BF–DW test statistics reached values around 0.3.)

194 The construction of the proxy for the weighted foreign R&D capital stock is described in Footnote b in Table 12.

and the share of industry x imports in gross domestic production of industry x, where x corresponds to: electrical and nonelectrical machinery plus transport equipment (m), electrical and nonelectrical machinery plus transport equipment plus industrial chemicals $(m+c)$, electrical and nonelectrical machinery $(m-t)$, electrical and nonelectrical machinery plus industrial chemicals $(m+c-t)$, industrial chemicals (c) and total manufacturing minus m ($manuf - m = mf$).

The Levin–Lin panel data unit root test statistics (adj ADF) in Table 14 indicate that the estimated steady-state linear combinations of all sets of variables are stationary.[195] The BFN–DW test statistics lie in all cases in the indeterminate range, i.e., they do reject neither the hypothesis of absence of first-degree autocorrelation nor the hypothesis of existence of first-degree autocorrelation.[196] This implies that the following conclusions, as far as they concern the significance of regression coefficients, have to be interpreted with some reservation.[197]

Table 14 shows that only the foreign capital stock weighted by the shares of imports of electrical machinery, nonelectrical machinery, transport equipment and industrial chemicals as well as the same share without industrial chemicals $(m+c \text{ and } m)$ has a significant coefficient (at the five percent level). To the contrary, the foreign R&D capital stock weighted by the share of total imports of goods and services in GDP $(g+s)$ as well as the foreign R&D capital stock weighted by the share of manufacturing imports minus $m\,(mf)$ does not have a significant regression coefficient, even at the ten percent level. It is interesting to note that excluding transport equipment $(m-t+c)$ reduces the magnitude of the coefficient and also the level of significance. This indicates that transport equipment plays an important role.

Following these results, electrical machinery, nonelectrical machinery, transport equipment and industrial chemicals play the dominant role in increasing domestic total factor productivity through the transmission of foreign technological knowledge. This result corresponds to the fact that most R&D activities of OECD countries are belong to these industries. As Figure 30 shows, together they hold a

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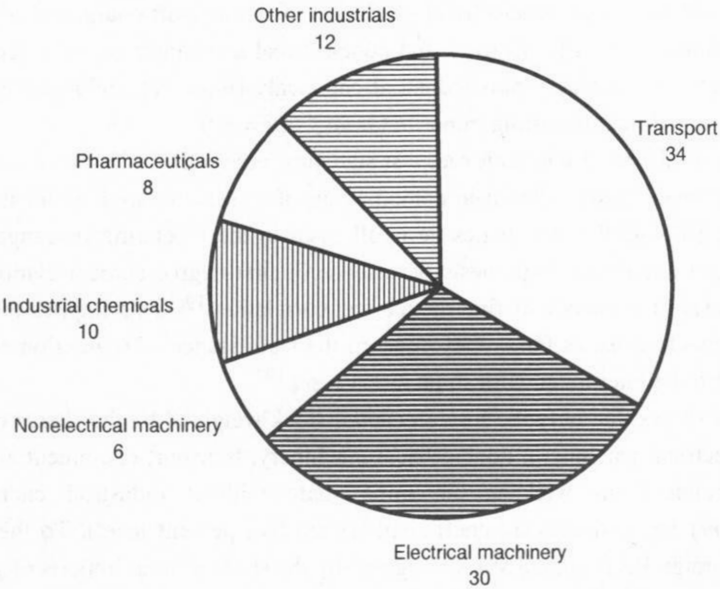
195 See Footnote 191 for the definition of the steady-state linear combination.

196 The lag structure of the ECM was chosen such that the BFN–DW statistic approaches 2 as close as possible. The critical value for a rejection of the null hypothesis of absence of first-degree positive autocorrelation for nine explanatory variables of the BFN–DW test statistic is 1.816, the critical value for a rejection of the null hypothesis of existence of first-degree positive autocorrelation is 1,894 (Bhargawa and Sargan 1983).

197 A simple Engle–Granger cointegration regression yielded BFN–DW statistics that strongly rejected the null hypothesis of absence of first-degree autocorrelation (with

Figure 30 — Industry Shares in Total R&D Expenditures of the Eight Largest OECD Countries, 1980–1990 Averages (percent)[a]



[a]United States, Japan, Germany, France, Italy, United Kingdom, Canada, Sweden. National R&D expenditures converted using PPP-US-dollars.

Source: OECD (1994b).

share in total OECD-R&D expenditures of 80 percent. Consequently, according to the predictions of the theory capital goods seem to play the dominant role in transmitting foreign technological knowledge to the domestic economy.

Another characteristic feature of the results in Table 14 is the low level of significance for the domestic R&D capital stock over all countries, i.e., *DOM*. It is interesting to note that the domestic R&D capital stock over the countries of the G7 group, i.e., *DOM*G7*, is significant (at least at the 10 percent level). Figure 31 suggests a simple explanation for this finding: 92 percent of all OECD R&D expenditures belong to the countries of the G7 group. Consequently, if R&D activities give rise to new technological knowledge, which increases total factor productivity, it is to be supposed that the group of G7 countries has the predominant impact on total factor productivity in countries with a low level of own R&D activities. Hence, in

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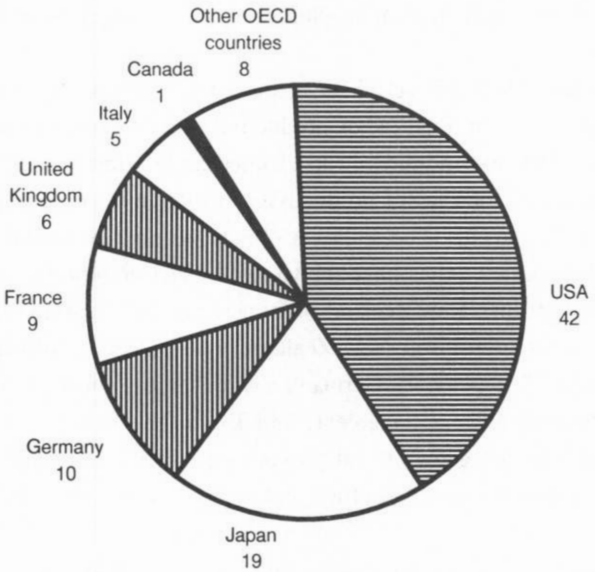
BFN–DW values around 0.3). Consequently, the ECM estimation of [C.23.] seems to eliminate a great part of the autocorrelation in the residuals.

Figure 31 — National Shares in Total OECD R&D Expenditures, 1980–1990 Averages (percent)[a]



[a]National R&D expenditures converted using PPP-US-dollars.

Source: OECD (1994b).

those countries the development of the foreign R&D capital stock displays a stronger impact on domestic total factor productivity than the development of the domestic R&D capital stock.

d. The Quantitative Impact of the R&D Activities of G7 Countries

Given this importance of R&D activities in G7 countries, it is interesting to estimate their quantitative impact. Following [C.24] the elasticity of total factor productivity of country i with respect to a one-percent increase of R&D expenditures in country j is given by the following formula:

$$[\text{C.24}] \quad \varepsilon\left(TFP_{i,t};S^{D}_{j,t}\right)=\frac{\delta\ln\left(TFP_{i,t}\right)}{\delta\ln\left(S^{D}_{j,t}\right)}=b_2\ imp(x)_{i,t}\ \frac{m(x)^{j}_{i,t}}{\sum\limits_{j} S^{D}_{j,t}\ m(x)^{j}_{i,t}},$$

where b_2 is the estimated coefficient of the foreign stock of technological knowledge, $imp(x)_{i,t}$ is the import quota of industry x in country i, $m(x)^{j}_{i,t}$ is the share of imports from country j to country i in industry x total imports of country i, and $S^D_{j,t}$ is the R&D capital stock of country j. Table 15 presents the results of the elasticity estimates based on column (3) in Table 14, i.e., $b_2 = 0.179$ and industry x equals electrical machinery, nonelectrical machinery, transport equipment and industrial chemicals.

Following Table 15, R&D activities in the United States, Japan and Germany have the largest impact on total factor productivity in foreign countries: a one-percent increase of R&D expenditures in the United States (Japan, Germany) induces an average increase of total factor productivity in foreign countries by 0.71 percent (0.80 percent, 0.70 percent). The spillover effects from other countries are significantly lower. The United States have the largest impact on total factor productivity in Canada (4.45 percent), New Zealand (4.59 percent) and Australia (3.37 percent). Japan has the largest impact on New Zealand (4.86 percent), Australia (3.25 percent) and Portugal (1.63 percent). Germany has the largest impact on Portugal (4.88 percent), the Netherlands (4.57 percent) and Denmark (3.11 percent). Taken together, this suggests that geographical proximity plays a certain role as a determinant of the strength of the spillover effect, but this role seems not to be predominant.

Table 15 — Estimates of the Elasticities of Total Factor Productivity with Respect to R&D Capital Stocks in the G7 Countries, 1990[a]

to \ from	United States	Japan	Germany	France	Italy	UK	Canada	Average
USA		1.11	0.27	0.10	0.06	0.14	0.62	0.33
Japan	0.29		0.12	0.02	0.02	0.02	0.00	0.07
Germany	0.39	0.51		0.54	0.29	0.31	0.02	0.29
France	0.82	0.51	1.40		0.68	0.47	0.02	0.56
Italy	0.29	0.21	1.38	0.70		0.29	0.02	0.41
UK	0.93	0.74	1.54	0.62	0.37		0.06	0.61
Canada	4.66	1.30	0.41	0.19	0.10	0.19		1.55
Australia	3.37	3.25	0.88	0.19	0.25	0.64	0.16	1.25
Denmark	1.32	1.21	3.11	0.60	0.56	1.09	0.02	1.13
Finland	1.13	1.32	2.18	0.49	0.49	0.64	0.08	0.90
Netherlands	1.75	1.21	4.57	1.17	0.58	1.65	0.14	1.58
New Zealand	4.59	4.86	1.05	0.31	0.45	1.38	0.21	1.84
Norway	2.08	1.09	2.41	0.51	0.35	1.15	0.08	1.10
Portugal	0.72	1.63	4.88	3.58	3.64	2.51	0.04	2.43
Spain	0.97	0.78	2.14	1.44	1.15	0.66	0.02	1.02
Sweden	1.13	0.76	1.95	0.41	0.35	0.56	0.04	0.74
Weighted SUM[b]	0.71	0.80	0.70	0.29	0.21	0.25	0.27	0.46

[a]Example: a one-percent increase of German R&D expenditures induces a 1.40 percent increase of total factor productivity in France. — [b]The weights correspond to the share of the recipient countries' GDP in the sum of all countries GDP measured in PPP-US-dollars.

Altogether, the results indicate that there are indeed significant and quantitatively important effects of foreign trade on total factor productivity. However, different to the findings of Coe and Helpman (1995), the results suggest that it is not total trade with goods and services but trade with capital goods that plays the major role in the transmission of foreign technological progress. This is in line with theories of endogenous growth which suggest that new technological knowledge, generated by R&D activities, is incorporated in capital goods. The results also suggest that an important transmission channel of trade with capital goods on per capita growth runs over the impact of capital goods imports on total factor productivity.

D. Conclusions: The Role of International Trade with Capital Goods in Economic Development

The results of this study indicate that international trade with capital goods plays an important role in economic development. The empirical evidence suggests that there is a significant negative effect of import tariffs on the process of capital accumulation (Tables 10 and 11). Import tariffs on foreign capital goods increase the domestic relative price of capital goods (Table 8). This has two implications for capital accumulation: *First,* a higher relative price of capital goods lowers *real* investment. Consequently, the accumulated stock of real physical capital is reduced by import tariffs on capital goods. *Second,* a higher relative price of capital goods lowers the amount of foreign capital goods in domestic real investment (Table 9). If foreign capital goods embody technological knowledge, which is not contained in domestic capital goods, this lowers the efficiency of the composition of the domestic capital stock. Consequently, import tariffs on capital goods lower both the real quantity and the efficiency of the domestic capital stock. This lowers the steady-state level of per capita GDP and the growth rate of per capita GDP in transition to the steady state. The estimates suggest that there is a significant negative effect of capital goods import tariffs on the development of real per capita GDP.

However, the effect of import tariffs on capita accumulation is only part of the total effect of capital goods imports on economic growth. Import tariffs primarily have a level effect on total factor productivity, but have only a second-order effect on the growth rate of total factor productivity. Therefore, in order to estimate the effect of foreign capital goods imports on total factor productivity growth, an estimation procedure is used that directly measures the effect of trade with capital goods on total factor productivity growth. The results of this estimation suggest that capital goods imports affect domestic total factor productivity, because capital goods transmit technological progress from abroad. For example, via capital goods imports, a one-percent increase of research and development expenditures in the United States (Japan, Germany) induces an average increase of total factor productivity for a set of 16 OECD countries by 0.71 percent (0.80 percent, 0.70 percent).

Following these results, the capacity of countries to import foreign capital goods can be an important positive factor for economic development. Although the analysis of capital goods imports on total factor productivity was confined to OECD countries only, it is obvious that this holds a fortiori for developing countries. This is due to the fact that, over the last decades, developed market economies account for more than 80 percent of total world expenditures on research and development (Figure 23). North America and the European Union alone reach a share of about 65 percent. Similarly, over 80 percent of capital goods world production is concentrated on the group of developed market economies (Figure 22). Within this group the European Union, the United States and Japan hold a major share of about 75 percent. Consequently, research and development activities as well as the production of capital goods is highly concentrated on a small group of developed countries. Accordingly, most developing countries, due to a missing domestic production base, heavily rely on capital imports from a small group of developed countries. This is also reflected in Figure 24 indicating that nearly 80 percent of domestic capital goods absorption in developing countries stems from capital goods imports, while the corresponding number for developed countries ranges around 20 percent.

Taken together, these stylized facts imply that developing countries, which are able to import capital goods, can significantly benefit from technological progress made abroad. Consequently, foreign trade regimes that allow for imports of capital goods favor the inflow of foreign technological progress. This is to say that, on the one hand, trade regimes which restrict imports of capital goods negatively affect the inflow of foreign technological progress. But that, on the other hand, also trade regimes which restrict exports necessary to pay capital goods imports negatively affect the inflow of foreign technological progress.

However, the empirical evidence presented here allows, in a strict sense, no answer to the question, whether import substitution policies, at least in the long run, have a positive impact on economic development or not. Going back to List's (1841) infant industry arguments (Section B.I.1), endogenous growth models based on the assumption of immobile technological knowledge can show scenarios where such kind of policies are welfare-improving (Section B.III.3.a).[198] Within the framework of these models, short-run negative dynamic effects of import substitution policies may be offset by the long-run positive dynamic effects of import substitution policies.

To empirically evaluate the long-run performance of import substitution policies, case studies are typically applied. Krueger (1982) presented a meanwhile classical case study on the effect of infant industry protection on the Turkish industry. She

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198 As Section B.III.b demonstrates, even under the extreme assumption of immobile technological knowledge, structural hysteresis on "low-tech" industries induces not necessarily a poor growth performance. Instead, capital goods imports from "high-tech" countries can completely transmit technological progress from high-tech countries to low-tech countries. Under these conditions, there are even parameter constellations where the low-tech country reaches a higher per capita income than the high-tech country.

finds that protected industries did not exhibit higher productivity growth than unprotected industries.[199] Similar results provides a recent case study for the South Korean manufacturing industry (Lee 1995). Another type of case study is presented by Helleiner (1992: 274): Instead of providing empirical evidence for the bad performance of infant industry policies, this study provides empirical evidence that the establishment of the South Korean semiconductor industries succeeded "without direct subsidy or trade-restricting policies to protect them from foreign competition". Following this result, gaining competence in an technologically advanced industry is possible without infant-industry protection. Of course, these studies are not providing a steadfast "proof" that infant industry protection is never necessary and never successful. However, they do at least indicate that infant industry protection is not always necessary and not always successful.

Another point that casts doubt on the necessity of infant industry policies is the stylized fact that developed market economies, with a strong domestic production base for capital goods, widely engage in intraindustry trade with capital goods (Figure 25). Following this, the capital goods industry of a developed market economy typically does not produce all existing types of capital goods, but specializes on certain types of capital goods and imports the rest. If this is a successful pattern of specialization in capital goods production, import substitution policies directed towards a complete domestic autonomy in capital goods production are ostensibly mistaken.

This is also suggested by empirical studies on the pattern of specialization of successful capital goods producers like Japan and Germany. Klodt and Maurer (1994) find that Japanese nonelectrical manufacturing industries are more intensively specialized in so-called volume business, while German nonelectrical manufacturing industries exhibit a stronger specialization in engineering business and plant manufacturing business. According to this pattern of specialization, Japanese firms are more engaged in large-scale physical-capital-intensive production of standardized machines, while German firms are typically engaged in small-scale human-capital-intensive production of custom-oriented machines.

This implies that even the major capital goods producers do not exhibit leading competence in all fields of technology. The example of Japan and Germany suggests much more that a successful world market penetration strategy is typically based on some kind of technological specialization. Consequently, instead of trying to replace all kind of foreign capital goods by domestic production, the search for new technological specialization paths may be a much more promising strategy for developing

[199] Harrison (1994) questions some of the results of Krueger (1982).

countries. Of course, the capability to find such paths depends on the technological competence of an economy. However, this competence may be much more dependent on the educational and scientific infrastructure of a country than on its import substitution production capacities.

This suggests that economic policy for developing countries should primarily focus on the establishment of this kind of infrastructure and the provision of favorable conditions for the accumulation of human and physical capital. This development strategy has, contrary to import substitution strategies, the great advantage of being compatible with the possibility to absorb foreign technological progress via imports of capital goods. Consequently, gaining technological competence and simultaneously absorbing technological progress from abroad is not necessarily incompatible. In this sense, trade policies that allow to absorb the benefits from foreign technological progress may not necessarily become victim of a "Trojan horse" as stated by List's dictum.[200] Instead, there is reason to believe that openness towards capital goods imports can be a valuable means for economic development.

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200 List (1841:218) argues, in an attempt to disprove Jean Baptiste Say's statement that export subsidies of foreign countries are "gifts" for the domestic economy, that "since the Trojans were given a wooden horse by the Greeks, it has become a dangerous thing for a nation to accept gifts from others" (translation by the author). List builds this statement on his theory of structural hysteresis (see Section B.I.1).

E. Appendices

Appendix 1: Determination of the Technical Elasticity of Substitution for Differentiated Goods

This appendix derives the technical elasticity of substitution for differentiated capital goods of production function [B.3].[201] Consider the following production function:

$$[A.1.1]\quad Y_t = L_t^{\alpha}\left(\sum_i^A X_{i,t}^{\beta}\right), \quad \text{where} \quad \alpha+\beta=1,\ 0<\alpha,\beta<1.$$

For two arbitrary types of capital goods, $k,l \in A$, the elasticity of substitution is defined as:

$$[A.1.2]\quad \varepsilon = \frac{\delta(X_k/X_l)}{\delta(Y_{X_l}/Y_{X_k})}\frac{(Y_{X_l}/Y_{X_k})}{(X_k/X_l)},$$

where Y_{X_k} is the first derivation of the production function with respect to the capital good X_k, and $\delta(X_k/X_l)/\delta(Y_{X_l}/Y_{X_k})$ is the inverse of the first derivation of the marginal rate of substitution with respect to X_k/X_l. Inserting the corresponding terms from [A.1.1] in this definition of the elasticity of substitution equals:

$$[A.1.3]\quad \frac{\delta(X_k/X_l)}{\delta(Y_{X_l}/Y_{X_{kl}})} = \frac{1}{1-\gamma}\left(\frac{X_k}{X_l}\right)^{\gamma},$$

$$[A.1.4]\quad \frac{(Y_{X_l}/Y_{X_{kl}})}{(X_k/X_l)} = \left(\frac{X_k}{X_l}\right)^{-\gamma},$$

such that the technical elasticity of substitution between X_k and X_1 equals:

$$[A.1.5]\quad \varepsilon = \frac{1}{1-\gamma}.$$

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201 The interpretation of this function in terms of a utility function (e.g., [B.1]) is straightforward.

Appendix 2: Determination of First-Order and Second-Order Effects of a New Input in a General Neoclassical Function

This appendix derives the first- and second-order effects from the introduction of a new input in a general neoclassical function. This function can be interpreted as a utility function as well as a production function. Consider a function with the following properties:

[A.2.1] $f(x_1, x_2, x_3, \ldots, x_n)$, with

$$f_{x_i} = f_x > 0 \ \forall\, i \in n\,,\ f_{x_i x_i} = f_{xx} < 0 \ \forall\, i, j \in n \ \text{ and } \ f_{x_i x_j} = 0 \ \forall\, i, j \in n\,,$$

where x_i is input *i*, *n* is the set of all available input types, f_x is the first derivation of the function with respect to *x*, and f_{xx} is the second derivation of the function with respect to *x*. Assume that the quantity of each type of input is identical and given by the following formula:

[A.2.2] $x_i = g(n)_i = E/n$,

where *E* is the sum of all inputs. Assume *E* is fixed. Inserting [A.2.2] into [A.2.1] yields:

[A.2.3] $f(n) = f\big(g(n)_1, g(n)_2, g(n)_3, \ldots, g(n)_n\big)$.

The total differential of function [A.2.3] with respect to the number of available inputs, *n*, equals:

[A.2.4] $df = \sum_i^n f_{g_i}\, g_n dn + \frac{1}{2} \sum_i^n \left(f_{g_i g_i}\, g_n + f_{g_i}\, g_{nn}\right) dn^2 + f_{g_n}\, g(n+1) \quad$ with $dn = 1$

$$<=> \frac{df}{dn} = \sum_i^n f_{x_i} \frac{-E}{n(n+1)} + \frac{1}{2} \sum_i^n \left(f_{x_i x_i} \frac{-E}{(n+1)} + f_{x_i} \frac{2E}{(n+1)(n+2)} \right) + f_{x_n} \frac{-E}{(n+1)}$$

$$<=> \frac{df}{dn} = \frac{1}{2} f_{x_i x_i} \frac{-E}{(n+1)} + f_{x_i} \frac{nE}{(n+1)(n+2)} \quad > \quad 0\,.$$

Following the properties of function [A.2.1] this expression is strictly positive. Consequently, introducing a new input in a function of type [A.2.1] increases the value of this function, even if the sum of all inputs, *E*, stays constant.

Appendix 3: The Solow–Ramsey Growth Model

1. Description of the Production Function

This appendix derives the solution of the Solow–Ramsey growth model (Section B.II.1). In this model aggregated output, i.e., GDP, of country i at period t is given by the following Cobb–Douglas-type function:

[A.3.1] $Y_{i,t} = \Lambda_i \left(A_{i,t} L_{i,t}\right)^{\alpha} K_{i,t}^{\beta} \qquad \alpha+\beta=1, \quad 0<\alpha,\beta<1, \qquad i=A,B,$

where $L_{i,t}$ is population and labor force of country i at period t, $A_{i,t}$ is a measure of labor productivity, $K_{i,t}$ is the stock of accumulated capital, Λ_i is a measure of government performance and/or the endowment with public goods, which are not accumulated by market forces. For simplicity, Λ_i is assumed to be exogenous.[202] It is assumed that $A_{i,t}$ and $L_{i,t}$ grow with exogenous rates, $A_{i,t} = A_{i,0}\, e^{gt}$ and $L_{i,t} = L_{i,0}\, e^{nt}$. The capital stock $K_{i,t}$ consists of homogenous capital goods and is accumulated endogenously. It is assumed that $Y_{i,t}$ can be used for consumption as well as for capital accumulation. To derive the steady state solution of the model all variables will be expressed in terms of per effective workers corresponding to the following definitions.

[A.3.2] $\bar{y}_{i,t} := Y_{i,t} / A_{i,t} L_{i,t}$ and $\bar{k}_{i,t} := K_{i,t} / A_{i,t} L_{i,t}$.

Using these definitions, [A.3.1] can be rewritten:

[A.3.3] $\bar{y}_{i,t} = \Lambda_{i,t}\, \bar{k}_{i,t}^{\beta}$.

2. Determination of the Open Economy Budget Constraint Per Effective Worker

In an open economy total expenditures add up to GDP according to the following identity:

[A.3.4] $Y_{i,t} = C_{i,t} + \delta\, K_{i,t} + \dot{K}_{i,t} + X_{i,t} - M_{i,t}$,

202 See Section B.II.1 for an interpretation of Λ_i.

where $C_{i,t}$ is consumption in country *i* at period *t*, $\delta K_{i,t}$ is capital consumption per period, $\dot{K}_{i,t}$ is gross investment, $X_{i,t}$ are exports and $M_{i,t}$ are imports. By the current account identity, the trade balance surplus equals the decrease of the country *i's* net debt position plus interest payments to foreign holders of domestic debt. Hence, defining $D_{i,t}$ to equal the country's net debt position, the trade balance surplus equals:

$$[A.3.5]\ X_{i,t} - M_{i,t} = -\dot{D}_{i,t} + r D_{i,t}.$$

Inserting this in [A.3.4] and arranging terms yields:

$$[A.3.6]\ C_{i,t} = \Lambda (AL)^{\alpha} K^{\beta} - \dot{K}_{i,t} - \delta K_{i,t} + \dot{D}_{i,t} - r D_{i,t}.$$

Define:

$$[A.3.7]\ \bar{c}_{i,t} := C_{i,t} / A_{i,t} L_{i,t} \quad \text{and} \quad \bar{d}_{i,t} := K_{i,t} / A_{i,t} L_{i,t}.$$

Using these definitions, [A.3.7] can be rewritten:

$$[A.3.8]\ \bar{c}_{i,t} = \Lambda \bar{k}^{\beta} - \frac{\dot{K}_{i,t}}{A_{i,t} L_{i,t}} - \delta \bar{k}_{i,t} + \frac{\dot{D}_{i,t}}{A_{i,t} L_{i,t}} - r \bar{d}_{i,t}.$$

Taking the first derivations of $\bar{d}_{i,t}$ and $\bar{k}_{i,t}$ with respect to time from the definitions [A.3.7] yields:

$$[A.3.9]\ \dot{\bar{d}}_{i,t} = \frac{\dot{D}_{i,t}}{A_{i,t} L_{i,t}} - \bar{d}_{i,t}(g+n) \quad \text{and} \quad \dot{\bar{k}}_{i,t} = \frac{\dot{K}_{i,t}}{A_{i,t} L_{i,t}} - \bar{k}_{i,t}(g+n).$$

Inserting this in [A.3.8] yields the following equation (which equals [B.9] in Section B.II.1):

$$[A.3.10]\ \bar{c}_{i,t} = \Lambda_i \bar{k}_{i,t}^{\beta} - \dot{\bar{k}}_{i,t} - (g+n+\delta)\bar{k}_{i,t} + \dot{\bar{d}}_{i,t} - (r-g-n)\bar{d}_{i,t}\cdot$$

In the steady state all variables expressed in per effective worker intensities (see Definitions [A.3.2] and [A.3.7]) do not grow. Furthermore, in autarky the net foreign debt position equals zero, i.e., $\bar{d}_{i,t} = 0$. Therefore, the autarky steady-state version of [A.3.10] equals:

$$[A.3.11]\ \bar{c}_{i,t} = \Lambda_i \bar{k}_{i,t}^{\beta} - (g+n+\delta)\bar{k}_{i,t}\cdot$$

This equation describes a semicircle (strictly speaking a "semiellipsoid") in the $(\bar{c}, \bar{k})$ plane. This follows from the continuity of the function and the values of $\bar{k}$

for $\bar{c}=0$ and $\bar{c}=\max_{\bar{k}}\bar{c}(k)$: For $\bar{c}=0$, $\bar{k}$ can take the values $\bar{k}_{i,t}^{\bar{c}=0}=0$ and $\bar{k}_{i,t}^{\bar{c}=0}=(\Lambda_i/(g+n+\delta))^{1/(1-\beta)}$. The capital stock per effective worker, which yields $\bar{c}=\max_{\bar{k}}\bar{c}(k)$, is found by equating the first derivation of $\bar{c}$ with respect to $\bar{k}$ with zero. This yields $\bar{k}_{i,t}^{\bar{c}=\max}=(\beta\Lambda_i/(g+n+\delta))^{1/(1-\beta)}$. From $0<\beta<1$ follows then: $\bar{k}_{i,t}^{\bar{c}=\max}<\bar{k}_{i,t}^{\bar{c}=0}$. As in an autarky steady state all variables expressed in per effective worker intensities do not grow, the steady-state solution must lay on this semicircle. Which $(\bar{c},\bar{k})$ combination is chosen, depends on the intertemporal consumption preferences of the households of the economy. These are specified in the next section.

3. Determination of the Intertemporal Household Optimum

The representative household of a neoclassical growth model with Ramsey-type consumer optimization behavior is typically assumed to have the following CES-type utility function:

[A.3.12] $u(c_{i,t})=\dfrac{c_{i,t}^{1-\sigma}-1}{1-\sigma}$

where σ is the inverse of the intertemporal elasticity substitution of consumption. It is assumed that $\sigma>0$. For $\sigma\to 0$ the utility function becomes logarithmic, i.e., $u(c_{i,t})=\ln(c_{i,t})$. Given this utility function, the present value function of an infinitely living household "dynasty" with a growth rate n equals:

[A.3.13] $U_{i,0}=\int_0^\infty e^{-(\rho-n)}\dfrac{c_{i,t}^{1-\sigma}-1}{1-\sigma}dt$,

where ρ is the rate of time preference. The budget constraint of the household in each point of time equals:

[A.3.14] $\dot{a}_{i,t}=w_{i,t}+a_{i,t}r_{i,t}-c_{i,t}$,

where $a_{i,t}$ are accumulated savings (assets) in period t, $r_{i,t}$ is the market interest rate and $w_{i,t}$ is the wage per period. It is assumed that each household offers one unit labor per period. Combining [A.3.13] and [A.3.14], the household intertemporal optimization problem can be written:

[A.3.15] $\max_{c_{i,t}}\int_0^\infty e^{-(\rho-n)}\dfrac{c_{i,t}^{1-\sigma}-1}{1-\sigma}dt \qquad s.t.\ \dot{a}_{i,t}=w_{i,t}+a_{i,t}r_{i,t}-c_{i,t}$.

The Hamiltonian of this optimization problem equals:

[A.3.16] $H = e^{-(\rho-n)} \frac{c_{i,t}^{1-\sigma}-1}{1-\sigma} + \lambda_t\left(w_{i,t} + a_{i,t}r_{i,t} - c_{i,t}\right).$

Given the specification of the utility function, the Hamiltonian is concave. Therefore, the first-order conditions for an intertemporal utility maximum are:

[A.3.17] $\frac{\delta H}{\delta c_t} = 0 \Leftrightarrow e^{-(\rho-n)t}\, c_{i,t}^{-\sigma} = \lambda_t$

[A.3.18] $\dot{\lambda}_{i,t} = -e^{-(\rho-n)t}\, c_{i,t}^{-\sigma}\left(\rho - n\right) + e^{-(\rho-n)} c_{i,t}^{-\sigma-1}\dot{c}_{i,t}\,\sigma,$

[A.3.19] $\dot{\lambda}_{i,t} = -\lambda_{i,t}\left(r_{i,t} - n\right).$

The transversality condition equals:

[A.3.20] $\lim_{t\to\infty}\left(\lambda_{i,t}a_{i,t}\right) = 0.$

The transversality condition says that, intuitively spoken, approaching infinity, no savings must be left. If savings were left, they could had been used to increase utility. Therefore, if the transversality condition does not hold, within the framework of this model, the first-order conditions would not describe an intertemporal utility maximum. Equalizing [A.3.18] with [A.3.19] and inserting [A.3.17] yields:

[A.3.21] $\frac{\dot{c}_{i,t}}{c_{i,t}} = \sigma^{-1}\left(r_{i,t} - \rho\right).$

The definition for consumption per effective worker is:

[A.3.22] $\overline{c}_{i,t} := C_{i,t}/A_{i,t}L_{i,t}\ .$

Consequently, the first derivation with respect to time can be written:

[A.3.23] $\frac{\dot{\overline{c}}_{i,t}}{\overline{c}_{i,t}} = \frac{\dot{c}_{i,t}}{c_{i,t}} - g.$

Inserting this into [A.3.21] yields:

[A.3.24] $\frac{\dot{\overline{c}}_{i,t}}{\overline{c}_{i,t}} = \sigma^{-1}\left(r_{i,t} - \rho - \sigma g\right).$

Integrating over [A.3.19] with respect to time yields:

[A.3.25] $\lambda_{i,t} = \lambda_{i,0}\, e^{-\left(\int_0^{\infty}(r_{i,t}-n)dt\right)}$.

Inserting this into the transversality condition [A.3.20] yields:

[A.3.26] $\lim_{t\to\infty}\left(a_{i,t}\,\lambda_{i,0}\exp\left(-\int_0^{\infty}(r_{i,t}-n)dt\right)\right) = 0$.

As $\lambda_{i,0}$ is constant and as $a_{i,t}$ equals (as will be seen) the capital stock $k_{i,t}$, [A.3.26] can be rewritten, regarding definition $\bar{k}_{i,t} = k_{i,t}\, A_{i,0} e^{gt}$, as follows:

$$\lim_{t\to\infty}\left(\hat{k}_{i,t}\exp\left(-\int_0^{\infty}(r_{i,t}-n-g)dt\right)\right) = 0 .$$

Consequently, the transversality condition implies the following condition to hold:

[A.3.27] $r > g + n$.

4. Profit Maximization and Factor Compensation

The profit function of the representative firm equals:

[A.3.28] $Y_{i,t} = \Lambda_i \left(A_{i,t}\, L_{i,t}\right)^{\alpha} K_{i,t}^{\beta} - K_{i,t}\left(r_{i,t}+\delta\right) - L_{i,t}\, w_{i,t}$,

where $r_{i,t}$ is the per period price for one capital unit, i.e., the market interest rate, δ is the rate of physical depreciation of the capital stock per period and $w_{i,t}$ is the wage rate. Following [A.3.28], the first-order conditions of a profit maximum equals:

[A.3.29] $\dfrac{\delta Y_{i,t}}{\delta K_{i,t}} = \beta\, \Lambda_i \left(A_{i,t}\, L_{i,t}\right)^{\alpha} K_{i,t}^{\beta-1} - r_{i,t} - \delta = 0$,

[A.3.30] $\dfrac{\delta Y_{i,t}}{\delta L_{i,t}} = \alpha\, A_{i,t}\, \Lambda_i \left(A_{i,t}\, L_{i,t}\right)^{\alpha-1} K_{i,t}^{\beta} - w_{i,t} = 0$.

Equivalently, these conditions can be rewritten in terms of capital intensities:

[A.3.31] $r_{i,t} = \beta\, \Lambda_i\, \bar{k}_{i,t}^{-\alpha} - \delta$, [A.3.32] $w_{i,t} = \alpha A_{i,t} \Lambda_i \overline{k}_{i,t}^{\beta}$.

In order to yield a decentralized market equilibrium with perfect competition, single firms must not make positive, nonzero profits. Consequently, the following condition must hold:

[A.3.33] $Y_{i,t} = K_{i,t}\left(r_{i,t} + \delta\right) + L_{i,t}\ w_{i,t}$.

Inserting the formulas for the interest rate and wage rate according to [A.3.31] and [A.3.32] shows that this condition is fulfilled, because $\alpha + \beta = 1$ holds.

5. Determination of the Steady-State Capital Stock

The steady-state capital stock can be derived by inserting the formula for the market interest rate, i.e., the inverse capital demand (see [A.3.31]), into the formula for the optimal consumption path, i.e., the inverse capital supply (see [A.3.24]). As in steady-state consumption in terms of effective worker does not grow, the steady-state capital stock per effective worker can be derived inserting $\dot{\overline{c}}_{i,t}/\overline{c}_{i,t} = 0$ and solving for $\overline{k}_{i,t}$. This yields:

[A.3.34] $k_i^* = \left(\dfrac{\beta \Lambda_i}{\rho + \sigma g + \delta}\right)^{\frac{1}{1-\beta}}$.

Hence, the steady-state capital stock per effective worker is higher, the higher the endowment of the economy with public goods, λ_i, is. The intersection point of the vertical lines at $\overline{k}_A^*$ resp. $\overline{k}_B^*$ with the corresponding ($\overline{k}_{i,t} = \overline{d}_{i,t} = 0$) loci determine the autarky steady-state value of consumption per effective worker, $\overline{c}_A^{autarky}$ resp. $\overline{c}_B^{autarky}$.

6. A Solow–Ramsey Model with a Closed Oligopoly on the Domestic Market for Capital Goods

This section explores the impact of trade policy in a Solow–Ramsey model with a closed oligopoly on the domestic market for capital goods (Section B.1.2). Consider a closed oligopoly on the domestic market for capital goods, which is caused by restricted access to the technological knowledge to produce capital goods. Assume that only a fixed number of N_D domestic firms have the technological knowledge to transform one unit GDP into one unit of the capital good. Furthermore, assume that the number of foreign capital goods producers, N_F, is finite but large. Hence, [A.3.1] can be rewritten as follows:

$$[A.3.35]\ Y_t = \Lambda(A_t L_t)^{\alpha}\left(\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t}\right)_{i,t}^{\beta},$$

$$\text{with } \alpha+\beta=1,\ 0<\alpha,\beta<1 \text{ and } \quad i=A,B,$$

where $\sum_i^{ND} x_{i,t}$ equals the real stock of domestic capital goods and $\sum_j^{NF} x_{j,t}$ equals the real stock of foreign capital goods. Production function [A.3.35] implies that domestic and foreign capital goods are perfect substitutes. It is assumed that domestic oligopolists choose quantities as interaction parameters and play uncooperative Nash strategies. To derive the equilibrium supply with capital goods given this set of assumptions, the demand for capital goods has to be determined first. Consider therefore the profit maximization problem of the representative firm:

$$[A.3.36]\ \max_{L,H,\bar{X}} F! \text{ with } F=\Lambda A^{\alpha} L_t^{\alpha} K_t^{\beta} - L_t w_L - K_t p_t \text{ and } K_t := \sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t}.$$

From the first-order conditions for a profit maximum follows inter alia:

$$[A.3.37]\ \frac{\delta F}{\delta \bar{X}} = \beta A^{\alpha} L_t^{\alpha} K_t^{\beta-1} - p_t \overset{!}{=} 0.$$

Hence, the price for capital goods depending on total supply, K_t, equals:

$$[A.3.38]\ p_t = \beta A^{\alpha} L_t^{\alpha} K_t^{\beta-1} =: \beta\, \bar{k}_t^{\beta-1}.$$

The strategic calculus of the domestic capital goods producers is as follows: The number of foreign capital goods producers, N_F, is large enough such that there is perfect competition on the world market. Consequently, the world market price for capital goods equals marginal costs. As everywhere the same Cobb–Douglas production function with constant returns to scale ([A.3.35]) is used, marginal cost prices are identical for producers of all countries. Hence, given the other assumptions of the model, the world market price of capital goods equals unity. From this follows that domestic producers have no price-setting power on the world market. Their oligopolistic market behavior is restricted to the domestic market. Following the above assumptions, domestic capital goods producers play uncooperative Nash strategies on the domestic market. Therefore, the Nash equilibrium quantity of capital goods follows by maximizing the profit of each domestic capital goods producer under the assumption that the supply of the other producers is given. This leads to the following maximization approach:

$$[A.3.39]\ \max_{\overline{X}} \Pi_{i,t}!\ \text{with}\ \Pi_{i,t} = \overline{X}_{i,t}\ p_{i,t} - \overline{X}_{i,t}(r+\delta),$$

where $\overline{X}_{i,t}$ equals the supply of each capital goods producer. With respect to [A.3.38] the first-order conditions yield:

$$[A.3.40]\ \frac{\delta \Pi_{i,t}}{\delta \overline{X}_{i,t}} = p_{i,t} - r - \delta - \overline{X}_{i,t}\ (1-\beta)\ \beta\ L_t^{\alpha}\ K_t^{\beta-2} \stackrel{!}{=} 0$$

$$\Leftrightarrow$$

$$\frac{\delta \Pi_{i,t}}{\delta \overline{X}_{i,t}} = p_{i,t} - r - \delta - \overline{X}_{i,t}\ (1-\beta)\ p_{i,t}\ K_t^{-1} \stackrel{!}{=} 0.$$

Solving [A.3.40] for the price yields:

$$[A.3.41]\ p_{i,t} = (r+\delta)\left(1-(1-\beta)\frac{\overline{X}_{i,t}}{\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t}}\right)^{-1}$$

$$\Leftrightarrow$$

$$p_{i,t} = (r+\delta)\left(1-(1-\beta)\frac{\sum_i^{N_D} X_{i,t} \Big/ N_D}{\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t}}\right)^{-1}.$$

Under the assumption that the per period imports of capital goods are restricted by the government on a market share of q of the domestic capital goods market this can be rewritten in the following way:

$$[A.3.42]\ p_t = (r+\delta)\left(1-(1-\beta)\frac{(1-q)}{N_D}\right)^{-1}\ \text{with}\ q = \frac{\sum_j^{N_F} X_{j,t}}{\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t}}.$$

Inserting the steady-state interest rate, according to [A.3.24], yields:

$$[A.3.43]\ p_t = (\rho+\sigma g+\delta)\left(1-(1-\beta)\frac{(1-q)}{N_D}\right)^{-1}.$$

Following [A.3.38] capital demand in terms of the capital stock per effective worker equals:

[A.3.44] $p_t = \beta\, \bar{k}_t^{\beta-1}$.

Combining [A.3.43] and [A.3.44] yields the steady-state capital stock per effective worker:

$$[\text{A.3.45}]\ \bar{k}_i^* = \left(\frac{\beta \Lambda_i}{(\rho + \sigma g + \delta)\left(1 - (1-\beta)\dfrac{(1-q)}{N_D}\right)^{-1}} \right)^{\frac{1}{1-\beta}}.$$

Appendix 4: The Rivera-Batiz–Romer Model under Different Assumptions Concerning International Patent Protection and International Mobility of Technological Knowledge

This appendix derives the solutions of the Rivera-Batiz–Romer model (Section B.III.1, Figure 8) for different assumptions concerning international patent protection and international mobility of technological knowledge.

1. The Solution for Cases 6 and 8

In Cases 6 and 8, international trade is not possible and technological knowledge is internationally immobile. In Case 8, international patent protection is not guaranteed. However, the international immobility of technological knowledge implies that foreign blueprints cannot be used for the production of differentiated goods. Hence, Case 8 is identical to Case 6. To derive the steady-state solution for these cases, consider first the profit maximization problem of the representative manufacturing firm:

[A.4.1] $\max\limits_{L_{k,t},\, H_{k,t},\, X_{k,t}} F_{k,t}\,!$

$$F_{k,t} = Y_{k,t} - H_{Y,k,t}\, w_{H,Y,k,t} - L_{k,t}\, w_{L,k,t} - \sum_{i}^{A_{k,t}} X_{i,k,t}\, p_{i,k,t} \text{ where } Y_{k,t} = L_{k,t}^{\alpha}\, H_{Y,k,t}^{\beta} \sum_{i}^{A_{k,t}} X_{i,k,t}^{\gamma}.$$

The notation is conventional: $H_{Y,k,t}$ is human capital used in manufacturing of country k in period t, $L_{k,t}$ is raw labor of country k in period t, $A_{k,t}$ is the set of available blueprints for the production of capital goods in country k in period t, $w_{H,Y,k,t}$ is the wage rate for human capital paid in manufacturing of country k in period t, $w_{L,k,t}$ is the wage rate for raw labor of country k in period t, and $p_{i,k,t}$ is the price for one unit of a differentiated capital good in period t. It is assumed that differentiated capital goods do not depreciate. Since $F_{k,t}$ is a concave function in all production factors, setting the first-order derivations zero yields the necessary conditions for a profit maximum:

$$[A.4.2]\ \frac{\delta F_{k,t}}{\delta X_{k,i,t}} = \gamma\ L_{Y,k,t}^{\alpha}\ H_{Y,k,t}^{\beta}\ X_{i,k,t}^{\gamma-1} - p_{i,k,t} \overset{!}{=} 0\ .$$

Consequently, the demand for a differentiated capital good equals:

$$[A.4.3]\ X_{i,k,t} = \left(\gamma\ L_{k,t}^{\alpha}\ H_{Y,k,t}^{\beta}\ p_{i,t}^{-1}\right)^{\frac{1}{\gamma-1}}$$

$$p_{i,k,t} = \gamma\ L_{Y,k,t}^{\alpha}\ H_{Y,k,t}^{\beta}\ X_{i,k,t}^{\gamma-1}\ .$$

Since the blueprint for each differentiated capital good is protected by an eternal patent, an owner of a blueprint chooses a monopolistic price. As the cost for the production of a blueprint is fixed, the resulting maximization problem refers only to the variable costs of capital goods production. The per period costs of the production of one unit of a capital good equal the interest rate. Consequently, the monopolistic per period price for one unit of a capital good is found by solving the following maximization problem:

$$[A.4.4]\ \max_{X_{i,k,t}} \Pi\,!$$

$$\Pi_{i,k,t} = X_{i,k,t}\ p_{i,k,t} - X_{i,k,t} r_{k,t} \text{ with } p_{i,k,t} = \gamma\ L_{Y,k,t}^{\alpha}\ H_{Y,k,t}^{\beta}\ X_{i,k,t}^{\gamma-1}\ .$$

The first-order condition equals:

$$[A.4.5]\ \frac{\delta \Pi_{i,k,t}}{\delta X_{i,k,t}} = \gamma^{2}\ L_{Y,k,t}^{\alpha}\ H_{Y,k,t}^{\beta}\ X_{k,t}^{\gamma-1} - r_{k,t} \overset{!}{=} 0\ .$$

Inserting [A.4.3] yields:

$$[A.4.6]\ \frac{\delta \Pi_{i,k,t}}{\delta \hat{X}_{i,k,t}} = \gamma\ p_{i,k,t} - r_{k,t} \overset{!}{=} 0\ .$$

From this follows the monopolistic per period price for a differentiated capital good:

$$\hat{p}_{i,k,t} := \frac{r_{k,t}}{\gamma}.$$

Inserting this price in [A.4.3] yields the demand for a differentiated capital good:

$$\text{[A.4.7]}\ \hat{X}_{i,k,t} := \left(\gamma\ L^{\alpha}_{k,t}\ H^{\beta}_{Y,k,t}\ \frac{\gamma}{r_{i,k,t}} \right)^{\frac{1}{\alpha+\beta}}.$$

Inserting this in the profit formula of a capital goods producer ([A.4.4]) yields:

$$\text{[A.4.8]}\ \Pi_{i,k,t} = (\alpha+\beta)\ \hat{p}_{i,k,z} \hat{X}_{i,k,t}.$$

Since the possession of a blueprint renders this profit in all future periods, the price of a blueprint equals the present value of an eternal rent of $\Pi_{i,k,t}$. As in steady state the interest rate, $r_{k,t}$, is constant, this yields the following price of a blueprint:

$$\text{[A.4.9]}\ p_{A,k,t} = (\alpha+\beta)\gamma\ r^{-1}_{k,t}\ L^{\alpha}_{Y,k,t}\ H^{\beta}_{Y,k,t}\ X^{\gamma}_{i,k,t}.$$

The production function for new blueprints equals:

$$\text{[A.4.10]}\ \dot{A}_{k,t} = \delta\ A_{k,t}\ H_{A,k,t}.$$

Consequently the marginal productivity (measured in units of manufacturing output) of human capital used for the production of blueprints equals:

$$\text{[A.4.11]}\ \frac{\delta \dot{A}_{k,t}}{\delta H_{A,k,t}} p_{A,k,t} = \delta\ A_{k,t}\,(\alpha+\beta)\gamma\ r^{-1}_{k,t}\ L^{\alpha}_{Y,k,t}\ H^{\beta}_{Y,k,t}\ X^{\gamma}_{i,k,t}.$$

Profit maximization of an R&D firm implies that marginal productivity of human capital equals the wage rate:

$$\text{[A.4.12]}\ w_{H,A,k,t} = \delta\ A_{k,t}\,(\alpha+\beta)\gamma\ r^{-1}_{k,t}\ L^{\alpha}_{Y,k,t}\ H^{\beta}_{Y,k,t}\ X^{\gamma}_{i,k,t}.$$

This shows that the monopolistic profits from selling differentiated capital goods are completely spent to pay the human capital wage bill. No monopolistic profit is left for R&D firms. This is a consequence of the assumption that access to R&D activities is free, such that there is perfect competition for human capital between R&D firms. Therefore, human capital is paid according to its marginal productivity. Additionally, R&D firms compete for human capital also with manufacturing firms.

Since there is free access to manufacturing activities, too, profit maximization of a manufacturing firm implies that the marginal productivity of human capital equals the wage rate:

[A.4.13] $w_{H,Y,k,t} = \beta \; L^{\alpha}_{Y,k,t} \; H^{\beta-1}_{Y,k,t} \; A_{k,t} \; X^{\gamma}_{i,k,t}$.

This follows from [A.4.1]. In a market equilibrium, wages for human capital in both sectors must be equal, $w_{H,Y,k,t} = w_{H,A,k,t}$. Inserting [A.4.12] and [A.4.13] yields:

[A.4.14] $H_{Y,k,t} = \delta^{-1} \Lambda r_{k,t}$, where $\Lambda = \beta/(\alpha+\beta)\gamma$.

Given the human capital endowment of country k, $H_{k,t}$, the amount of human capital allocated to the R&D sector equals:

[A.4.15] $H_{A,k,t} = H_{k,t} - \delta^{-1} \Lambda r_{k,t}$.

Combining [A.4.15] and [A.4.10] yields:

[A.4.16] $g_k := \dfrac{\dot{A}_k}{A_k} = \delta \, H_k - \Lambda r_k$.

The intertemporal utility optimization problem of the representative household corresponds to the same problem in the Solow–Ramsey model (Appendix 3). Therefore, the formula for optimal consumption growth equals (see Appendix A.3.3., [A.3.21]):

[A.4.17] $r_{t,k} = \dfrac{\dot{c}_{k,t}}{c_{k,t}} \sigma + \rho$.

As is shown below, the steady-state growth rate of consumption equals the steady-state growth rate of the knowledge capital stock, $(\dot{c}/c)_k = g_k$. Therefore, [A.4.17] can be rewritten:

[A.4.18] $r_k = g_k \, \sigma + \rho$.

Inserting this in [A.4.16] and solving for g yields the formula for the steady-state growth rate in Cases 6 and 8:

[A.4.19] $\breve{g}_k = \dfrac{\delta \; H_k - \; \Lambda \rho}{1 + \sigma \Lambda}$.

Since the assumption $(\dot{c}/c)_k = g_k$ was used to derive [A.4.19], it has to be shown that this assumption holds in steady state. Consider therefore the value of the capital stock measured in manufacturing output units:

[A.4.20] $K_{k,t} = \sum_{i}^{A_{k,t}} X_{i,k,t}\, p_{i,k,t} = A_{k,t}\, \hat{X}_{i,k,t}\, \hat{p}_{i,k,t}$.

Taking the first derivation of [A.4.20] with respect to time and dividing through [A.4.20] yields:

[A.4.21] $\frac{\dot{K}_{k,t}}{K_{k,t}} = \frac{\dot{A}_{k,t}}{A_{k,t}} = g_k$.

Repeating the same exercise with the formula for the manufacturing production function yields ([A.4.1]):

[A.4.22] $\frac{\dot{Y}_{k,t}}{Y_{k,t}} = \frac{\dot{A}_{k,t}}{A_{k,t}} = g_k$.

The output of the manufacturing sector is used for consumption and capital investment:

[A.4.23] $Y_{k,t} = C_{k,t} + \dot{K}_{k,t} \Leftrightarrow \frac{C_{k,t}}{Y_{k,t}} = 1 - \frac{K_{k,t}\, g_{k,t}}{Y_{k,t}}$.

Together with [A.4.21] and [A.4.22] this implies:

[A.4.24] $\frac{\dot{C}_{k,t}}{C_{k,t}} = g_k$.

Hence, the assumption that consumption grows with the same rate as the number of blueprints for new capital goods actually holds in steady state. Finally, the growth rate of GDP is determined: GDP equals the output of the manufacturing sector plus the output of the R&D sector measured by its relative price, p_A :

[A.4.25] $GDP_{k,t} = Y_{k,t} + \dot{A}_{k,t}\; p_{A,t}$.

Taking the first derivation from [A.4.25] with respect to time and dividing through [A.4.25] yields:[203]

[A.4.26] $\frac{G\dot{D}P_{k,t}}{GDP_{k,t}} = \frac{\dot{Y}_{k,t} + \ddot{A}_{k,t}\; p_{A,t}}{Y_{k,t} + \dot{A}_{k,t}\; p_{A,t}} = \frac{Y_{k,t}\, g + \dot{A}_{k,t} g\; p_{A,t}}{Y_{k,t} + \dot{A}_{k,t}\; p_{A,t}} = g_k$.

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203 From [A.4.10] follows in the steady state: $\frac{\ddot{A}_k}{\dot{A}_k} = \frac{\dot{A}_k}{A_k} = g$.

Hence, in the steady state per capita GDP grows with the same rate as the stock of technological knowledge. Finally, the steady-state level of manufacturing output is determined. From [A.4.1] manufacturing output is given by:

$$[\text{A.4.27}]\ Y_{k,t} = L_{k,t}^{\alpha}\, H_{Y,k,t}^{\beta} \sum_{i}^{A_{k,t}} X_{i,k,t}^{\gamma} \quad .$$

Inserting the steady-state values for $H_{Y,k,t}$ and $X_{i,k,t}$ from [A.4.7] and [A.4.14] this yields:

$$[\text{A.4.28}]\ \breve{Y}_{k,t} = \Omega\left(g_k\,\sigma+\rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}}\, L_k^{\frac{\alpha}{\alpha+\beta}}\, A_{k,t} \text{ , where } \Omega := \left(\delta^{-1}\Lambda\right)^{\frac{\beta}{\alpha+\beta}}\,\gamma^{\frac{\gamma}{\alpha+\beta}} \ .$$

2. The Solution for Cases 2 and 4

In Case 2, free international trade is possible, international patent protection is guaranteed, but technological knowledge is still internationally immobile. In Case 4, free international trade is possible, technological knowledge is internationally immobile, but international patent protection is not guaranteed. However, as technological knowledge is internationally immobile, it is not possible to copy blueprints from abroad, such that Cases 2 and 4 are equivalent. Since both countries are identical by assumption, [A.4.7] implies that free trade doubles the demand for each differentiated capital good:

$$[\text{A.4.29}]\ \sum_k X_{i,k,t} = \sum_k \left(\gamma\ L_{k,t}^{\alpha}\, H_{Y,k,t}^{\beta}\, p_{i,k,t}^{-1}\right)^{\frac{1}{\alpha+\beta}} = 2X_{i,k,t} \, .$$

Solving for $p_{i,k,t}$ yields:

$$[\text{A.4.29}]\ p_{i,k,t} = \left(\sum_k \left(\gamma\, L_{k,t}^{\alpha} H_{k,t}^{\beta}\right)^{\frac{1}{1-\gamma}}\right)^{-(1-\gamma)} \left(\sum_k X_{k,i,t}\right)^{-(1-\gamma)} \ .$$

For convenience, define the quantity sold:

$$[\text{A.4.30}]\ \overline{X}_{k,i,t} := \sum_k X_{k,i,t} \, .$$

Now profit maximization of a capital goods producer implies:

[A.4.31] $\max\limits_{X_{i,k,t}} \Pi !$

$$\Pi_{i,k,t} = \overline{X}_{i,k,t}\; p_{i,k,t} - \overline{X}_{i,k,t} r_{k,t} \text{ with } p_{i,k,t} = \left(\sum_k \left(\gamma\, L^{\alpha}_{k,t} H^{\beta}_{k,t} \right)^{\frac{1}{1-\gamma}} \right)^{-(1-\gamma)} \left(\overline{X}_{i,k,t} \right)^{-(1-\gamma)}.$$

The first-order condition for a profit maximum yields:

$$\frac{\delta \Pi_{i,k,t}}{\delta \overline{X}_{i,k,t}} = p_{i,k,t} - r_{k,t} - \overline{X}_{i,k,t}(1-\gamma)\left(\sum \left(\gamma\, L^{\alpha}_{k,t} H^{\beta}_{k,t} \right)^{\frac{1}{1-\gamma}} \right)^{-(1-\gamma)} \overline{X}_{i,k,t}^{-(2-\gamma)} \overset{!}{=} 0 .$$

Using [A.4.29] this can be rewritten:

[A.4.32] $\dfrac{\delta \Pi_{i,t}}{\delta \overline{X}_{i,t}} = p_{i,k,t} - r_{k,t} - (1-\gamma)\, p_{i,k,t} \overset{!}{=} 0 .$

From this follows the profit maximizing price of a monopolistic capital goods producer:

$$\hat{p}_{i,k,t} := \frac{r_{k,t}}{\gamma} .$$

Consequently, the increase in capital goods demand caused by free trade does not change the profit maximizing price of a monopolistic capital goods producer (compare [A.4.32] and [A.4.6]). Inserting this price in [A.4.29] yields the corresponding demand for a differentiated capital good:

[A.4.33] $\sum\limits_k X_{i,k,t} = \sum\limits_k \left(\gamma\; L^{\alpha}_{k,t}\, H^{\beta}_{Y,k,t} \dfrac{\gamma}{r_{i,k,t}} \right)^{\frac{1}{\alpha+\beta}} = 2\hat{X}_{i,k,t} ,$

[A.4.34] $\Pi_{i,k,t} = (\alpha + \beta)\; \hat{p}_{i,k,z} 2\hat{X}_{i,k,t} .$

Consequently, the price of a blueprint now reads (see [A.4.9]):

[A.4.35] $p_{A,k,t} = 2(\alpha+\beta)\gamma\;\, r^{-1}_{k,t}\, L^{\alpha}_{Y,k,t}\, H^{\beta}_{Y,k,t}\, X^{\gamma}_{i,k,t} .$

Inserting this in the formula for the wage rate of human capital (see [A.4.12]) used in the R&D sector yields:

[A.4.36] $w_{H,A,k,t} = 2\delta\, A_{k,t}\, (\alpha+\beta)\gamma\;\, r^{-1}_{k,t}\, L^{\alpha}_{Y,k,t}\, H^{\beta}_{Y,k,t}\, X^{\gamma}_{i,k,t} .$

As free trade doubles in each country the set of available capital goods, the manufacturing production function now reads:

[A.4.37] $Y_{k,t} = L_{k,t}^{\alpha} H_{Y,k,t}^{\beta} \sum_{i}^{2A_{k,t}} X_{i,k,t}^{\gamma} = L_{k,t}^{\alpha} H_{Y,k,t}^{\beta} 2A_{k,t} X_{i,k,t}^{\gamma}$.

Therefore, profit maximization of a manufacturing firm implies now (see [A.4.13]):

[A.4.38] $w_{H,Y,k,t} = \beta L_{Y,k,t}^{\alpha} H_{Y,k,t}^{\beta-1} 2A_{k,t} X_{i,k,t}^{\gamma}$.

In a market equilibrium wages for human capital in both sectors must be equal: $w_{H,Y,k,t} = w_{H,A,k,t}$. Inserting [A.4.36] and [A.4.38] in this equation yields:

[A.4.39] $H_{Y,k,t} = \delta^{-1} \Lambda r_{k,t}$, where $\Lambda = \alpha / (\alpha + \beta)\gamma$.

This shows that free trade does not change the allocation of human capital between manufacturing and the R&D sector. Therefore, the growth rate does not change compared to autarky, as follows by inserting [A.4.17] in [A.4.39] and [A.4.39] in [A.4.10] and solving for g. However, since the set of available differentiated capital goods has doubled (see [A.4.37]), the output of the manufacturing sector doubles. This follows by inserting the steady-state values for $H_{Y,k,t}$ and $X_{i,k,t\,t}$ from [A.4.7] resp. [A.4.14] in [A.4.37]:

[A.4.40] $\widehat{Y}_{k,t} = \Omega \left(g_k \sigma + \rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}} 2A_{k,t}$ where $\Omega := \left(\delta^{-1}\Lambda\right)^{\frac{\beta}{\alpha+\beta}} \gamma^{\frac{\gamma}{\alpha+\beta}}$.

3. The Solution for Case 1

In Case 1, free international trade is possible, international patent protection is guaranteed and technological knowledge is now internationally mobile. Since both countries are identical by assumption, [A.4.7] implies that free trade doubles the demand for each differentiated capital good. Consequently, following the same derivation as given for Case 2, this implies that the price for a blueprint doubles, such that [A.4.35] holds again:

[A.4.35] $p_{A,k,t} = 2(\alpha + \beta)\gamma \; r_{k,t}^{-1} L_{Y,k,t}^{\alpha} H_{Y,k,t}^{\beta} X_{i,k,t}^{\gamma}$.

However, now international mobility of technological knowledge doubles the stock of capital knowledge in the production function for new blueprints. Therefore, [A.4.10] must be rewritten in the following way:

[A.4.41] $\dot{A}_{k,t} = \delta 2A_{k,t} H_{A,k,t}$.

Consequently, the marginal productivity of human capital used for the production of blueprints equals now:

$$[A.4.42]\ \frac{\delta \dot{A}_{k,t}}{\delta H_{A,k,t}} = w_{H,A,k,t} = 4\delta\, A_{k,t}\,(\alpha+\beta)\gamma\ r_{k,t}^{-1}\, L_{Y,k,t}^{\alpha}\, H_{Y,k,t}^{\beta}\, X_{i,k,t}^{\gamma}\,.$$

Thus, compared to Case 6, the marginal productivity of human capital measured in units of manufacturing output grows by factor 4. Remember that in Case 2, compared to Case 6, the marginal productivity of human capital measured in units of manufacturing output grows only by factor 2. Since, compared to Case 6, free trade doubles in each country the set of available capital goods, the manufacturing production function equals now:

$$[A.4.43]\ Y_{k,t} = L_{k,t}^{\alpha}\, H_{Y,k,t}^{\beta} \sum_{i}^{2A_{k,t}} X_{i,k,t}^{\gamma} = L_{k,t}^{\alpha}\, H_{Y,k,t}^{\beta}\, 2A_{k,t}\, X_{i,k,t}^{\gamma}\,.$$

Therefore, profit maximization of a manufacturing firm implies now (see [A.4.13]):

$$[A.4.44]\ w_{H,Y,k,t} = \beta\ L_{Y,k,t}^{\alpha}\, H_{Y,k,t}^{\beta-1}\, 2A_{k,t}\, X_{i,k,t}^{\gamma}\,.$$

In a market equilibrium wages for human capital in both sectors must be equal: $w_{H,Y,k,t} = w_{H,A,k,t}$. Inserting [A.4.42] in [A.4.44] in this equation yields now:

$$[A.4.45]\ H_{Y,k,t} = (2\delta)^{-1}\Lambda r_{k,t}\,, \text{ where } \Lambda = \beta/(\alpha+\beta)\gamma\,.$$

Accordingly, the human capital input in manufacturing is halved compared to Case 2. Thus, inserting [A.4.45] in [A.4.10] shows that human capital input in the R&D sector doubles:

$$[A.4.46]\ H_{A,k,t} = H_{k,t} - (2\delta)^{-1}\Lambda r_{k,t}\,.$$

The reason for this reallocation of capital from manufacturing to R&D is the fact that, compared to Case 6, marginal productivity of human capital in R&D grows by factor 4, while marginal productivity of human capital in manufacturing grows only by factor 2. Given the special functional form of the marginal productivity formulas of both sectors, this implies that a human capital input in manufacturing has to be halved and human capital input in R&D has to be doubled, in order to equate the marginal productivity of human capital in both sectors. Inserting [A.4.46] in [A.4.41] and solving for the growth rate yields:

$$[A.4.47]\quad g_k := \frac{\dot{A}_k}{A_k} = 2\delta H_k - \Lambda r_k .$$

Combining this with the formula for the interest rate, which follows from the intertemporal maximization problem of a representative household ([A.4.18]), and solving for the growth rate yields:

$$[A.4.48]\quad \hat{g}_k = \frac{2\delta\, H_k - \Lambda\rho}{1+\sigma\Lambda} .$$

Comparing this growth rate with the growth rate of the Cases 2, 6, and 8, i.e., $\breve{g}_k$, shows that the following inequality holds:

$$[A.4.49]\quad \hat{g}_k = \frac{2\delta H_k - \Lambda\rho}{1+\sigma\Lambda} = 2\frac{\delta H_k - 0.5\Lambda\rho}{1+\sigma\Lambda} > 2\breve{g}_k = 2\frac{\delta H_k - \Lambda\rho}{1+\sigma\Lambda} .$$
$$\Leftrightarrow \hat{g}_k > 2\breve{g}_k .$$

Thus, the growth rate more than doubles in Case 1 compared to the Cases 2, 6 and 8. To determine the steady-state level of manufacturing output, remember that free international trade implies a doubling of the set of available differentiated capital goods (see [A.4.43]). At the same time, the input of human capital halves by [A.4.45]. Consequently, inserting [A.4.45] in [A.4.43] shows that the level of manufacturing output equals now the autarky level ([A.4.28]):[204]

$$[A.4.50]\quad \overline{Y}_{k,t} = 2^{\frac{\alpha}{\alpha+\beta}}\,\Omega\left(g_k\sigma+\rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}}\, L_k^{\frac{\alpha}{\alpha+\beta}}\, A_{k,t} \text{ where } \Omega := \left(\delta^{-1}\Lambda\right)^{\frac{\beta}{\alpha+\beta}}\, \gamma^{\frac{\gamma}{\alpha+\beta}} .$$

4. The Solution for Case 3

In Case 3 free international trade is possible, technological knowledge is internationally mobile, but international patent protection is not guaranteed. If it is assumed that governments do not regulate the usage of foreign blueprints, anyone can use foreign blueprints to produce capital goods. Since free international trade allows to export those capital goods to the country where they have been invented, there is perfect competition on the market for capital goods. Consequently, the per period rental rate of reproducing a capital good equals the per period marginal costs. Given

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204 All statements comparing the manufacturing output levels hold only for identical stocks of technological knowledge, $A_{k,t}$.

the production technology for capital goods, the per period marginal costs equal the interest rate (see [A.4.4]). Therefore, the per period profit from the production of a capital good is zero, such that the price of a blueprint (which equals the discounted value of the per period profits) is zero, too. As a result there is no incentive for the production of blueprints. Consequently, the growth rate of the stock of technological knowledge is zero and the economy does not grow. If there is an initial endowment with technological knowledge of $A_{k,0}$, the level of the manufacturing output equals:

$$[A.4.51]\ \hat{Y}_{k,t} = \left(g_k \sigma + \rho\right)^{\frac{-\gamma}{\alpha+\beta}}\ 2A_{k,0}\,\gamma^{\frac{2\gamma}{\alpha+\beta}}\,L_k^{\frac{\alpha}{\alpha+\beta}}\,H_k^{\frac{\beta}{\alpha+\beta}},$$

where H_k equals the total endowment with human capital of country *k*.

5. The Solution for Case 7

In Case 7, technological knowledge is internationally mobile, international patent protection is not guaranteed and international trade is not possible. Compared to Case 3, the prohibition of international trade implies that the domestic market is protected against foreign imitators of domestically produced blueprints. Consequently, domestic owners of blueprints are able to sell their differentiated capital goods at monopolistic prices at the domestic market and gain thereby nonzero profits. Therefore, compared to Case 3, in the absence of international patent protection restrictions on foreign trade can ensure the incentives to perform R&D. To derive the solution of Case 7 analytically, consider that international mobility of technological knowledge has two implications here. First, the foreign stock of technological knowledge enters the R&D production function. Given the assumption of two identically endowed countries, this implies that the stock of technological knowledge in R&D doubles:[205]

$$[A.4.52]\ \dot{A}_{k,t} = \delta\, 2A_{k,t}\, H_{A,k,t}.$$

Therefore, the marginal productivity of human capital in R&D doubles, such that [A.4.12] has to be rewritten in the following way:

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205 As technological knowledge is internationally mobile, there is no incentive to invent a blueprint that has already been invented abroad. Therefore, the intersection set of blueprints of both countries is empty, $A_{A,t} \cap A_{B,t} = 0$. Consequently, the number of available blueprints, i.e., the stock of knowledge capital, actually doubles, if there is international mobility of knowledge.

[A.4.53] $w_{H,A,k,t} = \delta 2A_{k,t} (\alpha+\beta)\gamma \; r_{k,t}^{-1} L_{Y,k,t}^{\alpha} H_{Y,k,t}^{\beta} X_{i,k,t}^{\gamma}$.

The second effect of the international mobility of technological knowledge is the doubling of the set of available differentiated capital goods.[206] Therefore, the marginal productivity of human capital in manufacturing doubles also (compared to Case 6) and [A.4.13] has to be rewritten:

[A.4.54] $w_{H,Y,k,t} = \beta \; L_{Y,k,t}^{\alpha} H_{Y,k,t}^{\beta-1} \; 2A_{k,t} X_{i,k,t}^{\gamma}$.

In a market equilibrium wages for human capital in both sectors must be equal: $w_{H,Y,k,t} = w_{H,A,k,t}$. Inserting [A.4.52] and [A.4.53] in this equation yields:

[A.4.55] $H_{Y,k,t} = \delta^{-1} \Lambda r_{k,t}$, where $\Lambda = \alpha / (\alpha+\beta)\gamma$.

This shows that (compared to Case 6) no reallocation of human capital between the manufacturing and the R&D sector takes place. However, as the input of technological knowledge in R&D has doubled, the resulting growth rate is nevertheless higher than in Case 6. To see this insert [A.4.54] in [A.4.52] and solve for the growth rate with respect to [A.4.18]. This yields the following formula for the growth rate:

[A.4.56] $\ddot{g}_k = \dfrac{\delta \; H_k - \Lambda\rho}{0.5 \; + \sigma \Lambda}$.

Comparing this growth rate with those of Cases 1 and 2 yields the following ranking:

[A.4.57] $$\hat{g}_k = \frac{2\delta \; H_k - \Lambda\rho}{1+\sigma\Lambda} > \ddot{g}_k = \frac{2\delta \; H_k - 2\Lambda\rho}{1 + 2\sigma\Lambda} = \frac{\delta \; H_k - \Lambda\rho}{0.5 \; + \sigma\Lambda} > \breve{g}_k = \frac{\delta \; H_k - \Lambda\rho}{1+\sigma\Lambda} \Leftrightarrow \hat{g}_k > \ddot{g}_k > \breve{g}_k.$$

Hence, in Case 7 the growth rate is just in between the growth rate of Case 1 and Case 2 (and Cases 4, 6, 8). To determine the steady-state level of manufacturing output, consider that the set of available differentiated capital goods has doubled, while at the same time there is (compared to Case 6) no reallocation of human capital from R&D to manufacturing. Consequently, compared to Case 6, manufacturing output doubles:

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[206] Assume for simplicity that for each foreign blueprint one property right is granted by the government to a domestic capital goods producer.

[A.4.58] $\hat{Y}_{k,t} = \Omega\left(g_k\,\sigma + \rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}} L_k^{\frac{\alpha}{\alpha+\beta}}\, 2A_{k,t}$, where $\Omega := \left(\delta^{-1}\Lambda\right)^{\frac{\beta}{\alpha+\beta}} \gamma^{\frac{\gamma}{\alpha+\beta}}$.

6. The Solution for Case 5

In Case 5, technological knowledge is internationally mobile, international trade is not possible, but international patent protection is guaranteed. International mobility of technological knowledge has the implication that the foreign stock of technological knowledge enters the R&D production function, such that the stock of technological knowledge doubles:

[A.4.59] $\dot{A}_{k,t} = \delta\, 2A_{k,t}\, H_{A,k,t}$.

Consequently, the marginal productivity of human capital in R&D doubles and the following equation holds:

[A.4.60] $w_{H,A,k,t} = \delta\, 2A_{k,t}\left(\alpha+\beta\right)\gamma\; r_{k,t}^{-1}\, L_{Y,k,t}^{\alpha}\, H_{Y,k,t}^{\beta}\, X_{i,k,t}^{\gamma}$.

However, as the usage of foreign blueprints is prohibited by the international protection of patents and foreign capital goods cannot be imported because of the absence of free trade, the set of available capital goods is restricted to the domestic set. Therefore, the marginal productivity of human capital in manufacturing equals:

[A.4.61] $w_{H,Y,k,t} = \beta\; L_{Y,k,t}^{\alpha}\, H_{Y,k,t}^{\beta-1}\; A_{k,t}\, X_{i,k,t}^{\gamma}$.

In a market equilibrium, wages for human capital in both sectors must be equal: $w_{H,Y,k,t} = w_{H,A,k,t}$. Inserting [A.4.60] and [A.4.61] in this equation yields now:

[A.4.62] $H_{Y,k,t} = \left(2\delta\right)^{-1} \Lambda r_{k,t}$, where $\Lambda = \beta/\left(\alpha+\beta\right)\gamma$.

Accordingly, the human capital input in manufacturing halves compared to Case 2. Thus, inserting [A.4.62] in [A.4.10] shows that human capital input in the R&D sector doubles:

[A.4.63] $H_{A,k,t} = H_{k,t} - \left(2\delta\right)^{-1} \Lambda r_{k,t}$.

The reason for this reallocation of capital from manufacturing to R&D is the fact that, compared to Case 6, marginal productivity of human capital in R&D doubles, while marginal productivity of human capital in manufacturing stays constant. Given the special functional form of the marginal productivity formulas of both sectors, this implies that a human capital input in manufacturing has to be halved and human capital input in R&D has to be doubled, in order to equate the marginal productivity of human capital in both sectors. Inserting [A.4.63] in [A.4.59] and solving for the growth rate yields:

[A.4.64] $g_k := \frac{\dot{A}_k}{A_k} = 2\delta\, H_k - \Lambda r_k\,.$

Combining this with the formula for the interest rate, which follows from the intertemporal maximization problem of a representative household, [A.4.18], and solving for the growth rate yields:

[A.4.65] $\bar{g}_k = \frac{2\delta\ H_k -\ \Lambda\rho}{1+\sigma\Lambda}\,.$

Hence, the growth rate reaches the same level as in Case 1, although there is no free trade. To determine the output level of manufacturing, consider that the combination of international patent protection and absence of free international trade restricts the set of available capital goods to the domestic set. Inserting [A.4.62] in the manufacturing output function yields therefore:

[A.4.66] $\breve{\bar{Y}}_{k,t} = 2^{\frac{-\beta}{\alpha+\beta}}\,\Omega\left(g_k\,\sigma+\rho\right)^{\frac{\beta-\gamma}{\alpha+\beta}}\, L_k^{\frac{\alpha}{\alpha+\beta}}\, A_{k,t},$ where $\Omega := \left(\delta^{-1}\Lambda\right)^{\frac{\beta}{\alpha+\beta}}\,\gamma^{\frac{\gamma}{\alpha+\beta}}\,.$

Appendix 5: Trade Hysteresis in the Rivera-Batiz–Romer Model

This appendix derives the solutions of the modified version of the Rivera-Batiz–Romer model (Section B.III.3). Throughout the analysis, it is assumed that technological knowledge is internationally immobile.

1. Derivation of the Basic Equations

Consider the two-country version of the Rivera-Batiz–Romer model. One country is called North with index N, the other country is called South with index S. Equation [A.5.1] displays the production function of country k. For convenience the set of differentiated capital goods is split into two subsets, which represent the stock of differentiated capital goods in the North, A_N, and in the South, A_S:[207]

$$[A.5.1]\quad Y_{k,t} = L^{\alpha}_{Y,k,t}\left(\sum_{i}^{A_N} X^{\beta}_{i,k,t} + \sum_{j}^{A_S} X^{\beta}_{j,k,t}\right) \text{ with } \alpha+\beta=1 \text{ and } 0<\alpha,\beta<1,$$

where $L_{Y,k,t}$ denotes to the labor force of country k employed in manufacturing, $X_{i,k,t}$ denotes to the input of country k of a differentiated capital good of the North, $X_{j,k,t}$ denotes to the input of country k of a differentiated capital good of the South. Assume that the production period measured in time units is large enough such that each differentiated capital good is consumed at the end of the period.[208] The output of the manufacturing sector corresponds to the neoclassical "universal good". Therefore, it can be used for consumption as well as for production of capital goods. The ownership of a blueprint allows the transformation of one unit of manufacturing output into one unit of a differentiated capital good. Given production function [A.5.1], the profit maximization problem of the representative manufacturing firm can be written:

$$[A.5.2]\quad \max_{L_{Y,k,t},\, X_{i,k,t},\, X_{j,k,t}} F_{k,t}\,!$$

$$F_{k,t} = L^{\alpha}_{Y,k,t}\left(\sum_{i}^{A_N} X^{\beta}_{i,k,t} + \sum_{j}^{A_S} X^{\beta}_{j,k,t}\right) - L_{Y,k,t}\, w_{Y,k,t} - \sum_{i}^{A_N} X_{i,k,t}\, p_{i,t} - \sum_{j}^{A_S} X_{j,k,t}\, p_{j,t}\ ,$$

where $w_{L,k,t}$ is the wage rate for raw labor of country k in period t, $p_{i,k,t}$ is the price for one unit of a differentiated capital good of the North in period t, $p_{i,k,t}$ is the price for one unit of a differentiated capital good of the South in period t. The first-order condition for the optimal input quantity of a capital good of the North, $X_{i,k,t}$, of the representative firm equals:

$$[A.5.3]\quad \frac{\delta F_{k,t}}{\delta X_{k,i}} = \beta\, L^{\alpha}_{Y,k,t}\, X^{\beta-1}_{i,k,t} - p_{i,t} \overset{!}{=} 0\ .$$

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[207] In order to avoid indivisibility problems it has to be assumed that the set of differentiated goods A_k is a continuum. Therefore, instead of the summation symbol an integral symbol should be used. However, for convenience, throughout the analysis a summation symbol is used here.

[208] This assumption differs from the corresponding assumption of the Rivera-Batiz–Romer model in Appendix 4. This modification simplifies the algebra, because it excludes the emergence of some uncomfortable polynomial expressions.

The corresponding condition for the optimal input quantity of a capital good of the South, $X_{j,k,t}$, is analogous. From [A.5.3] follows the demand of country k for a differentiated capital good:

$$[\text{A.5.4}]\quad X_{i,k,t} = \left(\beta \; L^{\alpha}_{Y,k,t} \; p^{-1}_{i,t} \right)^{\frac{1}{\alpha}} .$$

Summing up, the demand for a single differentiated capital good of both countries yields then:

$$[\text{A.5.5}]\quad \hat{X}_{i,t} := \sum_{k}^{N,S} X_{i,k,t} \Leftrightarrow \hat{X}_{i,t} = \sum_{k}^{N,S} \left(\beta \; L^{\alpha}_{Y,k,t} \; p^{-1}_{i,t} \right)^{\frac{1}{\alpha}} .$$

Solving for the price yields:

$$[\text{A.5.6}]\quad p_{i,t} = \left(\sum_{k}^{N,S} \left(\beta \; L^{\alpha}_{Y,k,t} \right)^{\frac{1}{\alpha}} \right)^{\alpha} \hat{X}^{-\alpha}_{i,t} .$$

Since an eternal patent is granted for a blueprint, capital goods are sold at monopolistic prices. The resulting maximization problem accounts only for the variable costs of capital goods production, because the production costs of a blueprint are fixed. Since the costs for the production of one unit of the capital good equal the price of one unit of manufacturing output, the monopolistic price for one unit of a differentiated capital good is found by solving the following maximization problem:

$$[\text{A.5.7}]\quad \max_{\hat{X}_{i,t}} \Pi ! \text{ with } \Pi_{i,t} = \hat{X}_{i,t} \; p_{i,t} - \hat{X}_{i,t} ,$$

where $\Pi_{i,t}$ equals the per period profit of the owner of a blueprint. As the profit function is concave with respect to $\hat{X}_{i,t}$, the profit maximizing price is found by setting the first-order derivations with respect to $\hat{X}_{i,t}$ zero:

$$[\text{A.5.8}]\quad \frac{\delta \Pi_{i,t}}{\delta \hat{X}_{i,t}} = p_{i,t} - 1 - \hat{X}_{i,t} \, \alpha \left(\sum_{k}^{N,S} \left(\beta \; L^{\alpha}_{Y,k,t} \right)^{\frac{1}{\alpha}} \right)^{\alpha} \hat{X}^{-1-\alpha}_{i,t} \overset{!}{=} 0 ,$$

$$\frac{\delta \Pi_{i,t}}{\delta \hat{X}_{i,t}} = p_{i,t} - 1 - \alpha \; p_{i,t} \overset{!}{=} 0 .$$

This yields the following monopolistic price:[209]

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[209] Comparing this price with that of the Rivera-Batiz–Romer model of Appendix 4, remember that, contrary to Appendix 4, here a capital good is consumed within one period.

$$[A.5.9]\ p_{i,t} = \frac{1}{\beta}.$$

Prices of foreign and domestic capital goods are equal, because the same procedure has to be applied for the profit maximization problem of a foreign capital goods producer:

$$[A.5.10]\ p_{i,t} = p_{j,t} = \frac{1}{\beta}.$$

The per period profit of a capital goods producer can be written in the following way:

$$[A.5.11]\ \Pi_{i,t} = \left(p_{i,t} - 1\right)\hat{X}_{i,t} = \left(\frac{\alpha}{\beta}\right)\hat{X}_{i,t}.$$

As the ownership of a blueprint for a differentiated good allows to eternally capture this profit, the price of a blueprint equals the present value of an eternal rent of $\Pi_{i,k,t}$. Since in steady state the interest rate, $r_{k,t}$, is constant, this yields a price for a blueprint of:

$$[A.5.12]\ p_A = \frac{\Pi_{i,t}}{r} = \left(\frac{\alpha}{\beta}\right)\hat{X}_{i,t}\, r^{-1}.$$

The production function for new blueprints equals:

$$[A.5.13]\ \dot{A}_k = \delta\, A_k\, L_{A,k}.$$

Therefore:

$$[A.5.14]\ \frac{\delta \dot{A}_k}{\delta L_{A,k}} = \delta\, A_k.$$

Since there is free access to the production of blueprints, blueprint producers compete on the labor market. Therefore, labor is paid according to its marginal productivity. The marginal productivity of labor used for the production of blueprints (measured in units of manufacturing output) equals:

Therefore, the marginal per period usage cost of a capital good equals one and not the interest rate. Therefore, intuitively spoken, the "mark-up" formula for a monopolistic price applies to unity and not to the interest rate (compare [A.5.10] to [A.4.6]).

[A.5.15] $w_{A,k} = \dfrac{\delta \dot{A}_k}{\delta L_{A,k}} p_A = \delta A_k \left(\dfrac{\alpha}{\beta}\right) \hat{X}_{i,t} r^{-1} = \delta A_k \left(\dfrac{\alpha}{\beta}\right) r^{-1} \sum_k^{N,S} \left(\beta L^{\alpha}_{Y,k,t} p^{-1}_{i,t}\right)^{\frac{1}{\alpha}}$

$\Leftrightarrow w_{A,k} = \delta A_k \alpha \beta^{1+\frac{2\beta}{\alpha}} r^{-1} \left(L_{Y,N,t} + L_{Y,S,t}\right).$

From [A.5.10] follows in market equilibrium:

[A.5.16] $X_{i,k,t} = X_{j,k,t}$.

Hence, [A.5.1] can be rewritten:

[A.5.17] $Y_{k,t} = L^{\alpha}_{Y,k,t} \left(A_N + A_S\right) X^{\beta}_{i,k,t}$.

Since manufacturers also compete on the labor market, labor is paid according to its marginal productivity in manufacturing. Hence, the wage in manufacturing equals:

[A.5.18] $\dfrac{\delta Y_{k,t}}{\delta L_{Y,k,t}} = w_{Y,k,t} = \alpha L^{\alpha-1}_{Y,k,t} \left(A_N + A_S\right) X^{\beta}_{i,k,t}$.

Inserting [A.5.4] yields:

[A.5.19] $\dfrac{\delta Y_{k,t}}{\delta L_{Y,k,t}} = w_{Y,k,t} = \alpha \beta^{\frac{2\beta}{\alpha}} \left(A_N + A_S\right).$

In a market equilibrium with active manufacturing (and in R&D sectors), wages must be equal, $w_{Y,k,t} = w_{A,k,t}$, such that

[A.5.20] $\alpha\beta^{\frac{2\beta}{\alpha}} \left(A_N + A_S\right) = \delta A_k \alpha \beta^{1+\frac{2\beta}{\alpha}} r^{-1} \left(L_{Y,N,t} + L_{Y,S,t}\right).$

Setting $k = N$ and solving for $L_{Y,N,t}$ yields:

[A.5.21] $L_{Y,N,t} = \left(\beta\delta\right)^{-1} \dfrac{A_{N,t} + A_{S,t}}{A_{N,t}} r_t - L_{Y,S,t}$.

Setting $k = S$ and solving for $L_{Y,S,t}$ yields:

[A.5.22] $L_{Y,S,t} = \left(\beta\delta\right)^{-1} \dfrac{A_{N,t} + A_{S,t}}{A_{S,t}} r_t - L_{Y,N,t}$.

2. Compensation of Production Factors

Before the different steady-state solutions are derived, consider the compensation of the production factors. From [A.5.19] and [A.5.20] follows that wages must equal across countries and across sectors, if both countries are engaged in both sectors:

[A.5.23] $w_{Y,N,t} = w_{A,N,t} = w_{Y,S,t} = w_{A,S,t}$.

Labor is paid according to its marginal productivity. Capital goods are paid according to their monopolistic price, $p_{i,t}$. The input quantities of capital goods are reduced, such that the monopolistic price equals the marginal productivity of capital goods. As the following shows, this implies that the sum of labor and capital goods compensation absorbs the whole output of manufacturing. The share of labor compensation in total manufacturing output equals because of [A.5.17] and [A.5.18]:

[A.5.24] $L_{Y,k,t}\, w_{Y,k,t} = \alpha\, L_{Y,k,t}^{\alpha} \left(A_N + A_S\right) X_{i,k,t}^{\beta} = \alpha\, Y_{k,t}$.

From [A.5.3] follows:

[A.5.25] $X_{i,k,t}\; p_{i,t} = \beta\; L_{Y,k,t}^{\alpha}\, X_{i,k,t}^{\beta}$,

[A.5.26] $X_{j,k,t}\; p_{i,t} = \beta\; L_{Y,k,t}^{\alpha}\, X_{j,k,t}^{\beta}$.

Multiplying [A.5.25] and [A.5.26] with A_N resp. A_S and adding both equations yields then:

[A.5.27] $A_N\, X_{i,k,t}\; p_{j,t} + A_S\, X_{j,k,t}\; p_{i,t} = \beta\; L_{Y,k,t}^{\alpha} \left(A_N + A_S\right) X_{i,k,t}^{\beta} = \beta Y_{k,t}$.

As $\alpha + \beta = 1$, adding the left-hand sides of [A.5.24] and [A.5.27] yields total manufacturing output, $Y_{k,t}$. Consequently, the sum of labor and capital goods compensation absorbs the whole output of manufacturing. Blueprints for capital goods, A_k, are paid according to [A.5.12]. Inserting [A.5.5] and reorganizing the terms yields:

[A.5.28] $$\Pi_{i,t} = \left(p_{i,t} - 1\right) \hat{X}_{i,t} = \frac{\alpha}{\beta}\left(\beta^{\frac{2}{\alpha}}\, L_{Y,N} + \beta^{\frac{2}{\alpha}}\, L_{Y,S}\right)$$
$$= \alpha\,\beta\left(\beta^{\frac{2\beta}{\alpha}}\left(A_N + A_S\right) L_{Y,N} + \beta^{\frac{2\beta}{\alpha}}\left(A_N + A_S\right) L_{Y,S}\right)\left(A_{N+} + A_S\right)^{-1}.$$

Inserting [A.5.3] in [A.5.17] yields:

[A.5.29] $Y_{k,t} = \beta^{\frac{2\beta}{\alpha}}\left(A_N + A_S\right) L_{Y,k,t}$.

Therefore, [A.5.28] can be rewritten in the following way:

$$[A.5.30]\ \Pi_{i,t} = \alpha\,\beta\left(Y_N + Y_S\right)\left(A_N + A_S\right)^{-1}.$$

However, it is interesting to note that the marginal productivity of the knowledge to produce an additional capital good is higher than $\Pi_{i,t}$. The following calculation reveals this: to derive the marginal productivity of $A_{k,t}$, the total amount of savings and the capital stock has to be kept constant. The capital stock is given by the following equation:[210]

$$[A.5.31]\ K_{k,t} = \left(\sum_{i}^{A_N} X_{i,k,t} + \sum_{j}^{A_S} X_{j,k,t} \right).$$

Due to [A.5.16], in a market equilibrium this equals:

$$[A.5.32]\ K_{k,t} = \left(A_N + A_S\right) X_{i,k,t}.$$

Inserting this into [A.5.1] yields:

$$[A.5.33]\ Y_{k,t} = L_{Y,k,t}^{\alpha}\left(A_N + A_S\right)^{1-\beta} K_{k,t}^{\beta}.$$

Taking the first derivation of [A.5.33] with respect to $A_N + A_s$ yields then:

$$[A.5.34]\ \frac{\delta Y_{k,t}}{\delta A_{k,t}} = \alpha\ L_{Y,k,t}^{\alpha}\ X_{i,k,t}^{\beta}.$$

Consequently, the total marginal productivity of A_k in manufacturing output of both countries equals:

$$[A.5.35]\ \frac{\delta Y_{N,t}}{\delta A_{k,t}} + \frac{\delta Y_{S,t}}{\delta A_{k,t}} = \alpha\left(L_{Y,N,t}^{\alpha}\ X_{i,N,t}^{\beta} + L_{Y,S,t}^{\alpha}\ X_{i,S,t}^{\beta}\right)$$
$$= \alpha\left(Y_N + Y_S\right)\left(A_{N+} + A_S\right)^{-1}.$$

Comparing [A.5.35] with [A.5.30] shows that the per period increase of marginal productivity generated by a new blueprint is by factor $1/\beta$ higher than the per period compensation paid for a new blueprint. Romer (1986) hints at this kind of

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210 [A.5.31] is the aggregated physical capital stock. This aggregation is possible, because the input quantities of all differentiated capital goods are equal and all capital goods have the same market value, $p_{i,t}$. Consequently, if instead of the aggregated physical capital stock the value of the aggregated capital stock (i.e., the sum over all differentiated capital goods multiplied by their price) were used, the above calculation would not change.

(Marshallian) externality from the production of blueprints. It follows from the fact that the first derivation of production function [A.5.1] with respect to a capital good does not include the productivity effect of the introduction of a new capital good. This productivity effect of the introduction of a new capital good stems from the fact that different types of capital goods are not perfect substitutes (see the discussion of the productivity effect of new capital goods in Section B.II). The technical elasticity of substitution between different types of capital goods equals $1/(1-\beta)$ (see Appendix 1). Consequently, as $0<\beta<1$ the elasticity is finite and capital goods are imperfect substitutes.

Besides this technical externality of capital goods variety there exists another kind of externality that may be called monetary externality. It stems from the fact that a new capital good increases the productivity of capital investments. As it is assumed that households perform Ramsey-type intertemporal utility maximization (see Appendix A.3.3), capital supply is interest elastic. Therefore, new capital goods increase savings and capital accumulation. To capture this effect, one has to take the first derivation of the manufacturing production function, [A.5.1], without holding constant the total amount of savings and the aggregated capital stock. As the price of capital goods is interest inelastic (see [A.5.9]), a new blueprint increases the capital stock in each country by $X_{i,t}=\beta^{2/\alpha}L_{Y,k,t}$ (insert [A.5.9] in [A.5.3]). Consequently, the total effect of the introduction of a new capital good in manufacturing output is given by the first derivation of [A.5.17] with respect to $A_{k,t}$:

$$[A.5.36]\quad \frac{\delta Y_{N,t}}{\delta A_{k,t}}+\frac{\delta Y_{S,t}}{\delta A_{k,t}}=\left(L_{Y,N,t}^{\alpha}\ X_{i,N,t}^{\beta}+L_{Y,S,t}^{\alpha}\ X_{i,S,t}^{\beta}\right)=\left(Y_N+Y_S\right)\left(A_N+A_S\right)^{-1}.$$

Comparing [A.5.36] with [A.5.30] shows that the total effect of a new blueprint on the output of the manufacturing sector of both countries is higher than its compensation by a factor of $1/\alpha\beta$. Given these strong externalities it is clear that the decentralized market equilibria of the model, which are derived in the following sections, are not Pareto-efficient. Typically, a potential for welfare improvements exists.

3. Steady State (2): The North Performs Manufacturing and R&D, the South is Specialized in Manufacturing

a. The Growth Rate of Technological Knowledge in Steady State (2)

In this section, the growth rate of Steady State (2) is determined. In this steady state the North is diversified in R&D and manufacturing, while the South is specialized in manufacturing only. Consequently, the following allocation of the labor forces must hold:

$$[A.5.37]\ L_{A,S}=0 \Leftrightarrow \dot{A}_S=0 \Leftrightarrow L_{Y,S}=\overline{L}_S,$$

$$[A.5.38]\ L_{A,N}>0 \Leftrightarrow \dot{A}_N>0 \Rightarrow L_{A,N}=\frac{\dot{A}_N}{A_N}\delta^{-1}=g_N\ \delta^{-1}$$

$$\Rightarrow L_{Y,N}=\overline{L}_N-g_N\ \delta^{-1}$$

where g_N equals the steady-state growth rate of the stock of technological knowledge, or blueprints. Given the same assumptions concerning household preferences as in the Solow–Ramsey model (Appendix A.3.3), from the intertemporal utility optimization problem of the representative household follows (see [A.3.24]):

$$[A.5.39]\ r_t=\frac{\dot{c}_t}{c_t}\sigma+\rho\,.$$

As will be shown in the next section, the steady-state growth rate of consumption equals the steady-state growth rate of capital variety, $\dot{c}/c=g_N$. Therefore, [A.5.39] can be rewritten:

$$[A.5.40]\ r_t=g_N\,\sigma+\rho\,.$$

Inserting [A.5.37], [A.5.38] and [A.5.40] in [A.5.21] and solving for g_N yields the steady-state growth rate of technological knowledge in the North:

$$[A.5.41]\ g_N=\frac{\beta\delta\ \left(\overline{L}_N+\overline{L}_S\right)-\ \rho}{\beta+\sigma}\,.$$

b. *Steady-State Growth Rates of GDP, Manufacturing Output, Capital Stock and Consumption in Steady State (2)*

Taking the first derivation from [A.5.29] with respect to time and dividing through [A.5.29] yields the growth rate of manufacturing output of both countries:

$$[A.5.42]\ \frac{\dot{Y}_{k,t}}{Y_{k,t}}=\frac{\dot{A}_{k,t}}{A_{k,t}}=g_N\,.$$

From [A.5.32] follows the steady-state growth rate of the capital stock (remind that $X_{i,k,t}$ is time-invariant):

[A.5.43] $\frac{\dot{K}_{k,t}}{K_{k,t}} = \frac{\dot{A}_{N,t}}{A_{N,t}} = g_N .$

The output of the manufacturing sector is used for consumption and capital investment:[211]

[A.5.44] $Y_{k,t} = C_{k,t} + K_{k,t} \Leftrightarrow \frac{C_{k,t}}{Y_{k,t}} = 1 - \frac{K_{k,t}}{Y_{k,t}} .$

Together with [A.5.42] and [A.5.43] this implies:[212]

[A.5.45] $\frac{\dot{C}_{k,t}}{C_{k,t}} = \frac{\dot{c}_{k,t}}{c_{k,t}} = g_N .$

Hence, the assumption of [A.5.40] that consumption grows with the same rate as the number of blueprints for new capital goods actually holds in steady state. Next, the growth rate of GDP is determined. GDP equals manufacturing output plus the output of the R&D sector valued in manufacturing units, p_A :

[A.5.46] $GDP_{k,t} = Y_{k,t} + \dot{A}_{k,t} \ p_{A,t} .$

Taking the first derivation from [A.5.46] with respect to time and dividing through [A.5.46] yields:[213]

[A.5.47] $\frac{\dot{GDP}_{k,t}}{GDP_{k,t}} = \frac{\dot{Y}_{k,t} + \ddot{A}_{k,t} \ p_{A,t}}{Y_{k,t} + \dot{A}_{k,t} \ p_{A,t}} = \frac{Y_{k,t} \, g_N + \dot{A}_{k,t} \, g_N \ p_{A,t}}{Y_{k,t} + \dot{A}_{k,t} \ p_{A,t}} = g_N .$

Hence, together with [A.5.42] the expression [A.5.47] implies that, whether a country performs R&D or not, the growth rate of per capita GDP is the same. Hence, the GDP steady-state growth rate of North and South is identical in every type of steady state.[214]

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211 Remember that the production period is chosen long enough such that the total capital stock is eroded at the end of the period and new investment equals the capital stock, $I_{k,t} = K_{k,t}$.

212 Define $C / L = c$ and remember that the labor force does not grow by assumption such that $C / L = C / L = c$.

213 From [A.5.13] follows in the steady state: $\frac{\ddot{A}_k}{\dot{A}_k} = \frac{\dot{A}_k}{A_k} = g$.

214 Since the growth rates of output in manufacturing and R&D are equal, the Grossman–Helpman procedure of growth rate determination (weighting the growth rate of each sector by its share in total GDP) yields the same result.

c. Determination of Wages and Levels of Per Capita GDP in Steady State (2)

From [A.5.19] and [A.5.20] follows that wages must equal across countries, if both countries are engaged in manufacturing:

[A.5.23] $w_{Y,N,t} = w_{A,N,t} = w_{Y,S,t} = w_{A,S,t}$.

Consequently, per capita labor income is the same in North and South. Nevertheless, capital income can principally diverge in both countries as the different pattern of specialization can offer investment possibilities of different volumes.[215] Given perfect international financial markets this would of course not affect the investment possibilities of a single household. However, if financial markets were imperfect, the country with the larger investment possibilities would offer its inhabitants better investment opportunities. As the wage rates in both countries are equal, the country with the higher per capita income offers more per capita investment possibilities.[216] Therefore, the level of per capita GDP is compared as follows. Inserting [A.5.29], [A.5.12] and [A.5.13] into [A.5.46] yields for the per capita GDP of the North:

[A.5.48] $$\frac{GDP_{N,t}}{L_{N,t}} = \beta^{\frac{2\beta}{\alpha}} A_N \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{g}{r} \alpha \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{L_{S,t}}{L_{N,t}} \right) \right) .$$

The same procedure yields for the per capita GDP of the South:

[A.5.49] $$\frac{GDP_{S,t}}{L_{S,t}} = \beta^{\frac{2\beta}{\alpha}} A_N .$$

Inserting [A.5.49] into [A.5.48] yields:

[A.5.50] $$\frac{GDP_{N,t}}{L_{N,t}} = \frac{GDP_{S,t}}{L_{S,t}} \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{g}{r} \alpha \beta \left(\frac{L_{Y,N,t}}{L_{N,t}} + \frac{L_{S,t}}{L_{N,t}} \right) \right) .$$

Consequently, per capita GDP in the North is higher than per capita GDP in the South, if the term in brackets is greater than one and vice versa. To determine the value of the term in brackets, insert [A.5.38] and [A.5.40] into the brackets of [A.5.50]. This yields the following expression:

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215 The volume of investment possibilities may diverge even though the return from investment, i.e., the interest rate is equal in both countries.

216 This follows from the fact that within this model labor and capital compensation must equal total GDP.

$$[A.5.51]\ 1-\frac{\beta}{\beta+\sigma}-\frac{\beta L_{S,t}-\rho\delta^{-1}}{L_{N,t}(\beta+\sigma)}$$
$$+\left(\sigma+\rho\frac{\beta+\sigma}{\beta\delta\left(L_{N,t}+L_{S,t}\right)-\rho}\right)^{-1}\alpha\beta\left(1-\frac{\beta}{\beta+\sigma}-\frac{\beta L_{S,t}-\rho\delta^{-1}}{L_{N,t}(\beta+\sigma)}+\frac{L_{S,t}}{L_{N,t}}\right).$$

The magnitude of this expression depends on the concrete values of the structural parameters of the economy and the size of North and South, $L_{S,t}$ and $L_{N,t}$. Unfortunately, it cannot be determined without further assumptions. However, it is possible to draw the limits for large L_N and L_S. Doing this, it has to be taken into consideration that Steady State (2), which is analyzed here, does only emerge if L_S compared to L_N is not too large. If the ratio L_S / L_N grows large, R&D wages in the North may become higher than manufacturing wages (see [A.5.19] and [A.5.15]). In this case, the labor force of the North would completely shift from manufacturing to R&D, such that the North would completely specialize in R&D. Thus, Steady State (3) would emerge. Therefore, an evaluation of expression [A.5.51] by taking the limits with respect to L_N and L_S has to be subjected to the condition that $w_{Y,N}=w_{A,N}$. Inserting [A.5.19] and [A.5.15] in this equation shows that this condition implies $\delta\sigma L_N-(1+\sigma)\delta L_{Y,N}+\rho=\beta\delta L_S$. Consequently, holding L_S constant and taking the limit with respect to $L_{N,t}\rightarrow\infty$ does not hurt the condition $w_{Y,N}=w_{A,N}$.[217] Taking the limits for $L_{N,t}\rightarrow\infty$ expression [A.5.51] turns to:

$$[A.5.52]\ \frac{\beta\alpha+\sigma}{\beta+\sigma}.$$

Consequently, if $0<\alpha<1$, as implied by the Cobb–Douglas specification of [A.5.1], this expression must be smaller than unity. Hence, if the North is sufficiently large, the production of blueprints in Steady State (2) may indeed be compatible with a lower per capita income than the production of manufacturing goods. If one chooses L_N such that $w_{Y,N}=w_{A,N}$ always holds as L_S is increased, i.e., $L_N=L_S(\beta/\sigma)-\rho/\sigma\delta$, and takes the limit for $L_S\rightarrow\infty$, expression [A.5.51] turns to α and is, hence, again smaller than unity.[218] Consequently, if the scale of both economies grows large and L_N is not too small compared to L_S, the production of

217 As L_N is allocated to manufacturing and R&D, any increase of L_N is split between both sectors such that the pattern of specialization does not change. From [A.5.19] follows that an increase of $L_{Y,N}$ that would generate a higher wage rate in R&D compared to manufacturing, is automatically reduced by a reallocation of labor towards R&D (such that $L_{Y,N}$ decreases again).

218 This results by inserting $L_N=L_S(\beta/\sigma)-\rho/\sigma\delta$ into expression [A.5.51] and taking the limit $L_S\rightarrow\infty$.

blueprints may also go hand in hand with a lower per capita income than the production of manufacturing goods in Steady State (2).

4. Steady State (3): The North is Specialized in R&D; the South is Specialized in Manufacturing

a. The Growth Rate of Technological Knowledge in Steady State (3)

In this section the steady-state growth rate is determined for Steady State (3), where the North is perfectly specialized in R&D, and the South is perfectly specialized in manufacturing. In Steady State (3), the following allocation of labor forces must hold:

[A.5.54] $L_{Y,S} = L_S$,

[A.5.55] $L_{A,N} = L_N$.

Inserting [A.5.29] into [A.5.13] yields the steady-state growth rate of R&D output:

[A.5.56] $g_N = \frac{\dot{A}_{k,t}}{A_{k,t}} = \delta \ L_N$.

This growth rate is higher than the growth rate with diversified production in the North (i.e., [A.5.41]), because now the total labor force of the North is employed in R&D. In the case of diversified production, only a part of the labor force is engaged in R&D, whilst the other part of the labor force is employed in manufacturing.

b. Determination of Wages and Levels of Per Capita GDP in Steady State (3)

From [A.5.15] and [A.5.19] follows that wages in the North must be at least as high as wages in the South, if the North is totally specialized in the R&D sector and the South is totally specialized in the manufacturing sector:

[A.5.58] $w_{A,N,t} \geq w_{Y,S,t}$.

Inserting [A.5.19] and [A.5.15] in [A.5.58] shows that this condition implies now $L_S \geq L_N(\sigma / \beta) + \rho / \sigma \delta$ to hold. Consequently, Steady State (3) emerges only, if the South is sufficiently large compared to the North. To compare the level of per capita GDP in the North and the South, consider the GDP of the North:

[A.5.59] $GDP_{N,t} = \dot{A}_{N,t}\ p_{A,t}$.

Inserting [A.5.15] into [A.5.59] and dividing by $L_{N,t}$ yields the per capita GDP of the North:

[A.5.60] $$\frac{GDP_{N,t}}{L_{N,t}} = \beta^{\frac{2\beta}{\alpha}} A_N L_S \delta\alpha\beta r^{-1} \ .$$

Per capita GDP of the South equals per capita output of manufacturing. Hence, according to [A.5.29] per capita GDP of the South is given by the following formula:

[A.5.61] $$\frac{GDP_{S,t}}{L_{S,t}} = \beta^{\frac{2\beta}{\alpha}} A_N \ .$$

Inserting [A.5.61] into [A.5.60] and using [A.5.40], [A.5.13] and [A.5.55] to replace the interest rate, r_t , yields:

[A.5.62] $$\frac{GDP_{N,t}}{L_{N,t}} = \frac{GDP_{S,t}}{L_{S,t}} \left(\delta\alpha\beta \frac{L_S}{\delta L_N \sigma + \rho} \right) .$$

Consequently, per capita GDP in the North is higher than per capita income of the South, if the term in brackets is higher than unity, and vice versa. The magnitude of this expression depends again on the concrete values of the structural parameters of the economy and the size of the North and the South, L_S and L_N . To evaluate the term in brackets, one has to take into consideration that Steady State (3) requires equation [A.5.58] and, hence, $L_S \geq L_N(\sigma/\beta)+\rho/\sigma\delta$ to hold. Inserting the minimal value of L_S that is compatible with Steady State (3), i.e., $L_S = L_N(\sigma/\beta)+\rho/\sigma\delta$, the term in brackets just equals α. Hence, as $0<\alpha<1$, in this case per capita GDP in the North is lower than per capita GDP in the South, although the North is completely specialized in R&D and the South in specialized in manufacturing. However, holding L_N constant and increasing L_S shows that per capita GDP in the North soon approaches a value higher than per capita income in the South. This relation is shown by Figure 16 in Section B.III.3.b. Nevertheless, it is worth being stated that, even if the North is completely specialized in R&D, its per capita income may be lower than per capita income in the South.

5. Steady State (1): North and South Perform Manufacturing and R&D

In this section the growth rate of technological knowledge is determined for Steady State (1), where the North and the South have a diversified production structure. In this steady state the following allocation of labor must hold:

[A.5.63] $L_{A,S} > 0 \Leftrightarrow \dot{A}_S > 0 \Rightarrow L_{A,S} = \frac{\dot{A}_S}{A_S}\delta^{-1} = g_S\ \delta^{-1} \Rightarrow L_{Y,S} = L_S - g_S\ \delta^{-1}$,

[A.5.64] $L_{A,N} > 0 \Leftrightarrow \dot{A}_N > 0 \Rightarrow L_{A,N} = \frac{\dot{A}_N}{A_N}\delta^{-1} = g_N\ \delta^{-1} \Rightarrow L_{Y,N} = L_N - g_N\ \delta^{-1}$.

Diversified production is only sustainable, if wages in both sectors are equal. Hence, wages in both sectors must grow with an equal rate. This implies that the stock of technological knowledge in both countries must grow with an equal rate. Manufacturing wages grow with a rate equal to the growth rate of the world stock of technological knowledge ([A.5.19]); R&D wages grow with a rate equal to the growth rate of the national stocks of technological knowledge. Consequently, the following equation must hold:

[A.5.65] $g_N = g_S =: g$.

Hence, from [A.5.63] and [A.5.64] follows:

[A.5.66] $L_{Y,S} = L_S - g\ \delta^{-1}$,

[A.5.67] $L_{Y,N} = L_N - g\ \delta^{-1}$.

Inserting [A.5.66], [A.5.67] and [A.5.40] in [A.5.21] and solving for g yields the growth rate of technological knowledge in the North:

[A.5.68] $g_N = \frac{\beta\delta\left(L_N + L_S\right) - s_N^{-1}\ \rho}{\beta + s_N^{-1}\sigma}$ with $s_N = \frac{A_{N,t}}{A_{N,t} + A_{S,t}}$.

Inserting [A.5.66], [A.5.67] and [A.5.40] in [A.5.22] and solving for g yields the growth rate of technological knowledge in the South:

[A.5.69] $g_S = \frac{\beta\delta\left(L_N + L_S\right) - s_S^{-1}\ \rho}{\beta + s_S^{-1}\sigma}$ with $s_S = \frac{A_{S,t}}{A_{N,t} + A_{S,t}}$.

Both formulas equal only if $s_S = s_N$ resp. $A_{N,t} = A_{S,t}$. Hence, a diversified steady state allows only L_N and L_S to differ, but not $\dot{A}_{N,t}$ and $\dot{A}_{S,t}$, and therefore not $L_{A,N,t}$ and $L_{A,S,t}$ (see [A.5.13]).

6. Steady State (4): The North is Specialized in R&D; the South Performs Manufacturing and R&D

In this section the growth rate of technological knowledge is determined for Steady State (4), where the North is specialized in R&D and the South has a diversified production structure. In this steady state the following allocation of labor must hold:

[A.5.72] $L_{Y,N} = 0 \Leftrightarrow L_{A,N} = L_N \Leftrightarrow g_N = \delta \; L_N$,

[A.5.73] $L_{A,S} > 0 \Leftrightarrow \dot{A}_S > 0 \Rightarrow L_{A,S} = \dfrac{\dot{A}_S}{A_S}\delta^{-1} = g_S \; \delta^{-1} \Rightarrow L_{Y,S} = L_S - g_S \, \delta^{-1}$.

Hence, following [A.5.72], [A.5.22] can be rewritten:

[A.5.74] $L_{Y,S,t} = (\alpha\beta\delta)^{-1} \dfrac{A_{N,t} + A_{S,t}}{A_{S,t}} \, r_t$.

Inserting [A.5.73] and [A.5.40] in [A.5.74] and solving for g_S yields the growth rate of technological knowledge in the South:

[A.5.75] $g_S = \dfrac{(\alpha\beta\delta)L_S - s_S^{-1}\rho}{\alpha\beta + s_S^{-1}\sigma}$.

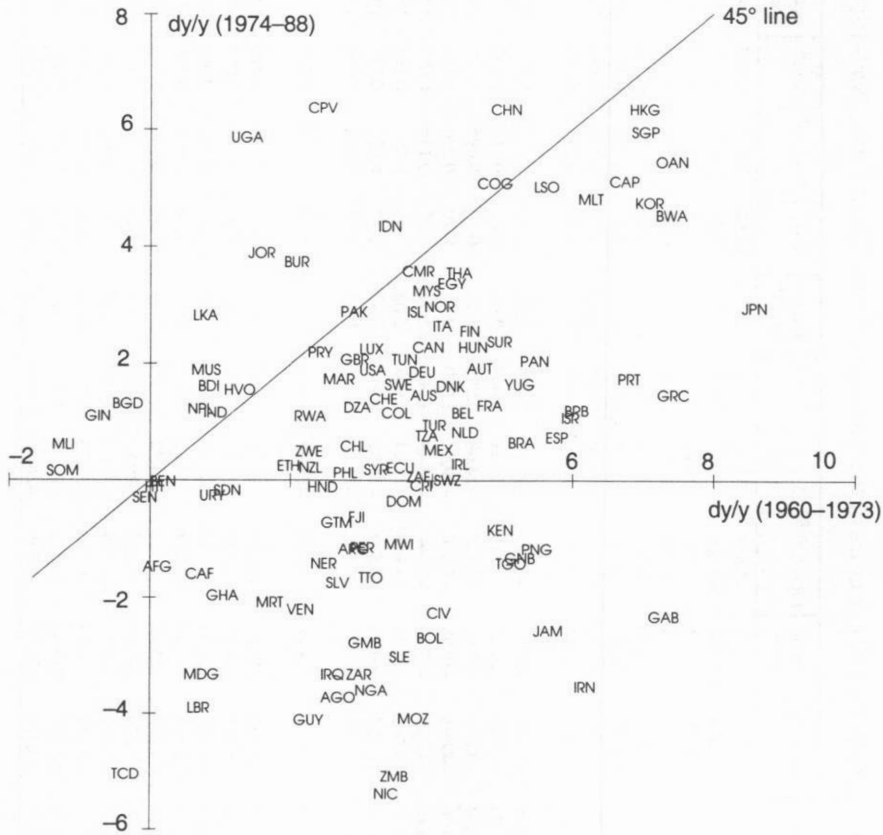
As in steady state $g_N = g_S = g$ must hold, [A.5.72] and [A.5.75] imply:

[A.5.76] $\dfrac{(\alpha\beta\delta)L_S - s_S^{-1}\rho}{\alpha\beta + s_S^{-1}\sigma} = L_N \, \delta$.

Hence, this steady state is only possible if L_S compared to L_N is sufficiently large. In this case, the share of the South in the total knowledge stock of both countries, s_S, is determined by [A.5.76].

Appendix 6: Results of Section C.I.1

Figure A.6.1 — Growth Rates of Per Capita GDP, 1960–1973 versus 1974–1988 (percent)[a]



[a]Least square growth rates of per capita GDP. The three-letter World Bank codes for country names are used to indicate a point (see the country list in Table A. 11.3).

Source: Summers and Heston (1991).

Table A.6.1 — Results of the Unit Root Tests for 120 Countries of the Summers–Heston World Table, 1950–1988[a]

Country	Obser-vations	Lag (Hall)[b]	PSW-Test[c]	ρ[d]	*t*-test (DF)[e]	*K*-test (DF)[f]	*t*-test (PP)[g]	*K*-test (PP)[h]	Sims[i]	Kahn/ Ogaki[j]	$\Phi 4$[k]	Nyblom[l]	Kim[m]	Year of break[n]	Period[o]
Algeria	22	5	0.67	0.84	–0.223	–1.24	**–5.665**	**–31.55**	0.760	0.61	**16.52**	0.837	0.252	1968	1961–1988
Angola	24	0	1.10	0.31	**–3.376**	**–16.51**	**–3.526**	**–16.51**	0.997	0.17	0.21	0.121	0.245	1975	1961–1985
Benin	28	0	1.08	0.07	**–4.879**	**–26.11**	**–5.063**	**–26.11**	1.000	–1.02	0.34	0.112	0.382	1982	1960–1988
Botswana	25	0	0.34	–0.10	**–4.774**	**–27.51**	**–4.977**	**–27.51**	1.000	1.10	0.20	0.270	0.310	1965	1961–1986
Burkina	20	2	0.44	–0.49	–2.649	**–42.84**	**–5.483**	**–22.44**	1.000	1.27	1.22	**1.655**	0.272	1979	1966–1988
Burundi	27	0	**5.56**	0.07	**–4.704**	**–25.19**	**–4.889**	**–25.19**	1.000	–0.24	0.98	0.306	0.507	1965	1961–1988
Cameroon	27	0	1.82	0.39	–2.500	**–16.50**	–2.598	**–16.50**	0.965	**5.12**	0.88	0.370	0.077	1981	1961–1988
Capverde	24	0	2.30	0.27	**–3.567**	**–17.56**	**–3.725**	**–17.56**	0.998	–0.07	0.77	0.134	0.108	1964	1961–1985
Centr. Afr. Rep.	27	0	0.75	–0.15	**–5.904**	**–31.14**	**–6.136**	**–31.14**	1.000	–0.30	0.20	0.202	0.110	1978	1961–1988
Chad	24	0	0.31	–0.09	**–4.040**	**–26.21**	**–4.219**	**–26.21**	1.000	**9.03**	0.07	0.214	0.335	1981	1961–1985
Congo	25	0	1.08	0.04	**–3.671**	**–24.08**	**–3.827**	**–24.08**	0.999	**5.25**	0.10	0.095	0.109	1982	1961–1986
Egypt	37	0	0.86	0.16	**–4.898**	**–30.98**	**–5.036**	**–30.98**	1.000	0.28	0.10	0.226	0.129	1954	1951–1988
Ethiopia	35	0	0.24	–0.10	**–7.539**	**–38.49**	**–7.764**	**–38.49**	1.000	–12.37	0.77	0.174	0.084	1982	1951–1986
Gambia	24	0	0.97	0.24	**–3.500**	**–18.24**	**–3.655**	**–18.24**	0.998	2.02	3.45	0.407	0.161	1980	1961–1985
Ghana	27	5	0.39	–0.46	–2.707	**60.93**	**–5.517**	**–26.82**	0.999	–0.30	**7.77**	0.653	**0.717**	1969	1956–1988
Guinea	21	4	0.11	0.36	–1.517	–10.35	**–7.426**	**–29.64**	0.861	–0.85	0.98	0.446	0.250	1966	1960–1985
Guinea Bissau	27	0	0.11	0.04	**–4.825**	**–25.98**	**–5.015**	**–25.98**	1.000	0.03	1.24	0.270	0.203	1970	1961–1988
Côte d'Ivoire	27	0	0.13	0.31	**–3.338**	**–18.55**	**–3.469**	**–18.55**	0.996	2.93	**10.42**	**0.733**	**0.469**	1979	1061–1988
Kenya	37	0	3.97	0.02	**–6.147**	**–36.41**	**–6.320**	**–36.41**	1.000	–4.64	0.00	0.463	0.087	1962	1951–1988
Lesotho	24	0	1.12	–0.06	**–4.770**	**–25.33**	**–4.982**	**–25.33**	1.000	0.12	0.21	0.318	0.097	1964	1961–1985
Liberia	23	2	1.15	0.39	–2.491	**–20.40**	**–3.637**	**–13.61**	1.000	–0.33	**4.70**	0.338	**0.756**	1977	1961–1986
Madagascar	27	0	0.22	0.11	**–4.398**	**–23.92**	**–4.570**	**–23.92**	1.000	1.36	3.77	**0.539**	0.175	1971	1961–1988
Malawi	33	0	2.11	0.10	**–5.059**	**–29.83**	**–5.220**	**–29.83**	1.000	–0.04	2.42	0.344	0.132	1958	1955–1988
Mali	27	0	0.33	–0.10	**–5.522**	**–29.75**	**–5.739**	**–29.75**	1.000	0.17	0.98	0.368	0.984	1964	1961–1988
Mauritania	27	0	0.29	–0.20	**–6.174**	**–32.53**	**–6.416**	**–32.53**	1.000	–0.19	0.86	0.230	0.304	1977	1961–1988
Mauritius	37	0	2.62	0.31	**–4.242**	**–25.40**	**–4.362**	**–25.40**	1.000	1.19	3.02	0.354	0.095	1954	1951–1988
Morocco	37	0	0.35	0.27	**–4.472**	**–26.93**	**–4.598**	**–26.93**	1.000	0.50	0.03	0.238	0.115	1980	1951–1988

Table A.6.1 continued

Country	Observations	Lag (Hall)[b]	PSW-Test[c]	ρ[d]	*t*-test (DF)[e]	*K*-test (DF)[f]	*t*-test (PP)[g]	*K*-test (PP)[h]	Sims[i]	Kahn/ Ogaki[j]	$\Phi 4$[k]	Nyblom[l]	Kim[m]	Year of break[n]	Period[o]
Mozambique	26	1	0.19	0.42	−2.640	**−15.80**	**−3.153**	**−14.91**	0.989	−0.21	0.70	0.447	0.206	1972	1961–1988
Niger	23	4	1.50	0.01	−1.973	**−27.75**	**−5.186**	**−27.14**	0.912	−0.53	0.88	0.519	0.257	1967	1961–1988
Nigeria	32	5	0.01	0.45	−1.858	**−24.81**	**−3.614**	**−15.46**	0.835	−0.16	0.73	0.808	0.283	1965	1951–1988
Rwanda	27	0	2.84	0.22	**−3.998**	**−20.98**	**−4.155**	**−20.98**	1.000	−0.14	0.07	0.096	0.717	1964	1961–1988
Senegal	27	0	1.93	−0.25	**−6.453**	**−33.64**	**−6.706**	**−33.64**	1.000	−0.18	0.40	0.122	0.318	1964	1961–1988
Sierra Leone	26	0	**4.42**	0.22	**−3.925**	**−20.33**	**−4.086**	**−20.33**	1.000	0.00	**9.43**	**0.768**	0.475	1983	1961–1987
Somalia	27	0	0.23	−0.32	**−6.896**	**−35.53**	**−7.166**	**−35.53**	1.000	0.30	0.01	0.143	0.285	1964	1961–1988
South Africa	37	0	3.45	0.11	**−5.304**	**−32.76**	**−5.454**	**−32.76**	1.000	−0.65	0.47	0.229	0.136	1981	1951–1988
Sudan	32	0	1.61	0.03	**−5.278**	**−31.09**	**−5.451**	**−31.09**	1.000	0.07	1.22	0.185	0.072	1984	1956–1988
Swaziland	24	0	0.28	0.03	**−4.998**	**−23.33**	**−5.220**	**−23.33**	1.000	−5.27	1.69	0.276	0.236	1980	1960–1985
Tanzania	24	3	0.31	−0.40	−2.770	**−48.88**	**−7.138**	**−34.21**	0.999	−7.01	**8.27**	0.807	0.099	1977	1961–1988
Togo	27	0	1.13	0.20	**−4.101**	**−21.58**	**−4.262**	**−21.58**	1.000	−0.11	**6.33**	**0.522**	0.192	1980	1961–1988
Tunisia	27	0	3.42	0.25	**−3.795**	**−20.38**	**−3.944**	**−20.38**	0.999	−1.04	1.34	**0.505**	0.180	1981	1961–1988
Uganda	30	4	0.38	−0.56	−2.108	**22.18**	**−3.900**	**−18.62**	0.841	0.27	0.43	**1.458**	0.000	1971	1951–1985
Zaire	37	0	0.89	0.15	**−5.319**	**−31.35**	**−5.469**	**−31.35**	1.000	−3.62	2.63	**0.743**	0.173	1974	1951–1988
Zambia	32	0	1.56	−0.01	**−5.568**	**−32.23**	**−5.751**	**−32.23**	1.000	−0.50	0.98	0.440	0.116	1975	1956–1988
Zimbabwe	33	0	2.83	−0.01	**−5.700**	**−33.43**	**−5.881**	**−33.43**	1.000	−0.88	0.19	0.294	0.175	1982	1955–1988
Barbados	24	0	0.76	0.33	**−3.286**	**−15.97**	**−3.432**	**−15.97**	0.996	−1.45	3.47	0.441	0.148	1980	1961–1985
Canada	32	5	0.20	−0.37	−2.784	103.70	**−7.786**	**−44.27**	0.998	−2.48	0.58	1.082	**0.691**	1958	1951–1988
Costa Rica	37	0	**4.80**	0.32	**−4.216**	**−25.05**	**−4.335**	**−25.05**	1.000	−0.01	3.32	**0.746**	0.110	1955	1951–1988
Dominican Rep.	37	0	0.02	−0.13	**−6.888**	**−41.69**	**−7.082**	**−41.69**	1.000	−2.88	0.66	0.282	0.074	1977	1951–1988
El Salvador	36	1	0.57	0.44	**−3.284**	**−22.99**	**−3.469**	**−19.05**	0.995	−1.08	1.37	0.740	0.132	1977	1951–1988
Guatemala	36	1	0.15	0.62	−2.368	−11.66	**−3.305**	**−15.26**	0.992	−0.03	1.50	0.489	0.562	1955	1951–1988
Haiti	27	0	0.51	−0.12	**−5.780**	**−30.15**	**−6.007**	**−30.15**	1.000	−1.49	0.22	0.228	0.169	1981	1961–1988
Honduras	37	0	0.67	0.24	**−4.418**	**−28.01**	**−4.542**	**−28.01**	1.000	3.58	0.00	0.381	0.565	1954	1951–1988
Jamaica	32	1	0.83	0.62	−2.208	−9.37	**−3.379**	**−14.31**	0.994	−1.19	1.85	0.544	0.364	1957	1954–1987
Mexico	37	0	2.74	0.34	**−4.205**	**−24.38**	**−4.323**	**−24.38**	1.000	−2.20	1.37	**0.484**	**0.855**	1981	1951–1988
Nicaragua	35	0	2.55	−0.12	**−6.481**	**−39.24**	**−6.674**	**−39.24**	1.000	−0.06	**4.63**	**0.531**	**0.417**	1979	1951–1986
Panama	35	0	**7.01**	0.05	**−5.881**	**−33.22**	**−6.056**	**−33.22**	1.000	−1.91	1.91	**0.731**	0.124	1982	1951–1986

Table A.6.1 continued

Country	Observations	Lag (Hall)[b]	PSW-Test[c]	ρ[d]	t-test (DF)[e]	K-test (DF)[f]	t-test (PP)[g]	K-test (PP)[h]	Sims[i]	Kahn/ Ogaki[j]	$\Phi 4$[k]	Nyblom[l]	Kim[m]	Year of break[n]	Period[o]
Trinidad/ Tobago	36	1	1.29	0.71	–2.086	–11.74	**–2.115**	–10.14	0.835	1.80	3.92	0.444	**0.962**	1981	1951–1988
USA	37	0	0.35	0.02	**–6.043**	**–36.10**	**–6.213**	**–36.10**	1.000	–3.47	0.49	0.196	0.113	1983	1951–1988
Argentina	35	2	0.29	–0.18	**–3.399**	**–38.30**	**–6.563**	**–35.52**	1.000	0.46	**5.19**	0.680	0.076	1981	1960–1988
Bolivia	33	4	0.13	0.76	–1.262	–5.35	**–5.054**	**–37.70**	0.709	–1.08	2.01	0.932	0.302	1974	1951–1988
Brazil	36	0	0.14	0.11	**–5.189**	**–31.88**	**–5.339**	**–31.88**	1.000	–0.12	0.95	0.303	0.075	1961	1951–1987
Chile	37	0	0.87	0.18	**–4.899**	**–30.38**	**–5.037**	**–30.38**	1.000	0.70	0.17	0.090	0.229	1954	1951–1988
Colombia	34	3	1.27	–0.09	**–3.695**	**–131.2**	**–5.898**	**–38.54**	0.999	–3.39	0.86	0.776	0.240	1960	1951–1988
Ecuador	37	0	1.91	0.34	**–4.133**	**–24.47**	**–4.250**	**–24.47**	1.000	0.87	0.40	0.189	0.198	1982	1951–1988
Guyana	37	0	3.19	0.15	**–5.081**	**–31.38**	**–5.224**	**–31.38**	1.000	–0.05	0.09	0.137	0.111	1954	1951–1988
Paraguay	37	0	0.53	0.14	**–5.247**	**–31.82**	**–5.394**	**–31.82**	1.000	–0.75	0.28	0.155	0.211	1954	1951–1988
Peru	35	2	1.33	–0.18	**–4.252**	**–143.8**	**–4.505**	**–27.83**	1.000	**3.85**	**11.82**	**1.236**	**0.411**	1975	1951–1988
Suriname	24	0	1.92	0.21	**–3.707**	**–19.06**	**–3.871**	**–19.06**	0.999	0.23	1.12	0.192	**0.534**	1978	1961–1985
Uruguay	37	0	**4.92**	0.10	**–5.924**	**–33.14**	**–6.091**	**–33.14**	1.000	–8.29	0.22	**1.253**	0.096	1967	1951–1988
Venezuela	36	0	1.01	0.21	**–4.685**	**–28.33**	**–4.821**	**–28.33**	1.000	–0.87	2.54	0.337	0.189	1978	1951–1987
Afghanistan	23	1	0.07	0.05	**–3.765**	**–33.78**	**–3.566**	**–18,00**	0.997	0.61	0.37	0.172	0,302	1964	1961–1985
Bangladesh	25	0	0.12	–0.16	**–5.647**	**–29.05**	**–5.887**	**–29.05**	1.000	–0.01	0.02	0.094	0,170	1963	1960–1985
Myanmar	34	0	1.53	–0.23	**–7.163**	**–41.92**	**–7.384**	**–41.92**	1.000	–0.22	0.17	0.181	0,087	1966	1951–1985
China	25	2	1.04	–0.31	**–4.704**	**–82.67**	**–5.714**	**–18.73**	1.000	0.55	0.78	0.406	0,809	1965	1961–1988
Hong Kong	25	2	0.16	–0.55	**–3.599**	**–99.10**	**–5.231**	**–23.79**	1.000	–0.72	0.09	0.247	0,338	1965	1961–1988
India	37	0	0.30	–0.11	**–6.371**	**–41.00**	**–6.551**	**–41.00**	1.000	2.89	0.00	0.150	0,111	1984	1951–1988
Indonesia	25	0	1.44	0.28	**–4.079**	**–18.11**	**–4.253**	**–18.11**	1.000	–1.51	0.29	0.211	**0,488**	1981	1963–1988
Iran	28	1	0.09	0.34	**–3.088**	**–21.11**	**–3.449**	**–17.44**	0.996	–0.69	0.79	0.506	**0,530**	1980	1956–1988
Iraq	29	2	0.51	–0.17	**–3.600**	**–67.14**	**–4.674**	**–23.08**	1.000	–0.08	0.79	**2.310**	0,049	1958	1954–1985
Israel	34	0	0.32	0.36	**–3.965**	**–21.92**	**–4.087**	**–21.92**	1.000	–3.59	3.55	0.407	0,105	1973	1954–1988
Japan	36	1	1.69	0.55	–2.716	**–14.90**	**–3.475**	**–16.74**	0.995	–1.39	2.65	0.427	**0,609**	1972	1951–1988
Jordan	33	0	**10.58**	–0.05	**–5.795**	**–34.54**	**–5.979**	**–34.54**	1.000	0.30	**5.24**	**0.882**	0,166	1961	1955–1988
Korea	34	0	0.86	0.21	**–4.551**	**–26.80**	**–4.691**	**–26.80**	1.000	1.70	1.84	0.267	0,155	1962	1954–1988
Kuwait	19	6	2.03	1.17	0.144	0.42	**–5.292**	**–23.00**	0.987	–1.04	**8.52**	0.866	0,000	1969	1961–1986
Malaysia	32	0	2.59	0.33	**–3.747**	**–21.34**	**–3.870**	**–21.34**	0.999	2.46	0.00	0.235	0,132	1959	1956–1988

Table A.6.1 continued

Country	Obser-vations	Lag (Hall)[b]	PSW-Test[c]	ρ[d]	*t*-test (DF)[e]	*K*-test (DF)[f]	*t*-test (PP)[g]	*K*-test (PP)[h]	Sims[i]	Kahn/Ogaki[j]	$\Phi 4$[k]	Nyblom[l]	Kim[m]	Year of break[n]	Period[o]
Nepal	24	0	0.30	–0.11	**–5.240**	**–26.64**	**–5.473**	**–26.64**	1.000	0.12	0.04	0.078	0,637	1964	1961–1985
Pakistan	37	0	2.79	0.20	**–4.805**	**–29.73**	**–4.941**	**–29.73**	1.000	0.98	0.33	0.218	0,107	1958	1951–1988
Philippines	35	2	0.37	0.32	**–3.732**	**–53.81**	**–3.073**	**–18.57**	0.999	–1.18	2.97	1.035	0,036	1980	1951–1988
Saudi Arabia	23	1	0.27	0.69	–1.356	–6.14	–2.174	–8.84	0.892	1.87	**6.65**	**0.970**	0.031	1980	1961–1985
Singapore	23	1	0.78	0.57	–1.731	–8.67	–2.390	–10.94	0.936	–0.01	0.55	0.283	0.473	1964	1961–1985
Sri Lanka	35	1	0.55	–0.66	**–5.786**	**–71.16**	**–9.243**	**–48.64**	1.000	–0.09	3.31	0.712	**0.416**	1976	1951–1987
Syria	27	0	3.41	–0.02	**–5.111**	**–27.58**	**–5.311**	**–27.58**	1.000	0.08	2.52	**0.574**	0.165	1982	1961–1988
Taiwan	36	1	0.24	0.28	**–3.644**	**–28.24**	**–4.235**	**–24.30**	1.000	–0.94	1.44	0.502	0.122	1961	1951–1988
Thailand	37	0	2.09	0.03	**–5.721**	**–35.96**	**–5.882**	**–35.96**	1.000	**3.41**	2.00	0.242	0.518	1956	1951–1988
Yemen	18	0	2.50	0.41	–2.695	–10.69	–2.859	–10.69	0.977	–1.95	**4.53**	0.371	0.334	1979	1970–1988
Austria	35	2	1.55	0.38	–2.415	**–15.68**	**–5.274**	**–31.40**	1.000	0.78	**14.41**	**1.320**	0.196	1955	1951–1988
Belgium	37	0	1.76	0.16	**–4.961**	**–31.02**	**–5.101**	**–31.02**	1.000	1.51	0.90	0.336	**0.565**	1974	1951–1988
Cyprus	37	0	0.59	0.05	**–5.626**	**–35.20**	**–5.785**	**–35.20**	1.000	0.34	0.06	0.131	0.158	1956	1951–1988
Denmark	37	0	1.71	0.06	**–5.813**	**–34.69**	**–5.976**	**–34.69**	1.000	–1.07	2.57	0.379	0.074	1973	1951–1988
Finland	31	6	0.13	–0.64	**–3.072**	**25.60**	**–5.238**	**–21.92**	0.997	1.36	2.79	0.901	0.036	1959	1951–1988
France	37	0	0.05	0.44	**–3.746**	**–20.68**	**–3.852**	**–20.68**	0.999	–1.19	3.76	**0.472**	0.327	1973	1951–1988
Germany	35	2	1.70	0.48	–2.538	**–14.61**	**–3.887**	**–18.44**	0.999	–1.18	**6.60**	0.516	0.865	1955	1951–1988
Greece	37	0	**4.46**	0.14	**–5.128**	**–31.76**	**–5.272**	**–31.76**	1.000	–0.24	**4.28**	**0.739**	**0.741**	1973	1951–1988
Iceland	35	2	0.83	–0.21	**–4.842**	**–158.70**	**–4.881**	**–27.32**	1.000	–5.31	0.16	0.352	0.025	1980	1951–1988
Ireland	36	1	0.62	0.33	**–3.504**	**–26.60**	**–4.100**	**–24.00**	1.000	–0.02	2.56	0.703	0.441	1955	1951–1988
Italy	32	5	0.25	0.17	–1.842	**–17.58**	**–5.411**	**–27.63**	0.997	0.15	**10.40**	0.803	**0.572**	1958	1951–1988
Luxembourg	35	2	2.03	–0.70	**–4.834**	**–164.70**	**–8.800**	**–41.63**	1.000	0.04	0.17	0.525	0.201	1955	1951–1988
Malta	33	0	**4.80**	0.34	**–3.882**	**–21.79**	**–4.006**	**–21.79**	0.999	2.33	0.29	0.265	0.230	1961	1955–1988
Netherlands	35	2	0.39	0.25	**–3.014**	**–27.57**	**–4.724**	**–25.48**	1.000	–3.82	4.00	0.848	0.177	1956	1951–1988
Norway	37	0	1.44	0.19	**–5.001**	**–29.97**	**–5.142**	**–29.97**	1.000	0.21	0.10	0.108	0.102	1954	1951–1988
Portugal	37	0	0.25	0.20	**–4.923**	**–29.75**	**–5.062**	**–29.75**	1.000	–1.15	0.49	0.249	0.151	1974	1951–1988
Spain	37	0	0.64	0.25	**–5.089**	**–27.79**	**–5.232**	**–27.79**	1.000	–7.30	1.59	**0.899**	0.081	1974	1951–1988
Sweden	32	5	0.60	0.62	–1.238	–4.86	**–4.668**	**–26.17**	0.754	0.13	0.45	0.870	**0.568**	1958	1951–1988
Switzerland	37	0	3.84	0.12	**–5.378**	**–32.49**	**–5.530**	**–32.49**	1.000	–2.44	0.61	0.217	0.079	1954	1951–1988

Table A.6.1 continued

Country	Obser-vations	Lag (Hall)[b]	PSW-Test[c]	ρ[d]	t-test (DF)[e]	K-test (DF)[f]	t-test (PP)[g]	K-test (PP)[h]	Sims[i]	Kahn/ Ogaki[j]	Φ_4[k]	Nyblom[l]	Kim[m]	Year of break[n]	Period[o]
Turkey	34	3	1.22	–0.15	**–3.268**	**–68.20**	**–6.724**	**–34.68**	1.000	–3.62	1.28	1.035	0.005	1956	1951–1988
United Kingdom	35	2	0.46	–0.34	**–4.145**	**–114.30**	**–5.468**	**–30.87**	1.000	0.75	0.38	0.294	0.004	1980	1951–1988
Yugoslavia	26	0	0.10	0.01	**–4.695**	**–25.66**	**–4.887**	**–25.66**	1.000	–0.48	**5.25**	0.599	0.288	1979	1961–1987
Australia	32	5	0.61	0.34	–1.448	–7.97	**–6.397**	**–31.10**	0.883	–0.04	0.30	1.041	0.055	1966	1951–1988
Fiji	26	0	1.13	–0.05	**–4.771**	**–27.40**	**–4.966**	**–27.40**	1.000	2.76	2.19	0.476	0.342	1981	1961–1987
New Zealand	37	0	1.36	0.00	**–6.214**	**–36.91**	**–6.389**	**–36.91**	1.000	–2.45	1.77	0.241	0.180	1974	1951–1988
Papua New Guinea	26	1	0.70	0.45	**–3.297**	**–22.62**	–2.661	–12.42	0.954	–1.47	4.55	0.426	**0.569**	1970	1961–1988
H_0 rejected 5 percent					*26*	*12*	*5*	*5*		*6*	*19*	*22*	*(18)*		

[a]Bold letters indicate a rejection of the H_0 at the 5% significance level. — [b]Lags are chosen according to the Hall selection procedure (Hall 1990). — [c]Plosser–Schwert–White specification F-test (Plosser et al. 1982) following the modification by Maddala (1988). The H_0 of correct specification is rejected at the 5 percent significance level if, e.g., F(lags = 0, obs–3 = 17)≥4.45, F(lags = 0,obs–3=35)≥4.12, F(lags = 6,obs–15 = 20)≥2.6, F(lags = 6,obs–15 = 5)≥4.95. — [d]Estimated regression coefficient for $\hat{y}_{t-1}$. — [e]Augmented Dickey–Fuller t-test of the H_0 of a unit root. The H_0 is rejected at the 5 percent significance level if t(obs = 25)≤–3.0 and t(obs = 50)≤–2.93. — [f]Dickey–Fuller K-test of the H_0 of a unit root. The H_0 is rejected at the 5 percent significance level if K(obs = 25)≤–12.5 and K(obs = 50)≤–13.3. — [g]Phillips–Perron t-test of the H_0 of a unit root. The H_0 is rejected at the 5 percent significance level if t(obs = 25)≤–3.0 and t(obs = 50)≤–2.93. — [h]Phillips–Perron K-test of the H_0 of a unit root. The H_0 is rejected at the 5 percent significance level if K(obs = 25)≤–12.5 and K(obs = 50)≤–13.3. — [i]Prior probability in favor of a unit root necessary to equal the posterior probability of a unit root with the posterior probability of no unit root (Sims 1988). — [j]Kahn–Ogaki K_T-test of the H_0 of stationarity. The H_0 is rejected at the 5 percent significance level if the test statistic is larger than 3.2. — [k]F-test of the H_0 of a stationary AR(p) process without a trend against the H_1 of a stationary AR(p) process with a trend. The H_0 is rejected at the 5 percent significance level if Φ_4(obs = 25)≥4.35 and Φ_4(obs = 40)≥4.08. — [l]Nyblom test (Nyblom 1989) of the H_0 of an unknown structural break. The H_0 is rejected at the 5 percent significance level if the test statistic is larger than 0.461 (lags = 0), 0.748 (lags = 1), 1.9 (lags = 2), 1.237 (lags = 3), 1.686 (lags = 5). — [m]Maximum posterior probability of a structural break reached within the sample period (Kim 1991), Bayesian inference). Bold letters indicate a maximum posterior probability higher than 40 percent — [n]Year where the posterior probability of a structural break reaches its maximum. — [o]Sample period equals observations plus lags.

Table A.6.2 — Test Results for the Long-Run Equilibrium Growth Rate of 120 Countries of the Summers–Heston World Table, 1950–1988[a]

Country	Obser-vations	Period	$\frac{\mu}{\sigma_\mu}$ [b]	$\bar{y}=\frac{\mu}{1-\rho}$ [c]	$\tilde{y}$ [d]	$\frac{\tilde{y}-\bar{y}}{\sigma_{\tilde{y}}\sqrt{T}}$ [e]
Algeria	22	1961–1988	–0.088	–0.015	0.016	0.433
Angola	24	1961–1985	–0.606	–0.019	–0.018	0.014
Benin	28	1960–1988	–0.586	–0.006	–0.005	0.015
Botswana	25	1961–1986	2.897	0.059	0.058	–0.013
Burkina	20	1966–1988	1.920	0.017	0.017	0.013
Burundi	27	1961–1988	0.523	0.009	0.007	–0.023
Cameroon	27	1961–1988	1.079	0.023	0.027	0.089
Capverde	24	1961–1985	0.571	0.018	0.020	0.023
Centr. Afr. Rep.	27	1961–1988	–0.979	–0.007	–0.006	0.025
Chad	24	1961–1985	–0.951	–0.016	–0.014	0.024
Congo	25	1961–1986	1.867	0.036	0.035	–0.014
Egypt	37	1951–1988	2.635	0.044	0.042	–0.024
Ethiopia	35	1951–1986	1.539	0.008	0.009	0.010
Gambia	24	1961–1985	0.798	0.046	0.045	–0.006
Ghana	27	1956–1988	–0.082	–0.002	0.001	0.032
Guinea	21	1960–1985	-1.237	–0.010	–0.007	0.069
Guinea Bissau	27	1961–1988	0.539	0.010	0.008	–0.018
Côte d'Ivoire	27	1061–1988	0.353	0.006	0.008	0.047
Kenya	37	1951–1988	1.629	0.022	0.016	–0.117
Lesotho	24	1961–1985	2.996	0.062	0.061	–0.019
Liberia	23	1961–1986	–0.881	–0.014	–0.007	0.098
Madagascar	27	1961–1988	-2.030	–0.019	–0.019	0.010
Malawi	33	1955–1988	–0.030	–0.001	0.010	0.197
Mali	27	1961–1988	–0.278	–0.002	–0.004	–0.021
Mauritania	27	1961–1988	0.266	0.003	0.004	0.013
Mauritius	37	1951–1988	2.372	0.029	0.028	–0.002
Morocco	37	1951–1988	1.704	0.023	0.031	0.157
Mozambique	26	1961–1988	–0.687	–0.017	–0.014	0.047
Niger	23	1961–1988	–0.323	–0.006	0.000	0.084
Nigeria	32	1951–1988	0.228	0.007	0.002	–0.066
Rwanda	27	1961–1988	0.482	0.011	0.008	–0.029
Senegal	27	1961–1988	–0.239	–0.002	–0.001	0.016
Sierra Leone	26	1961–1987	–0.072	–0.001	0.000	0.026
Somalia	27	1961–1988	–0.169	–0.003	–0.003	0.003
South Africa	37	1951–1988	1.166	0.016	0.015	–0.017
Sudan	32	1956–1988	0.093	0.001	0.003	0.025
Swaziland	24	1960–1985	0.556	0.011	0.019	0.091
Tanzania	24	1961–1988	1.711	0.019	0.021	0.039
Togo	27	1961–1988	1.053	0.017	0.015	–0.025
Tunisia	27	1961–1988	**2.177**	0.026	0.028	0.044
Uganda	30	1951–1985	0.179	0.003	0.025	0.176
Zaire	37	1951–1988	–0.814	–0.016	–0.006	0.142
Zambia	32	1956–1988	–0.596	–0.012	–0.012	0.002

Table A.6.2 continued

Country	Observations	Period	$\dfrac{\mu}{\sigma_\mu}$ [b]	$\bar{\bar{y}}=\dfrac{\mu}{1-\rho}$ [c]	$\tilde{\bar{y}}$ [d]	$\dfrac{\tilde{\bar{y}}-\bar{\bar{y}}}{\sigma_{\tilde{\bar{y}}}\sqrt{T}}$ [e]
Zimbabwe	33	1955–1988	0.761	0.009	0.009	0.005
Barbados	24	1961–1985	1.502	0.026	0.029	0.073
Canada	32	1951–1988	**2.612**	0.026	0.027	0.043
Costa Rica	37	1951–1988	1.477	0.018	0.019	0.024
Dominican Rep.	37	1951–1988	**1.856**	0.021	0.019	–0.035
El Salvador	36	1951–1988	0.068	0.001	0.008	0.152
Guatemala	36	1951–1988	0.645	0.010	0.010	0.003
Haiti	27	1961–1988	0.019	0.000	–0.002	–0.044
Honduras	37	1951–1988	1.369	0.014	0.012	–0.057
Jamaica	32	1954–1987	0.343	0.009	0.009	0.006
Mexico	37	1951–1988	1.612	0.021	0.020	–0.021
Nicaragua	35	1951–1986	–0.219	–0.005	–0.004	0.011
Panama	35	1951–1986	**1.998**	0.028	0.031	0.094
Trinidad/ Tobago	36	1951–1988	–0.081	–0.004	0.006	0.113
USA	37	1951–1988	**2.950**	0.022	0.022	–0.027
Argentina	35	1960–1988	0.472	0.004	0.006	0.047
Bolivia	33	1951–1988	–0.586	–0.025	0.007	0.745
Brazil	36	1951–1987	**2.226**	0.028	0.042	0.186
Chile	37	1951–1988	0.505	0.008	0.009	0.021
Colombia	34	1951–1988	**3.990**	0.023	0.023	0.004
Ecuador	37	1951–1988	1.622	0.025	0.023	–0.034
Guyana	37	1951–1988	–0.206	–0.004	–0.003	0.014
Paraguay	37	1951–1988	**1.764**	0.022	0.023	0.005
Peru	35	1951–1988	0.446	0.007	0.010	0.065
Suriname	24	1961–1985	1.142	0.025	0.027	0.023
Uruguay	37	1951–1988	0.380	0.005	0.005	0.002
Venezuela	36	1951–1987	0.667	0.010	0.011	0.008
Afghanistan	23	1961–1985	–0.348	–0.003	–0.003	0.012
Bangladesh	25	1960–1985	0.389	0.006	0.006	0.006
Myanmar	34	1951–1985	**1.924**	0.020	0.025	0.084
Redchina	25	1961–1988	**3.876**	0.056	0.042	–0.148
Hong Kong	25	1961–1988	**3.471**	0.062	0.063	0.025
India	37	1951–1988	1.359	0.008	0.008	–0.004
Indonesia	25	1963–1988	**2.802**	0.041	0.035	–0.117
Iran	28	1956–1988	0.807	0.028	0.027	–0.010
Iraq	29	1954–1985	0.225	0.010	0.013	0.022
Israel	34	1954–1988	**1.815**	0.028	0.032	0.095
Japan	36	1951–1988	2.459	0.047	0.052	0.126
Jordan	33	1955–1988	0.764	0.016	0.022	0.077
Korea	34	1954–1988	**2.203**	0.062	0.060	–0.045
Kuwait	20	1961–1986	–0.222	0.084	–0.057	**–1.830**
Malaysia	32	1956–1988	**2.093**	0.037	0.036	–0.019
Nepal	24	1961–1985	1.227	0.008	0.008	–0.007

Table A.6.2 continued

Country	Observations	Period	$\frac{\mu}{\sigma_\mu}$ [b]	$\bar{\tilde{y}} = \frac{\mu}{1-\rho}$ [c]	$\tilde{y}$ [d]	$\frac{\tilde{y} - \bar{\tilde{y}}}{\sigma_{\tilde{y}}\sqrt{T}}$ [e]
Pakistan	37	1951–1988	**1.850**	0.024	0.023	–0.033
Philippines	35	1951–1988	**1.789**	0.017	0.018	0.020
Saudi Arabia	23	1961–1985	0.202	0.012	0.032	0.234
Singapore	23	1961–1985	1.404	0.056	0.058	0.037
Sri Lanka	35	1951–1987	**1.923**	0.014	0.013	–0.019
Syria	27	1961–1988	1.384	0.028	0.028	–0.006
Taiwan	36	1951–1988	**2.066**	0.063	0.062	–0.048
Thailand	37	1951–1988	**4.005**	0.038	0.038	–0.017
Yemen	18	1970–1988	1.783	0.057	0.063	0.106
Austria	35	1951–1988	**3.720**	0.031	0.032	0.023
Belgium	37	1951–1988	**3.201**	0.026	0.027	0.022
Cyprus	37	1951–1988	**2.005**	0.044	0.046	0.021
Denmark	37	1951–1988	**2.770**	0.021	0.023	0.038
Finland	31	1951–1988	**2.919**	0.032	0.033	0.049
France	37	1951–1988	**2.374**	0.027	0.028	0.046
Germany	35	1951–1988	2.507	0.025	0.025	0.006
Greece	37	1951–1988	**2.634**	0.036	0.040	0.077
Iceland	35	1951–1988	**2.571**	0.031	0.033	0.035
Ireland	36	1951–1988	0.837	0.014	0.021	0.236
Italy	32	1951–1988	1.654	0.032	0.034	0.078
Luxembourg	35	1951–1988	3.880	0.025	0.025	0.009
Malta	33	1955–1988	3.070	0.060	0.052	–0.217
Netherlands	35	1951–1988	2.595	0.024	0.024	–0.002
Norway	37	1951–1988	3.713	0.034	0.035	0.030
Portugal	37	1951–1988	2.645	0.041	0.042	0.024
Spain	37	1951–1988	1.276	0.026	0.034	0.217
Sweden	32	1951–1988	1.296	0.018	0.024	0.290
Switzerland	37	1951–1988	2.326	0.018	0.020	0.073
Turkey	34	1951–1988	2.323	0.027	0.027	–0.014
Unit. Kingdom	35	1951–1988	3.142	0.023	0.023	–0.009
Yugoslavia	26	1961–1987	2.921	0.034	0.035	0.007
Australia	32	1951–1988	3.844	0.024	0.022	–0.068
Fiji	26	1961–1987	1.027	0.012	0.013	0.007
New Zealand	37	1951–1988	1.506	0.011	0.011	–0.025
Papua New Guinea	26	1961–1988	0.611	0.009	0.014	0.084
H_0 rejected (5 percent):			45			1

[a]Bold letters indicate a rejection of the H_0 at the 5 percent significance level by the Dickey–Fuller t-test (see Table A.6.2). — [b]For stationary time series the H_0 of $\mu = 0$ is rejected at a significance level of 5 percent if the t-statistic reaches a level of 1.71 for a sample size of $T = 25$ and a level of 1.68 for a sample size of $T = 50$. For nonstationary time series the H_0 of $\mu = 0$ is rejected at a significance level of 5 percent if the t-statistic reaches a level of 2.61 for a sample size of $T = 25$ and a level of 2.56 for a sample size of $T = 50$. — [c]Intertemporal equilibrium solution of [C.1]. — [d]Compound growth rate. — [e]T-test statistic of the H_0 that the compound rate equals the intertemporal equilibrium solution. The H_0 is rejected at the 5 percent significance level, if the t-statistic reaches a level of 1.71 for a sample size of $T = 25$ and a level of 1.68 for a sample size of $T = 50$.

Appendix 7: How Important Are Mean Reverting Growth Rates if the Level of Per Capita GDP Follows a Random Walk?

The empirical findings in Section C.I.1 support the hypothesis that growth rate of per worker GDP typically follows a mean reverting time series process. From this, of course, no conclusion can be drawn, whether the mean around which growth rates fluctuate is the drift parameter of a random walk of the level per worker GDP or the deterministic trend of the level per worker GDP. Yet, it is important for an evaluation of growth theories to know what kind of time series behavior is prevalent. If the mean around which growth rates fluctuate is the drift parameter of a random walk, it probably plays only a minor role in the time series behavior of per worker GDP. Consequently, in this case growth theories would probably explain a parameter of minor importance for the development of per worker GDP.

This leads to the controversy whether there is a unit root in real GDP or not. As real per worker (as well as per capita) GDP typically displays a time trend, the question is now whether the level of per capita GDP fluctuates around this trend (i.e., whether real per worker GDP is trend-stationary) or whether this trend is the drift parameter of a random walk (i.e., whether real per worker GDP is difference-stationary).

In a sense, the controversy on this question ended with a stalemate: as Christiano and Eichenbaum (1990) argue, it is hardly possible to empirically discriminate between these types of time series behavior. The only difference between these types of time series behavior is the time series behavior of the error terms. This can be shown by taking first differences of both time series models. Taking first differences the trend-stationary model equals:

$$[A.7.1]\quad y_t = \gamma t + \varepsilon_t + \sum_{j=1}^{L} \alpha_j \varepsilon_{t+j} \Leftrightarrow \hat{y}_t = \gamma + \left(\varepsilon_t - \varepsilon_{t-1} + \sum_{j=1}^{L} \alpha_j \left(\varepsilon_{t-1-j} - \varepsilon_{t-2-j} \right) \right).$$

Taking the first differences, the difference-stationary model equals:

$$[A.7.2]\quad y_t = \mu + y_{t-1} + \varepsilon_t + \sum_{j=1}^{L} \alpha_j \varepsilon_{t+j} \Leftrightarrow \hat{y}_t = \mu + \left(\varepsilon_t + \sum_{j=1}^{L} \alpha_j \varepsilon_{t-j} \right).$$

In these equations μ and γ represent the means around which growth rates fluctuate. All the analysis of growth rates has shown so far is that these means are reverted by the time series behavior of economic growth. Equations [A.7.1] and [A.7.2] show that this empirical finding is compatible with a trend as well as with a difference-stationary behavior of the level of per worker GDP.

Although Christiano and Eichenbaum (1990) argue that it is not possible to discriminate between equation [A.7.1] and [A.7.2] on the basis of available data sets, the Levin–Lin panel data unit root test (Levin and Lin 1993) offers a new opportunity for a test based on a data set that is much larger than those Christiano and Eichenbaum (1990) have in mind. Their maximum data set consists of 148 quarterly observations of real per capita GDP of the USA. The panel data approach of Levin and Lin applied to the Heston–Summers data set (Summers and Heston 1991) allows to use about 2600 observations. The Levin and Lin approach allows a test of the H_0 that each individual country time series of real per worker GDP follows a random walk against the H_1 that it follows a deterministic trend. This test is based on the following time series model:

[A.7.3] $y_{i,t} = \mu_i + \alpha_i t + \rho_i y_{i,t-1} + \varepsilon_{i,t}$.

The H_0 implies then: $\alpha_i = 0$ and $\rho_i = 1$ for all $i = 1,2,3,\ldots N$ countries. The H_1 implies $\alpha_i > 0$ and $\rho_i < 1$ for all $i = 1,2,3,\ldots N$ countries. Table A.7.1 presents the results. Again several subsamples are tested in order to check the sensitivity of the results. As an intercept as well as a deterministic time trend is introduced, the resulting t-statistic of the H_0 that $\rho = 1$ has to be adjusted by the mean and standard deviation adjustment factors for „model 3" presented in Levin and Lin (1993: Table 2). This yields the adjusted t-statistics of Column 3 in Table A.7.1. The same lag selection procedure as for the Levin–Lin test on growth rates is used. The p-values presented in Column 4 show that with the exception of the OECD and African countries the H_0 is not rejected at a significance level of 5 percent. Hence, contrary to the results for growth rates, now the results of the Levin–Lin test display sensitivity to certain subsamples. Nevertheless, if there is a conclusion to be drawn from Table A.7.1, then it is that the H_0 of a random walk cannot be rejected against the H_1 of a deterministic trend.

Table A.7.1 — Levin–Lin Panel Data Unit Root Test for Per Worker GDP, 1960–1985

Sample	Panel-ρ	Adjusted t-value	p-value	Average lags	Average periods	Number of countries
All available	0.757	–0.503	0.615	0.84	22.16	118
Barro–Sala-i-Martin	0.766	–0.003	0.997	0.62	22.4	95
OECD	0.848	4.345	0.000	1.21	21.8	24
Africa	0.704	–2.014	0.044	0.58	22.4	39
Latin America	0.757	–0.242	0.331	0.87	22.1	24
Asia	0.706	–0.889	0.375	1.11	21.9	9

If the level of per worker GDP actually follows a random walk, then the mean around which growth rates fluctuate is a drift parameter. Therefore, the question arises, how important this drift parameter is compared to the "average" shock. If the drift parameter has an absolute magnitude that is significantly larger than the average shock, the time series behavior of per worker GDP would be dominated by the drift parameter, but not by shocks, even though the times series of per worker GDP followed a random walk. Therefore, the question of the relative importance of the drift parameter in real per worker GDP arises. A natural procedure to answer this question is to compute the ratio of the absolute value of the drift parameter to the absolute value of the average shock. The average shock to real per worker GDP of country *i* can be estimated according to the following formula:

[A.7.4] $\bar{\varepsilon}_i = T^{-1}\sum_{t=1}^{T}|\varepsilon_t|$,

where ε_t are the residuals taken from an OLS regression of [A.7.3].[219] This is an appropriate measure of the average shock, because [A.7.3] shows that in the case of a random walk the change of per worker GDP between two periods equals the sum of $\mu + \varepsilon_t$.[220] Hence, if the drift parameter, μ, is significantly larger than the average shock, it dominates the random walk. Table A.7.2 shows the drift/shock ratios for all countries of the Heston–Summers sample (Summers and Heston 1991), where data are available over the period 1960–1985. Column 2 contains the ratios, if lags are allowed for according to the Hall (1990) selection procedure. Column 6 contains the ratios if lags are suppressed. Allowing for a lag structure leads to a better fit of the regression and hence to lower estimates of shocks and thus higher drift/shock ratios. In this case the average drift/shock ratio equals 64.67 (median: 27.38) If no lags are allowed for, the average drift/shock ratio equals 23.23 (median: 17.75). All in all, Table A.7.2 shows that no matter what specification of the lag structure is chosen, the estimated drift parameters for the overwhelming majority of countries are much larger than the average shocks. Consequently, even if the real per worker GDP follows a random walk, the drift parameter typically dominates the random walk. Therefore, theories of economic growth which explain the drift parameter explain the dominant part of the change of real per worker GDP.

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219 The standard deviation of ε_t is not an appropriate measure of the average shock per period. According to the Cauchy–Schwarz inequality, it may be larger or smaller than the average shock given by [A.7.4]. As it turns out here, if the standard deviation is used to measure the average shock, the drift/shock ratios are significantly larger than those given by Table A.7.2.

220 Equation [A.7.3] equals $\hat{y}_t = \mu + \rho\,\hat{y}_{t-1} + \varepsilon_t$. In the case of a random walk, $\rho = 1$ holds such that $\hat{y}_t - \hat{y}_{t-1} = \mu + \varepsilon_t$.

Table A.7.2 — Drift/Shock Ratios of Real Per Worker GDP, 1960–1985

Country	Code[a]	Drift/ shock	Drift	Shock	ρ	Drift/ shock	Drift	Shock	ρ
Algeria	DZA	41.56	0.974	0.023	0.88	3.37	0.152	0.045	0.98
Angola	AGO	4.45	0.262	0.059	0.96	4.32	0.262	0.061	0.96
Benin	BEN	70.91	2.361	0.033	0.66	68.53	2.361	0.034	0.66
Botswana	BWA	1.36	0.087	0.064	1.00	1.38	0.087	0.063	1.00
Burkina	HVO	–	–	–	–	–	–	–	–
Burundi	BDI	7.01	0.379	0.054	0.94	6.62	0.379	0.057	0.94
Cameroon	CMR	–32.81	–0.578	0.018	1.10	–0.87	–0.031	0.035	1.01
Capverde	CPV	8.47	0.587	0.069	0.92	7.43	0.587	0.079	0.92
Centr. African Rep.	CAF	323.07	7.184	0.022	–0.08	42.68	1.288	0.030	0.81
Chad	TCD	8.70	0.502	0.058	0.92	8.77	0.502	0.057	0.92
Comoros	COM	–	–	–	–	–	–	–	–
Congo	COG	–3.27	–0.137	0.042	1.03	–3.18	–0.137	0.043	1.03
Egypt	EGY	3.51	0.110	0.031	0.99	3.62	0.110	0.030	0.99
Ethiopia	ETH	53.73	0.880	0.016	0.85	54.60	0.880	0.016	0.85
Gabon	GAB	18.27	1.365	0.075	0.84	8.50	0.933	0.110	0.89
Gambia	GMB	18.37	1.083	0.059	0.84	16.50	1.083	0.066	0.84
Ghana	GHA	–51.53	–1.671	0.032	1.24	9.13	0.348	0.038	0.95
Guinea	GIN	39.50	0.950	0.024	0.85	35.46	0.950	0.027	0.85
Guinea Bissau	GNB	21.67	1.375	0.063	0.79	22.55	1.375	0.061	0.79
Côte d'Ivoire	CIV	24.72	0.955	0.039	0.87	23.53	0.955	0.041	0.87
Kenya	KEN	21.87	0.753	0.034	0.89	21.50	0.753	0.035	0.89
Lesotho	LSO	4.10	0.258	0.063	0.97	4.15	0.258	0.062	0.97
Liberia	LBR	37.56	1.506	0.040	0.79	9.44	0.484	0.051	0.93
Madagascar	MDG	–13.94	–0.380	0.027	1.05	–14.20	–0.380	0.027	1.05
Malawi	MWI	20.00	0.684	0.034	0.89	17.19	0.684	0.040	0.89
Mali	MLI	32.62	1.105	0.034	0.82	33.29	1.105	0.033	0.82
Mauritania	MRT	28.62	1.590	0.056	0.77	30.38	1.590	0.052	0.77
Mauritius	MUS	–34.28	–0.719	0.021	1.10	5.56	0.224	0.040	0.97
Morocco	MOR	17.15	0.555	0.032	0.93	16.62	0.555	0.033	0.93
Mozambique	MOZ	–1.62	–0.074	0.045	1.01	–12.92	–0.716	0.055	1.10
Niger	NER	108.41	5.439	0.050	0.18	42.53	2.324	0.055	0.65
Nigeria	NGA	17.49	1.039	0.059	0.85	11.15	0.744	0.067	0.90
Rwanda	RWA	8.43	0.532	0.063	0.92	7.85	0.532	0.068	0.92
Senegal	SEN	861.71	15.593	0.018	–1.21	111.39	3.352	0.030	0.53
Seychelles	SYC	–	–	–	–	–	–	–	–
Sierra Leone	SLE	219.88	4.408	0.020	0.38	35.05	1.397	0.040	0.80
Somalia	SOM	123.19	8.909	0.072	–0.33	25.64	2.380	0.093	0.65
South Africa	ZAF	40.89	1.522	0.037	0.82	40.80	1.522	0.037	0.82
Sudan	SDN	57.00	2.944	0.052	0.57	57.21	2.944	0.051	0.57
Swaziland	SWZ	22.36	1.515	0.068	0.80	23.45	1.515	0.065	0.80
Tanzania	TZA	26.26	0.769	0.029	0.88	23.03	0.769	0.033	0.88
Togo	TGO	19.93	0.946	0.047	0.86	19.68	0.946	0.048	0.86
Tunisia	TUN	4.47	0.105	0.023	0.99	4.22	0.105	0.025	0.99
Uganda	UGA	60.27	4.756	0.079	0.13	3.69	0.298	0.081	0.95
Zaire	ZAR	371.87	7.911	0.021	–0.28	9.21	0.507	0.055	0.92

Table A.7.2 continued

Country	Code[a]	Drift/ shock	Drift	Shock	ρ	Drift/ shock	Drift	Shock	ρ
Zambia	ZMB	4.23	0.290	0.069	0.96	4.18	0.290	0.070	0.96
Zimbabwe	ZWE	6.35	0.298	0.047	0.96	6.07	0.298	0.049	0.96
Bahamas	BHS	–	–	–	–	–	–	–	–
Barbados	BRB	23.95	0.758	0.032	0.91	23.17	0.758	0.033	0.91
Canada	CAN	52.07	0.815	0.016	0.92	24.14	0.496	0.021	0.95
Costa Rica	CRI	43.40	0.873	0.020	0.88	28.16	0.750	0.027	0.91
Dominica	DMA	–	–	–	–	–	–	–	–
Dominican Rep.	DOM	23.21	0.998	0.043	0.87	23.01	0.998	0.043	0.87
El Salvador	SLV	42.72	0.998	0.023	0.87	47.52	1.543	0.032	0.80
Grenada	GRD	–	–	–	–	–	–	–	–
Guatemala	GTM	30.50	0.432	0.014	0.94	26.85	0.557	0.021	0.93
Haiti	HTI	51.72	1.537	0.030	0.77	51.98	1.537	0.030	0.77
Honduras	HND	27.26	0.670	0.025	0.91	25.71	0.670	0.026	0.91
Jamaica	JAM	27.38	0.870	0.032	0.89	23.38	0.907	0.039	0.89
Mexico	MEX	136.74	1.411	0.010	0.86	22.66	0.602	0.027	0.93
Nicaragua	NIC	22.78	2.044	0.090	0.74	23.29	2.044	0.088	0.74
Panama	PAN	30.72	0.670	0.022	0.92	21.96	0.526	0.024	0.94
St. Lucia	LCA	–	–	–	–	–	–	–	–
St. Vincent	VCT	–	–	–	–	–	–	–	–
Trinidad/Tobago	TTO	15.93	0.733	0.046	0.92	9.51	0.605	0.064	0.93
USA	USA	34.18	0.238	0.007	0.98	30.88	0.582	0.019	0.94
Argentina	ARG	34.34	1.102	0.032	0.87	31.01	1.102	0.036	0.87
Bolivia	BOL	25.76	0.622	0.024	0.92	32.18	0.841	0.026	0.89
Brazil	BRA	8.44	0.274	0.032	0.97	7.80	0.298	0.038	0.97
Chile	CHL	369.39	11.708	0.032	–0.42	62.32	2.727	0.044	0.67
Colombia	COL	152.51	1.392	0.009	0.83	10.69	0.265	0.025	0.97
Ecuador	ECU	11.16	0.364	0.033	0.96	9.87	0.364	0.037	0.96
Guyana	GUY	15.82	1.002	0.063	0.86	14.25	1.002	0.070	0.86
Paraguay	PRY	7.08	0.209	0.029	0.98	6.81	0.209	0.031	0.98
Peru	PER	58.48	1.765	0.030	0.78	60.32	1.765	0.029	0.78
Suriname	SUR	40.68	1.291	0.032	0.86	14.95	0.801	0.054	0.90
Uruguay	URY	39.85	1.372	0.034	0.84	22.56	0.899	0.040	0.89
Venezuela	VEN	28.10	1.009	0.036	0.88	27.82	1.009	0.036	0.88
Afghanistan	AFG	104.68	2.796	0.027	0.58	61.45	1.799	0.029	0.73
Bahrain	BHR	–	–	–	–	–	–	–	–
Bangladesh	BGD	56.45	2.397	0.042	0.63	56.73	2.397	0.042	0.63
Myanmar	BUR	–47.40	–0.884	0.019	1.15	14.56	0.593	0.041	0.91
China	CHN	1.64	0.072	0.044	1.00	–0.12	–0.007	0.057	1.01
Hong Kong	HKG	7.73	0.262	0.034	0.98	8.12	0.262	0.032	0.98
India	IND	115.51	3.184	0.028	0.51	110.99	3.184	0.029	0.51
Indonesia	IDN	–	–	–	–	–	–	–	–
Iran	IRN	17.02	1.165	0.068	0.86	12.22	0.992	0.081	0.88
Iraq	IRQ	16.59	1.844	0.111	0.78	16.65	1.844	0.111	0.78
Israel	ISR	224.03	2.907	0.013	0.68	21.65	0.599	0.028	0.94
Japan	JPN	35.37	0.637	0.018	0.93	31.50	0.637	0.020	0.93
Jordan	JOR	5.35	0.257	0.048	0.97	4.95	0.257	0.052	0.97

Table A.7.2 continued

Country	Code[a]	Drift/ shock	Drift	Shock	ρ	Drift/ shock	Drift	Shock	ρ
Korea	KOR	6.21	0.210	0.034	0.98	5.94	0.210	0.035	0.98
Kuwait	KWT	−150.9	−5.368	0.036	1.48	−9.59	−0.531	0.055	1.05
Malaysia	MYS	4.14	0.141	0.034	0.99	4.25	0.141	0.033	0.99
Nepal	NPL	29.96	0.819	0.027	0.87	30.79	0.819	0.027	0.87
Oman	OMN	–	–	–	–	–	–	–	–
Pakistan	PAK	−437.6	−4.223	0.010	1.61	17.75	0.522	0.029	0.93
Philippines	PHL	104.02	1.381	0.013	0.80	21.74	0.559	0.026	0.93
Saudi Arabia	SAU	35.14	1.193	0.034	0.86	17.08	0.997	0.058	0.89
Singapore	SGP	7.12	0.166	0.023	0.98	2.48	0.074	0.030	1.00
Srilanka	LKA	−40.47	−1.297	0.032	1.18	−2.34	−0.093	0.040	1.02
Syria	SYR	7.88	0.561	0.071	0.94	7.63	0.561	0.073	0.94
Taiwan	OAN	8.68	0.204	0.023	0.98	8.43	0.204	0.024	0.98
Thailand	THA	7.25	0.172	0.024	0.98	7.36	0.172	0.023	0.98
United Arab. Em.	ARE	–	–	–	–	–	–	–	–
Yemen	YEM	–	–	–	–	–	–	–	–
Austria	AUT	24.07	0.364	0.015	0.96	23.10	0.364	0.016	0.96
Belgium	BEL	35.98	0.651	0.018	0.93	36.88	0.651	0.018	0.93
Cyprus	CAP	9.31	0.641	0.069	0.93	9.46	0.641	0.068	0.93
Denmark	DNK	22.91	0.566	0.025	0.94	23.30	0.566	0.024	0.94
Finland	FIN	9.46	0.230	0.024	0.98	8.93	0.230	0.026	0.98
France	FRA	56.33	0.620	0.011	0.93	55.88	0.620	0.011	0.93
Germany	DEU	187.56	1.876	0.010	0.80	22.97	0.454	0.020	0.95
Greece	GRC	28.07	0.591	0.021	0.93	23.43	0.591	0.025	0.93
Hungary	HUN	–	–	–	–	–	–	–	–
Iceland	ISL	17.48	0.507	0.029	0.95	17.05	0.507	0.030	0.95
Ireland	IRL	40.14	0.739	0.018	0.92	35.95	0.749	0.021	0.91
Italy	ITA	14.39	0.319	0.022	0.97	14.94	0.319	0.021	0.97
Luxembourg	LUX	8.25	0.159	0.019	0.99	8.38	0.159	0.019	0.99
Malta	MLT	9.30	0.197	0.021	0.98	3.25	0.102	0.031	0.99
Netherlands	NLD	38.36	0.639	0.017	0.93	36.98	0.639	0.017	0.93
Norway	NOR	17.63	0.173	0.010	0.99	15.94	0.183	0.011	0.98
Poland	POL	–	–	–	–	–	–	–	–
Portugal	PRT	15.52	0.535	0.034	0.94	15.65	0.535	0.034	0.94
Spain	ESP	70.33	1.059	0.015	0.88	66.78	1.059	0.016	0.88
Sweden	SWE	857.28	3.493	0.004	0.63	38.01	0.516	0.014	0.95
Switzerland	CHE	51.87	0.804	0.015	0.92	50.97	0.804	0.016	0.92
Turkey	TUR	19.33	0.531	0.027	0.94	18.56	0.531	0.029	0.94
United Kingdom	GBR	73.91	0.906	0.012	0.91	11.75	0.213	0.018	0.98
Yugoslavia	YUG	15.87	0.498	0.031	0.94	15.63	0.498	0.032	0.94
Australia	AUS	41.61	0.741	0.018	0.92	44.19	0.741	0.017	0.92
Fiji	FJI	13.34	0.566	0.042	0.93	12.81	0.566	0.044	0.93
New Zealand	NZL	107.76	2.222	0.021	0.76	43.06	1.013	0.024	0.89
Papua New Guinea	PNG	187.96	3.347	0.018	0.56	41.10	1.480	0.036	0.80

[a]World Bank country code.

Appendix 8: Bayesian Criticism on Classical Unit Root Tests

While the Monte Carlo study of Schwert (1989) shows that classical unit root tests based on an AR(p) model are in some cases biased in favor of a rejection of the H_0 that $\rho=1$, *Bayesian criticism* as stated in Sims (1988) and Sims and Uhlig (1991) argues that unit roots tests tend to be biased in favor of an acceptance of the H_0 that $\rho=1$. To understand this criticism, one has to consider the principles of classical inference. Classical inference typically rejects the H_0 only if there is "overwhelming" evidence against it. This is to say that the H_0 is only rejected if the probability of rejecting the H_0, while the H_0 is true, is smaller than a significance level of, say, $\alpha=1$ percent or $\alpha=5$ percent. This is of course a rather conservative behavior towards the H_0. It implies a very critical attitude against the alternative hypothesis, H_1. However, the advantage of this procedure is that a rejection of the H_0 is strong evidence in favor of the H_1. Bayesians, however, claim that such a behavior implies an implicit prior in favor of the H_0. In the case of unit root tests they strengthen their criticism, because given the H_0 that $\rho=1$, its estimator $\hat{\rho}$ has not the standard symmetrical student distribution around $\rho=1$, but is asymmetrically distributed around $\rho=1$ with a concentration of probability in favor of $\hat{\rho}>1$ (see Figure A.8.1, probability density function $f(\hat{\rho}|\rho=1)$).[221] However, for any H_0 that ρ takes a value smaller than unity the estimator $\hat{\rho}$ has the standard symmetrical student distribution around ρ (see Figure A.8.1, probability density function $f(\hat{\rho}|\rho=0.9)$). This implies, for example, that for $\hat{\rho}<1$ a much higher t–value is necessary to reject H_0 that $\rho'=1$ than the H_0 that, say, $\rho''=\hat{\rho}-(1-\hat{\rho})$, although, in this case, $|\hat{\rho}-\rho'|=|\hat{\rho}-\rho''|$ holds. To see this, consider the following numerical example, drafted in Figure A.8.1: Assume an estimation yields $\hat{\rho}=0.95$. Then the H_0 that $\rho=0.9$ can be rejected with a p-value of α, whilst the H_0 that $\rho=1$ can only be rejected with a p-value of $\beta>\alpha$, although the absolute difference of $\hat{\rho}=0.95$ from $\rho=0.9$ equals that from $\rho=1$.

The Bayesian approach to avoid this kind of problems is to base the test conclusions not on the likelihood density function of the test (i.e., $f(\hat{\rho}|\rho)$) but on the posterior probability function $f(\rho|\hat{\rho})$. Since the posterior probability function $f(\rho|\hat{\rho})$ is symmetrical around $\hat{\rho}$, the discontinuity of classical asymptotic theory in the case of unit root tests does not emerge (see the posterior probability function $f(\rho|\hat{\rho}=0.95)$ in Figure A.8.1).[222] For example, suppose an OLS estimation

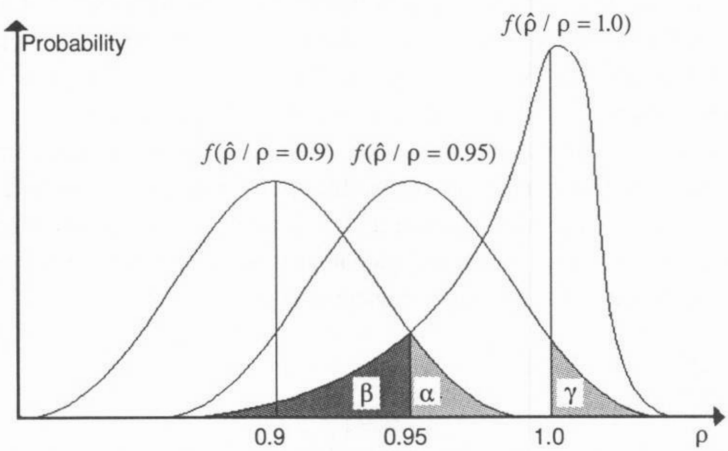
221 For an analytical derivation see Fuller (1976). For a Monte Carlo simulation see Sims and Uhlig (1991).

222 This is shown by the Monte Carlo simulation of Sims and Uhlig (1991).

provides a $\hat{\rho}=0.95$. Then, given the posterior probability function, the probability that the true $\rho \geq 1$ equals γ (see Figure A.8.1).

However, there is a price to pay for this comfort. A data sample only provides sufficient information for the determination of the likelihood density function of the test $f(\hat{\rho}|\rho)$. Yet, to derive the posterior probability function $f(\rho|\hat{\rho})$, the knowledge of the unconditional probability of ρ, i.e., $f(\rho)$, and the knowledge of the unconditional probability of the data, i.e., $f(\hat{\rho})$, has to be given.[223] As the unconditional probability of ρ is the probability of ρ "before the world has come to being"[224] the unconditional probability of ρ (and $\hat{\rho}$ as well) is unknown. To cope with this problem, Bayesians replace the unconditional probability of ρ by their own beliefs about $f(\rho)$.[225] Researchers, who have no own beliefs, or who refrain from substituting them for the unconditional probability of ρ, must follow other strategies.

Figure A.8.1 — Probability Density Functions for $\hat{\rho}$ under $\rho=0.9$ and $\rho=1$ and Posterior Probability Density for ρ under $\hat{\rho}=0.95$



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[223] Given the definition of conditional probability, the following relation holds: $f(\rho|\hat{\rho})=f(\hat{\rho}|\rho)f(\rho)/f(\hat{\rho})$.

[224] Since the point in time the world has come to being, all its parameters are determined. Hence one may argue that after this point in time the unconditional probability of a certain ρ is either zero or unity.

[225] This procedure is based on the Bayesian conviction that the more tests a theory passes the higher becomes the probability that it is the true theory. Therefore, the beliefs of a researcher, which should reflect this probability, is an appropriate substitute for the unconditional probability $f(d)$.

One such strategy is possible if, roughly spoken, the shape of the posterior probability function approximately equals the shape of likelihood density function. In this case, by the sake of symmetry, the *p*-value of the likelihood probability function for an estimate of $\hat{\rho}=0.95$ under the H_0 that $\rho=1$ equals the probability that the true $\rho \geq 1$ given an estimate of $\hat{\rho}=0.95$. This can be seen by drawing the standard student distribution as the likelihood density function for $f(\hat{\rho}|\rho=1)$ (see Figure A.8.2, where $\beta=\gamma$). Hence, the *p*-value of a *t*-test of the H_0 that $\rho=1$ based on the standard student distribution around $\rho=1$ equals the probability that the true $\rho \geq 1$.[226] However, as shown by the Monte Carlo study by Sims and Uhlig (1991), the posterior probability function is more dispersed than the standard student distribution. The degree of dispersion is the higher, the lower $\hat{\rho}$. Nevertheless, it should be clear from this discussion that the *p*-value of a *t*-test of the H_0 that $\rho=1$ based on the standard student distribution provides information. Therefore, the cumulative student distribution can be used to estimate the probability that the true parameter ρ is equal or larger than unity given the estimate $\hat{\rho}$, if one assumes that the shape of the posterior probability function approximately equals the shape likelihood density function (see the discussion of Bayesian unit root tests in Appendix 8). Given this assumption, the estimation results of the country-specific unit root tests presented in Table A.6.1 imply that the probability that the true parameter of ρ is equal or higher than unity is equal or lower than 5 percent for 113 countries.

Another strategy of avoiding a Bayesian "mixture" of personal priors and objective data is to determine the prior probability in favor of a unit root necessary to equal the posterior probability of a unit root with the posterior probability of no unit root. As the definition of conditional probability (Maddala 1989: 503) shows, this can be done by solving the following equation for ω:

[A.8.1] $$\frac{f(\rho=1|\hat{\rho})}{f(\rho<1|\hat{\rho})}=\frac{f(\hat{\rho}|\rho=1)}{f(\hat{\rho}|\rho<1)}\frac{\omega}{1-\omega}=1.$$

These ω-values based on a test statistic derived by Sims (1988) are provided in Table A.6.1, Column 10.

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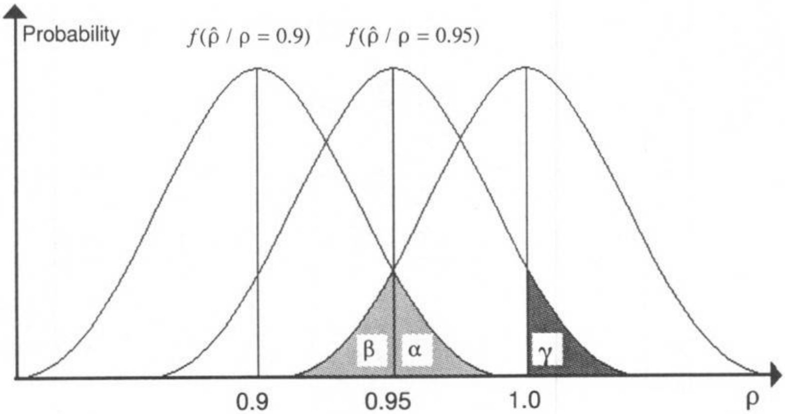
226 Pratt (1965) considers conditions where *p*-values and posterior probabilities will approximately coincide. In general, the one-tailed *p*-values and posterior probabilities will coincide, if the prior probabilities used to derive the posterior probability are equally distributed over the regression parameters and over the log of the residual variance. The Monte Carlo simulation of Sims and Uhlig (1991) is based on the assumption that the prior probability of all $\rho \in [0.8, 1.1]$, which are used to construct the time series, is equally distributed.

Figure A.8.2 — Probability Density Functions for $\hat{\rho}$ under $\rho = 0.9$ and Posterior Probability Density for ρ under $\hat{\rho} = 0.95$



Appendix 9: Results of Section C.I.2

Table A.9.1 — Immediate Effects of Trade Liberalization Episodes on Economic Growth

Country	Mean	Const.	Reform1		Reform2		Reform3		$\hat{y}_{t-1}$	F	Lag	SEE	DW	Obs.
Argentina	0.008	0.011	1966–1970	0.034	1976–1980	–0,010	–	–	–0.556	2.10	1	0.042	1.97	36
		(0.02)		(0.15)		(0.62)			(0.00)	(0.10)				
Brazil	0.041	0.031	1965–1973	–0.016	–	–	–	–	0.109	0.58	0	0.069	2.02	36
		(0.05)		(0.51)					(0.53)	(0.56)				
Chile	0.011	0.007	1956–1961	0.013	1974–1980	0.02	–	–	0.178	0.43	0	0.061	1.95	37
		(0.60)		(0.65)		(0.94)			(0.31)	(0.73)				
Colombia	0.009	0.008	1964–1966	0.043	1968–1982	0.000	–	–	–0.502	2.14	1	0.042	1.86	36
		(0.39)		(0.12)		(0.97)			(0.04)	(0.10)				
Greece	0.039	0.025	1953–1955	0.015	1962–1982	0.015	–	–	0.99	0.72	0	0.038	1.97	37
		(0.04)		(0.31)		(0.31)			(0.58)	(0.55)				
Indonesia	0.039	0.029	1966–1972	0.002	–	–	–	–	0.277	1.16	0	0.043	2.06	25
		(0.03)		(0.92)					(0.14)	(0.33)				
Israel	0.034	0.020	1962–1968	0.010	1969–1977	–0.005	–	–	0.370	1.71	0	0.039	2.04	34
		(0.01)		(0.51)		(0.02)			(0.04)	(0.18)				
Korea	0.057	0.040	1965–1967	0.010	1978–1979	0.017	–	–	0.19	0.57	0	0.048	1.953	34
		(0.00)		(0.73)		(0.64)			(0.50)	(0.64)				
New Zealand	0.016	0.020	1951–1956	–0.002	1962–1981	–0.01	1982–1984	–0.051	–0.008	0.053	0	0.041	2.05	37
		(0.10)		(0.93)		(0.68)		(0.85)	(0.96)	(0.99)				
Pakistan	0.021	0.013	1959–1965	0.053	1972–1978	–0.012	–	–	0.008	4.51	0	0.037	1.901	37
		(0.13)		(0.00)		(0.48)			(0.96)	(0.00)				

Table A.9.1 continued

Country	Mean	Const.	Reform1		Reform2		Reform3		$\hat{y}_{t-1}$	F	Lag	SEE	DW	Obs.
Peru	0.014	0.003	1979–1980	0.016	–	–	–	–	0.41	2.28	4	0.049	2.014	33
		(0.79)		(0.68)					(0.34)	(0.07)				
Philippines	0.034	0.019	1960–1965	0.019	1970–1974	0.016	–	–	0.264	1.99	0	0.39	1.97	34
		(0.06)		(0.31)		(0.44)			(0.02)	(0.13)				
Portugal	0.040	0.031	1970–1974	0.052	1977–1980	0.052	–	–	0.054	2.84	0	0.038	1.604	37
		(0.00)		(0.01)		(0.13)			(0.75)	(0.05)				
Singapore	0.058	0.035	1968–1973	0.039	–	–	–	–	0.222	5.05	0	0.038	1.721	24
		(0.03)		(0.08)					(0.39)	(0.02)				
Spain	0.033	0.021	1960–1966	0.037	1970–1974	0.019	1977–1980	–0.024	0.146	2.70	0	0.037	2.116	37
		(0.03)		(0.04)		(0.31)		(0.25)	(0.33)	(0.05)				
Sri Lanka	0.014	0.017	1968–1970	0.008	1977–1979	0.017	–	–	–0.385	2.23	0	0.043	2.23	36
		(0.05)		(0.77)		(0.46)			(0.02)	(0.10)				
Turkey	0.023	0.051	1970–1973	0.02	1980–1984	–0.056	–	–	–0.76	2.38	2	0.045	2.11	35
		(0.00)		(0.30)		(0.05)			(0.02)	(0.63)				
Uruguay	0.002	–0.005	1974–1982	0.029	–	–	–	–	–0.391	2.06	3	0.052	2.18	34
		(0.58)		(0.17)					(0.22)	(0.10)				
Yugoslavia	0.034	0.069	1965–1967	–0.038	–	–	–	–	–0.023	1.03	0	0.043	1.89	26
		(0.02)		(0.17)					(0.91)	(0.37)				

Appendix 10: A Solow–Swan Model with Differentiated Capital Goods

1. Determination of the Steady-State Solution

This section derives the steady-state solution of a Solow–Swan model with differentiated capital goods. The production function of the economy is assumed to be represented by a Cobb–Douglas production function of the following type:

[A.10.1] $Y_t = L_t^{\alpha} H_t^{\beta} \left(\sum_i^{A_D} X_{i,t}^{\gamma} + \sum_j^{A_F} X_{j,t}^{\gamma} \right)$ where $\alpha+\beta+\gamma=1,\ 0<\alpha,\beta,\gamma<1$,

where Y_t is GDP, L_t is the labor force, H_t is the stock of human capital, $X_{i,t}$ is a domestic capital good, $X_{j,t}$ is a foreign capital good, A_D is the set of domestic capital goods, and A_F is the set of foreign capital goods. The technical elasticity of substitution between two different types of capital goods, which is implied by [A.10.1], equals $\sigma = 1/(1-\gamma)$ (see Appendix 1). Consequently, the assumption that $0<\gamma<1$ ensures that the elasticity of substitution is finite, i.e., $\sigma<\infty$, such that capital goods are imperfect substitutes. Given this modeling of the stock of physical capital, exogenous technological progress is assumed to enter the model through an exogenous growth rate of the available set of production goods:

[A.10.2] $A_{D,t} = A_{D,0}\ e^{gt}$,

[A.10.3] $A_{F,t} = A_{F,0}\ e^{gt}$.

Technological knowledge is assumed to be free within (and only within) a country, such that there is free entry to the production of capital goods within each country and all domestic capital goods are sold at marginal cost prices. Following the basic assumptions of the Solow–Swan model one unit of GDP can be used for consumption as well as for the production of capital goods. This implies that the price of one unit of GDP equals the price of one unit of a domestic capital good, because one unit of GDP can be transformed into one unit of a domestic capital good. The alternative assumption of a monopolistic market structure on the domestic capital goods market (based on eternal patents for each type of capital good), does not alter the trade policy implications of the model.[227] The assumption of free entry to the

[227] The only difference is a reduction of the steady-state GDP due to a capital goods price that is by factor $1/\lambda$ larger than the marginal costs of capital goods production. See Maurer (1995b: Appendix 1) for a derivation of the steady-state solution of the Solow–

production of capital goods within each country implies that the price of foreign capital goods equals the price of domestic capital goods times $(1+\pi)$.[228] As the price for one unit of domestic capital goods equals unity, the price of one unit foreign capital goods equals $(1+\pi)$. Given a price of domestic capital goods of unity and a domestic price of foreign capital goods of $(1+\pi)$ and an equilibrium market interest rate r, the equilibrium per period rent for the usage of one unit of domestic capital goods equals r, and the per period rent for the usage of one unit of foreign capital goods equals $r \ (1+\pi)$. Under the assumption of a physical depreciation rate of capital goods of d, the per period opportunity costs of one unit of domestic capital goods equals $(r+d)$ and the per period opportunity costs of one unit of foreign capital goods equals $(r+d)(1+\tau)$. Consequently, profit maximization of the representative firm implies:

[A.10.4] $\max\limits_{L,H,X_i,X_j} F!$ with

$$F = L_t^\alpha H_t^\beta \left(\sum_i^{A_D} X_{i,t}^\gamma + \sum_j^{A_F} X_{j,t}^\gamma \right) - L_t w_L - H_t w_H - \sum_i^{A_D} X_{i,t} (r_t + d) - \sum_j^{A_F} X_{j,t} (r_t + d)(1+\tau)$$

$$F = L_t^\alpha H_t^\beta \left(\sum_i^{A_D} X_{i,t}^\gamma + \sum_j^{A_F} X_{j,t}^\gamma \right)$$

$$- L_t w_L - H_t w_H - \sum_i^{A_D} X_{i,t}(r_t + d) - \sum_j^{A_F} X_{j,t}(r_t + d)(1+\tau),$$

where w_L is the equilibrium per period price of raw labor, w_H is the equilibrium per period price of human capital. The first-order conditions for a profit maximum imply inter alia:

[A.10.5] $$\frac{\delta F}{\delta X_i} = \gamma L_t^\alpha H_t^\beta X_{i,t}^{\gamma-1} - r_t - d = 0$$

$$\Leftrightarrow X_{i,t} = \left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-1} \right)^{\frac{1}{1-\gamma}},$$

[A.10.6] $$\frac{\delta F}{\delta X_j} = \gamma L_t^\alpha H_t^\beta X_{j,t}^{\gamma-1} = (r_t + d)(1+\tau)$$

$$\Leftrightarrow X_{j,t} = \left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-1} (1+\tau)^{-1} \right)^{\frac{1}{1-\gamma}}.$$

Swan model with differentiated goods under the assumption of monopolistic competition on the market for capital goods.

228 Since all countries use the same production technologies ([A.10.1]), it is equal to say that the domestic price of foreign capital goods equals the world market price of foreign capital goods times $(1+\tau)$.

Consequently, the market equilibrium relation between domestic capital goods and foreign capital goods is given by:

[A.10.7] $X_{i,t} = X_{j,t}(1-\tau)^{\frac{1}{1-\gamma}}$.

Hence, the higher the import restrictions drive the price of foreign capital goods, the higher is the quantity of each type of domestic capital goods used in production in relation to the quantity of each type of foreign capital goods used in production. For the following calculations it is useful to notice that [A.10.5] implies the input quantities of all domestic capital goods to be identical:

[A.10.8] $X_{i,t} = \overline{X}_{i,t} \quad \forall i \in A_D$.

By the same argument, [A.10.6] implies the input quantities of all foreign capital goods to be identical:

[A.10.9] $X_{j,t} = \overline{X}_{j,t} \quad \forall j \in A_F$.

The market equilibrium value of the capital stock equals:[229]

[A.10.10] $K_t = \sum_i^{A_D} X_{i,t} + \sum_j^{A_F} X_{j,t}(1+\tau)$.

This equation shows that for a given amount of accumulated capital measured in GDP units, K_t, the real input quantities of capital goods are the lower, the higher the effective import tariff for foreign capital goods. This is the "income effect" of import tariffs. Inserting [A.10.7] and using [A.10.8] and [A.10.9], [A.10.10] can be rewritten in two alternative ways:

[A.10.11] $K_t = X_{i,t}\left(A_{D,t} + A_{F,t}(1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)$.

[A.10.12] $K_t = X_{j,t}\left(A_{D,t} + A_{F,t}\,(1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)(1+\tau)^{\frac{1}{1-\gamma}}$.

Inserting [A.10.8] and [A.10.9] in [A.10.1] yields:

[A.10.13] $Y_t = L_t^{\alpha}\, H_t^{\beta}\left(A_D\, X_{i,t}^{\gamma} + A_F\, X_{j,t}^{\gamma} \right)$.

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229 The market value of the capital stock is measured in GDP equivalent units and has to be distinguished from the physical quantity of the real capital stock within this model.

Solving [A.10.11] and [A.10.12] for $X_{i,t}$ and $X_{j,t}$ and inserting the resulting expressions in [A.10.13] yields:

$$[\text{A.10.14}] \quad Y_t = L_t^{\alpha} H_t^{\beta} \left(A_D \left(K_t \left(A_{D,t} + A_{F,t}(1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-1} \right) + A_F \left(K_t \left(A_{D,t} + A_{F,t}(1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-1} (1+\tau)^{\frac{-1}{1-\gamma}} \right) \right)^{\gamma}$$

$$\Leftrightarrow Y_t = L_t^{\alpha} H_t^{\beta} K^{\gamma} \left(A_D + A_F \; (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right) \left(A_D + A_F \; (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-\gamma}$$

$$\Leftrightarrow Y_t = L_t^{\alpha} \; H_t^{\beta} \; K_t^{\gamma} \; \Psi_t^{1-\gamma} \text{ with } \Psi_t := \left(A_{D,t} + A_{F,t} \; (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right).$$

This equals [C.21] in Section C.II.1. To derive the steady-state levels of these variables in terms of the structural parameters of the economy, the following definitions are useful:

$$[\text{A.10.15}] \quad \begin{aligned} h_t &:= H_t \,/\, L_t \Psi_t^{\vartheta} \\ k_t &:= K_t \,/\, L_t \Psi_t^{\vartheta} \quad \text{with } \vartheta := \frac{1-\gamma}{\alpha} \\ y_t &:= Y_t \,/\, L_t \Psi_t^{\vartheta} \end{aligned}$$

Now [A.10.14] can be rewritten:

$$[\text{A.10.16}] \quad y_t = h_t^{\beta} \, k_t^{\gamma} \; .$$

Following the assumptions of the human-capital-augmented Solow–Swan model of Mankiw et al. (1992), households save a fixed fraction of their income for investments in physical capital, s_k, and for investments in human capital, s_h.[230] Under the simplifying assumption of Mankiw et al. (1992) that physical and human

[230] This assumption distinguishes the Solow–Swan model from the Cass–Ramsey model. The latter is built on the assumption that households determine the size of their savings by an intertemporal utility maximization approach. As a consequence of this assumption, consumption growth, and consequently savings, are determined by the real interest rate but not by the level of income. The relation between real interest rates and real consumption growth has been subject to several tests. Many of them come to the conclusion that there is no significant positive relation between real interest rates and the real growth rate of consumption or real savings, especially when the level of real per capita income is added as a competing explanatory variable (Carrol and Summers 1991; Campbell and Mankiw 1989; Giovannini 1983, 1985). Earlier empirical studies (Feldstein 1970; McKinnon 1973; Fry 1978, 1980; Abe et al. 1977) could not reject the hypothesis of a positive relation between real savings and the real interest rate.

capital depreciate with the same rate, d, net investments in physical and human capital are given by the following equations:

[A.10.17] $\dot{K}_t = s_k Y_t - dK_t$,

[A.10.18] $\dot{H} = s_n Y_t - dK$.

From the definition of [A.10.15] follows:

[A.10.19] $\dot{k} = \dfrac{\dot{K}_t L_t \Psi_t^{\vartheta} - K\left(\dot{L}\Psi_t^{\vartheta} + L\dot{\Psi}_t^{\vartheta}\right)}{\left(L_t \Psi_t^{\vartheta}\right)^2} = \dfrac{\dot{K}_t}{L_t \Psi_t^{\vartheta}} - k\left(\dfrac{\dot{L}_t}{L_t} + \dfrac{\dot{\Psi}_t^{\vartheta}}{\Psi_t^{\vartheta}}\right)$.

The labor force, L_t, grows exogenously at rate n:

[A.10.20] $L_t = L_0 \, e^{nt}$.

Given [A.10.18], [A.10.2], [A.10.3] and inserting [A.10.16] into [A.10.19] yields:

[A.10.21] $\dot{k}_t = s_k \, y_t - k_t \, (d + n + g\,\vartheta)$.

This implies by analogy:

[A.10.22] $\dot{h}_t = s_h \, y_t - h_t \, (d + n + g\,\vartheta)$.

As in steady state all variables expressed in per capita units do not grow, the steady-state levels of k_t and h_t follow by equalizing [A.10.21] and [A.10.22] with zero:

[A.10.23] $\dot{k}_t = 0 \Leftrightarrow k_t = \left(\dfrac{s_k \, h_t^{\beta}}{n + d + g\,\vartheta}\right)^{\frac{1}{1-\gamma}}$,

[A.10.24] $\dot{h}_t = 0 \Leftrightarrow h_t = \left(\dfrac{s_h \, k^{\gamma}}{n + d + g\,\vartheta}\right)^{\frac{1}{1-\beta}}$.

Inserting [A.10.23] into [A.10.24], and [A.10.24] into [A.10.23] yields the steady-state levels of k and h in dependence from the structural parameters of the economy:

[A.10.25] $k^* = \left(\dfrac{s_k^{1-\beta} \, s_h^{\beta}}{n + d + g\,\vartheta}\right)^{\frac{1}{\alpha}}$,

$$[A.10.26]\quad h^* = \left(\frac{s_k^{\gamma}\, s_h^{1-\gamma}}{n + d + g\vartheta} \right)^{\frac{1}{\alpha}} .$$

Based on [A.10.25] and [A.10.26], [A.10.16] can now be rewritten:

$$[A.10.27]\quad \left(\frac{Y}{L}\right)_t^* = \left(n + d + g\vartheta\right)^{\frac{-\beta-\gamma}{\alpha}} s_k^{\frac{\gamma}{\alpha}} s_h^{\frac{\beta}{\alpha}} \Psi_0^{\vartheta} e^{g\vartheta t} \text{ with}$$

$$\Psi_0^{\vartheta} = \left(A_{D,0} + A_{F,0} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{\vartheta} .$$

Taking logs of [A.10.27], setting $gt\vartheta = a$, and allowing for an independent, normally distributed shock, ε, yields:

$$[A.10.28]\quad \ln\left(\frac{Y}{L}\right)^* = a - \frac{\beta+\gamma}{\alpha}\ln(n) + \frac{\gamma}{\alpha}\ln(s_k) + \frac{\beta}{\alpha}\ln(s_h) + \frac{1-\gamma}{\alpha}\ln(\Psi_0) + \varepsilon .$$

In order to estimate [A.10.28] by OLS it is necessary to assume that the country-specific error terms, ε, are uncorrelated with the explanatory variables s_k, s_h, n, and Ψ (Mankiw et al. 1992). If this condition does not hold, a simple OLS estimation does not yield an asymptotically unbiased estimate of the regression coefficients.[231] A test of [A.10.28] has to be based on the assumption that the economies of the cross-section sample are in their steady states. However, if most of the economies are out of steady state, the level of their current per capita GDP is not only influenced by the steady-state parameters (s_k, s_h, n, Ψ) but also by their initial states measured by some base period per capita GDP. In this case, the omission of their base-period per capita GDP implies a misspecification of the OLS estimation. Therefore, a sensitivity analysis of the steady-state assumption is useful. Consider, therefore, the out-of-steady-state implications of the Solow–Swan model. If the

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231 In a multivariate OLS regression the estimator of the regression coefficients corresponds to $\hat{\beta} = \beta + X'\,X\,X'\,u$, where $\hat{\beta}$ is the estimator of the regression coefficients, β is the true (but unknown) vector of regression coefficients, X is the matrix of explanatory variables and u is the vector of the error terms. Taking the probability limit of this formula shows that the estimated $\hat{\beta}$ asymptotically converges to the true β only if the explanatory variables are not correlated with the error terms. If the explanatory variables are correlated with the error terms, a linear regression yields unbiased estimates only, if instrumental variables are included in the regression. These instrumental variables must be highly correlated with the explanatory variables but uncorrelated with the error terms. Unfortunately, this kind of variables is difficult to find.

economy is out of steady state, the level of per capita GDP is determined by a weighted average of the steady-state level of per capita GDP and the initial level of per capita GDP as given by the following equation:[232]

$$[A.10.29]\quad \ln\left(\frac{Y_t}{L_t}\right) = \left(1-e^{-\lambda t}\right)\ln\left(\frac{Y_t}{L_t}\right)^*_t + e^{-\lambda t}\ln\left(\frac{Y_t}{L_t}\right)_0, \quad \text{with}$$

$$\lambda = (1-\beta-\gamma)\,(n+d+g\vartheta),$$

where $(Y/L)_0$ is the initial level of per capita GDP. As follows from [A.10.29], λ determines the speed of transition from the initial level of per capita GDP to its steady-state level. The higher λ, the faster the transition from the initial level of per capita GDP to its steady-state level. Inserting [A.10.27] in [A.10.29] and taking logs yields:

$$[A.10.30]\quad \ln\left(\frac{Y_{i,t}}{L_{i,t}}\right) = \omega g\vartheta t - \omega\frac{\beta+\gamma}{\alpha}\ln(g+d+n_i) + \omega\frac{\gamma}{\alpha}\ln(s_{i,k}) + \omega\frac{\beta}{\alpha}\ln(s_{i,h})$$

$$+\omega\frac{1-\gamma}{\alpha}\ln(\Psi_{i,0}) + e^{-\lambda t}\ln\left(\frac{Y_{i,0}}{L_{i,0}}\right), \quad \text{with } \omega = \left(1-e^{-\lambda t}\right).$$

This equals [C.24] in Section C.III.

2. Determination of the Relative Input Mix Indicator (RIM)

In a market equilibrium [A.10.7] must hold. Taking the first derivation of [A.10.7] with respect to time yields:

$$[A.10.31]\quad \dot{X}_i = \dot{X}_j(1-\tau)^{\frac{1}{1-\gamma}}.$$

Multiplying both sides with A_D/A_F and rearranging the terms yields:

$$[A.10.32]\quad \frac{\dot{X}_i}{\dot{X}_j}\frac{A_D}{A_F} = \frac{A_D}{A_F}\left(1+\tau\right)^{\frac{1}{1-\gamma}}.$$

As follows from [A.10.10] and [A.10.8] the market equilibrium per period increment of the capital stock with domestic goods, $K_D = A_D X_i$, equals:

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[232] For a derivation see Barro and Sala-i-Martin (1995: 37 and 53).

[A.10.33] $\dot{K}_D = A_D\,\dot{X}_i + \dot{A}_D\,X_i$.

By analogy the market equilibrium per period increment of the capital stock with foreign goods, $K_F = A_F\,X_j\,(1+\tau)$ equals:

[A.10.34] $\dot{K}_F = \left(A_F\,\dot{X}_j + \dot{A}_F\,X_j\right)\ (1+\tau)$.

From [A.10.7], [A.10.8], and [A.10.9] follows that in a market equilibrium the relation $\dot{X}_i/X_i = \dot{X}_j/X_j$ holds. From [A.10.2] and [A.10.3] follows that the relation $\dot{A}_D/A_D = \dot{A}_F/A_F$ holds. These equations can be rewritten in the following way:

[A.10.35] $$\frac{\dot{A}_D}{A_D}\frac{X_i}{\dot{X}_i} = \frac{\dot{A}_F}{A_F}\frac{X_j}{\dot{X}_j} := \omega\ .$$

Dividing [A.10.33] by [A.10.34] and using [A.10.35] the following relation holds:

[A.10.36] $$\frac{\dot{K}_D}{\dot{K}_F} = \frac{A_D\,\dot{X}_i + \dot{A}_D\,X_i}{A_F\,\dot{X}_j + \dot{A}_F\,X_j}\,(1+\tau)^{-1}$$
$$= \frac{\left(A_D\,\dot{X}_i\right)(1+\omega)}{\left(A_F\,\dot{X}_j\right)(1+\omega)}(1+\tau)^{-1}$$
$$= \frac{\left(A_D\,\dot{X}_i\right)}{\left(A_F\,\dot{X}_j\right)}(1+\tau)^{-1}.$$

Inserting this in [A.10.32] yields:

[A.10.37] $$\left(1+\tau\right)^{\frac{\gamma}{1-\gamma}} = \frac{\dot{K}_D}{\dot{K}_F}\bigg/\frac{A_D}{A_F},$$

where $\dot{K}_D$ equals the aggregate investment of domestic capital goods in period t. It is empirically measured here by the domestic production of capital goods minus exports of domestic capital goods. Similarly, $\dot{K}_F$ equals the aggregate investment of foreign capital goods in period t. It is empirically measured here by the domestic imports of foreign capital goods. A_F is the number of the varieties of foreign capital goods. It is assumed that the ratio of A_D/A_F equals approximately the ratio of exports of domestic capital goods to the world production of capital goods minus domestic production of capital goods. Consequently, the empirical proxy of [A.10.37] has the following dimension:

[A.10.38] $(1+\tau)^{\frac{\gamma}{1-\gamma}} = \dfrac{\text{ratio of domestic capital goods to foreign capital goods in } domestic \text{ production}}{\text{ratio of domestic capital goods to foreign capital goods in } world \text{ production}}$

The right-hand side of [A.10.38] is called the relative input mix value (RIM).

3. Determination of [C.20]

This section derives the formula of the relation between the import tariff for capital goods and the growth rate of total factor productivity. Following [C.21], the formula of total factor productivity equals:

[A.10.39] $$TFP_t = Y_t \big/ \left(L_t^{\alpha}\ H_t^{\beta}\ K_t^{\gamma}\right) = \left(A_{D,t} + A_{F,t}\ (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{1-\gamma}.$$

Taking the first derivation with respect to time yields the growth rate of total factor productivity:

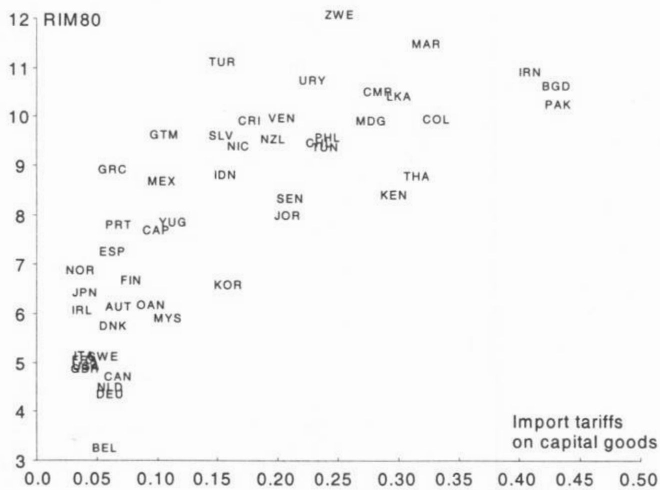
[A.10.40] $$\frac{T\dot{F}P}{TFP} = \frac{(1-\gamma)\left(\dot{A}_{D,t} + \dot{A}_{F,t}\ (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)}{\left(A_{D,t} + A_{F,t}\ (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)}.$$

Taking the first derivation with respect to the capital goods import tariff yields [C.31]:

[A.10.41] $$\frac{\delta(T\dot{F}P/TFP)}{\delta\tau} = \frac{(1+\tau)^{1-\gamma}\left(A_{D,t}\, A_{F,t}\left(\frac{\dot{A}_{D,t}}{A_{D,t}} - \frac{\dot{A}_{F,t}}{A_{F,t}} \right)\right)}{\left(A_{D,t} + A_{F,t}\,(1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{2}}.$$

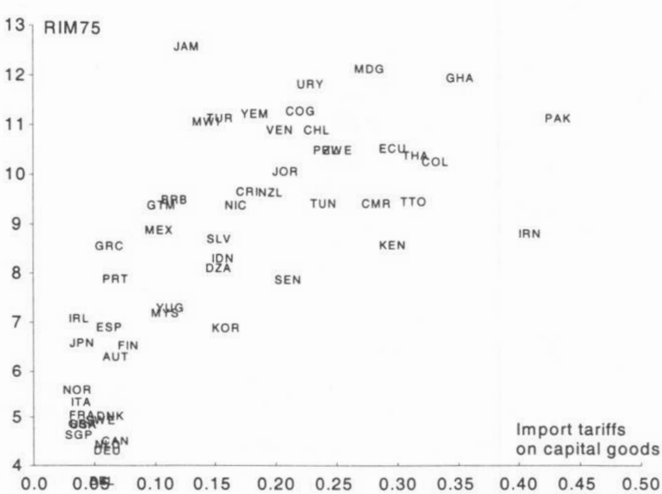
Appendix 11: Results of Section C.II.1

Figure A.11.1 — Import Tariffs on Capital Goods and Relative Input Mix Values, 1980[a]



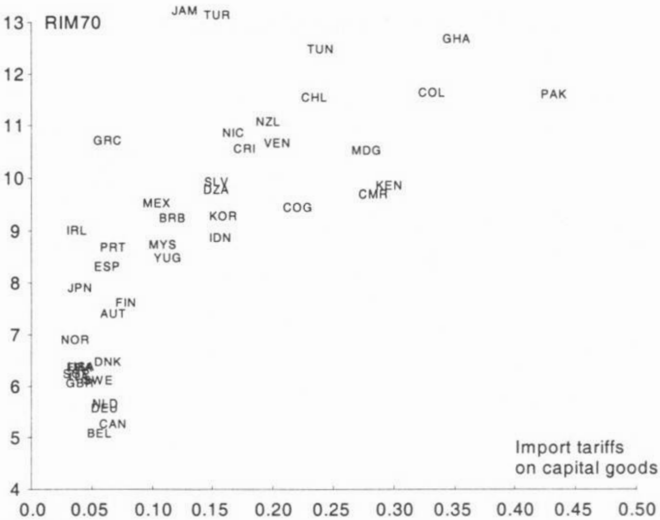
[a]The three-letter World Bank country code is used to mark the coordinate of the corresponding country.

Figure A.11.2 — Import Tariffs on Capital Goods and Relative Input Mix Values, 1975[a]



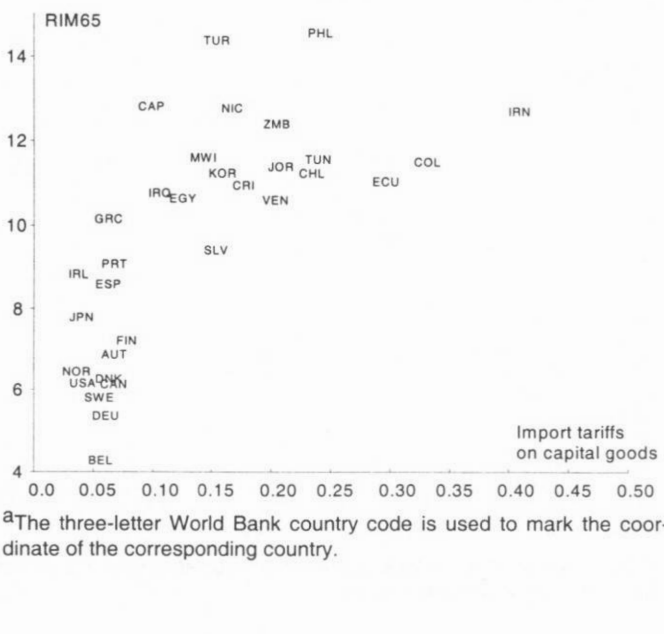
[a]The three-letter World Bank country code is used to mark the coordinate of the corresponding country.

Figure A.11.3 — Import Tariffs on Capital Goods and Relative Input Mix Values, 1970[a]



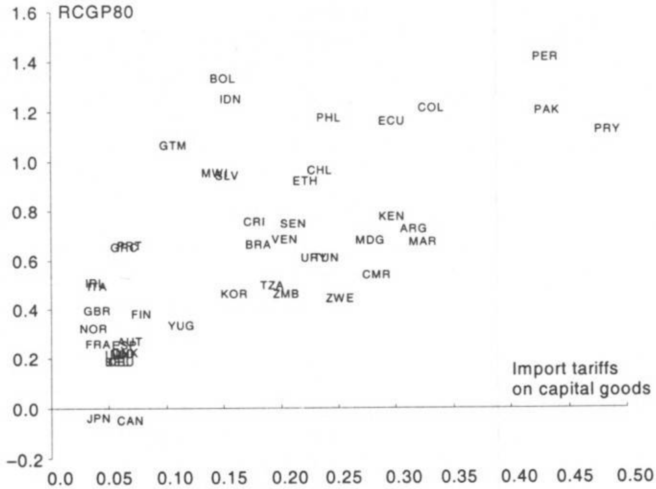
[a]The three-letter World Bank country code is used to mark the coordinate of the corresponding country.

Figure A.11.4 — Import Tariffs on Capital Goods and Relative Input Mix Values, 1965[a]



[a]The three-letter World Bank country code is used to mark the coordinate of the corresponding country.

Figure A.11.5 — Import Tariffs on Capital Goods and Relative Capital Goods Prices, 1980[a]



[a]The three-letter World Bank country code is used to mark the coordinate of the corresponding country.

Table A.11.1 — Estimation Results for the Steady-State Version of a Solow–Swan Model Based on the Macroversion of Ψ_t [a]

	All countries[b]				All non-OECD countries[c]				OECD countries			
	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]
Const.	4.541	6.074	6.814	6.320	8.718	5.974	9.614	6.192	4.896	7.918	6.794	7.993
$p(\beta=0)$	0.010	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.050	0.000	0.022	0.000
$\ln(n+g+d)$[e]	−2.247	−1.753	−1.446	−1.644	−0.658	−1.628	−0.371	−1.566	−1.668	−0.724	−1.053	−0.696
$p(\beta=0)$	0.000	0.000	0.018	0.000	0.475	0.000	0.682	0.000	0.043	0.016	0.255	0.016
s_K	1.061	1.138	0.909	1.029	1.180	1.145	1.051	1.066	0.004	0.215	0.040	0.192
$p(\beta=0)$	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.988	0.421	0.894	0.456
s_h	0.569	0.615	0.598	0.616	0.547	0.483	0.581	0.500	0.469	0.509	0.462	0.503
$p(\beta=0)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ψ			4.199	1.616			2.923	1.500			5.136	1.503
$p(\beta=0)$			0.002	0.000			0.055	0.000			0.218	0.000
α	0.308	0.363	0.409	0.378	0.603	0.380	0.729	0.390	0.375	0.580	0.487	0.590
β	0.175	0.223	0.244	0.233	0.330	0.184	0.424	0.195	0.176	0.295	0.225	0.297
γ	0.327	0.413	0.371	0.389	0.712	0.436	0.766	0.416	0.002	0.125	0.020	0.113
$\alpha+\beta+\gamma$	0.810	1.000	1.025	1.000	1.645	1.000	1.920	1.000	0.552	1.000	0.732	1.000
λ	0.022	0.026	0.029	0.027	0.045	0.028	0.054	0.029	0.022	0.034	0.028	0.034
F(restr.)		0.826		2.163		1.221		1.227		1.701		1.030
$p(F)$		0.367		0.123		0.274		0.302		0.210		0.380
$\overline{R}^2$	0.765	0.766	0.793	0.787	0.631	0.629	0.651	0.648	0.595	0.580	0.610	0.608
F	74.9	75.2	65.3	62.7	27.4	27.2	22.4	22.1	7.4	6.9	6.2	6.2
$p(F)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.003	0.003
SEE	0.296	0.295	0.260	0.269	0.317	0.319	0.300	0.303	0.072	0.074	0.069	0.069
DW	1.670	1.704	1.567	1.660	1.513	1.472	1.519	1.468	1.238	1.370	1.446	1.387
Obs.	74	74	74	74	53	53	53	53	21	21	21	21

[a]Variables as defined in text. $p(\beta=0)$ is the p-value of a t-test of the H_0 that the regression coefficient in the line above the p-value equals zero. $p(F)$ is the p-value of the F-value in the line above the p-value. $\overline{R}^2$ is the adjusted R-squared value. SEE is the standard error of the regression. DW is the Durbin–Watson test of first-order serial correlation of the regression errors. (The sample is ranked according to the 1985 level of per capita GDP.) — [b]The country sample corresponds to the „big sample" (98 countries) of Barro and Sala-i-Martin (1991). This sample excludes all small islands economies, the major oil exporters and the former socialist countries. — [c]All "big sample" countries minus OECD countries. — [d]The restrictions urge the sum of the implicit values of the production elasticities to equal unity (i.e., $\alpha+\beta+\gamma=1$). F(restr.) is the F-value of a test of the H_0 that the restricted model is false and the unrestricted model is true. — [e]$(g+d)$ is assumed to be 0.05.

Table A.11.2 — Estimation Results for the Steady-State Version of a Solow–Swan Model Based on the Microversion of Ψ_t[a]

	All countries[b]				All non-OECD countries[c]				OECD countries			
	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]	Unre-stricted	Restric-ted[d]
Const.	3.661	6.006	5.730	6.691	7.696	5.970	8.376	6.629	4.735	7.946	6.718	8.085
$p(\beta=0)$	0.056	0.000	0.002	0.000	0.014	0.000	0.005	0.000	0.065	0.000	0.030	0.000
$\ln(n+g+d)$[e]	−2.528	−1.820	−1.707	−1.464	−1.070	−1.660	−0.761	−1.367	−1.698	−0.702	−1.070	−0.654
$p(\beta=0)$	0.000	0.000	0.005	0.000	0.326	0.000	0.455	0.000	0.044	0.025	0.265	0.025
s_K	0.973	1.175	0.648	0.839	1.192	1.139	0.853	0.830	−0.040	0.197	0.028	0.160
$p(\beta=0)$	0.004	0.000	0.036	0.002	0.008	0.009	0.049	0.039	0.902	0.482	0.930	0.540
s_h	0.565	0.645	0.564	0.626	0.568	0.521	0.579	0.537	0.461	0.506	0.458	0.494
$p(\beta=0)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ψ			2.195	1.626			1.720	1.537			2.459	1.494
$p(\beta=0)$			0.000	0.000			0.015	0.000			0.235	0.000
α	0.283	0.355	0.369	0.406	0.483	0.376	0.568	0.422	0.371	0.587	0.483	0.605
β	0.160	0.229	0.208	0.254	0.274	0.196	0.329	0.227	0.171	0.297	0.221	0.298
γ	0.276	0.417	0.239	0.340	0.576	0.428	0.484	0.351	−0.015	0.116	0.014	0.097
$\alpha+\beta+\gamma$	0.719	1.000	0.817	1.000	1.334	1.000	1.381	1.000	0.527	1.000	0.718	1.000
λ	0.020	0.025	0.026	0.029	0.036	0.028	0.042	0.032	0.022	0.034	0.028	0.035
F(restr.)		1.622		0.930		0.346		0.227		1.816		0.537
$p(F)$		0.208		0.401		0.560		0.798		0.197		0.595
$\overline{R}^2$	0.726	0.723	0.782	0.783	0.539	0.547	0.601	0.618	0.590	0.570	0.602	0.624
F	47.7	47.0	46.7	46.9	12.8	13.3	12.0	12.9	7.2	6.6	4.5	5.0
$p(F)$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.004	0.013	0.009
SEE	0.288	0.291	0.229	0.228	0.334	0.328	0.289	0.277	0.075	0.078	0.072	0.068
DW	1.708	1.761	1.520	1.633	1.631	1.611	1.566	1.540	1.145	1.170	1.274	1.186
Obs.	59	59	59	59	39	39	39	39	20	20	20	20

[a]Variables as defined in text. $p(\beta=0)$ is the p-value of a t-test of the H_0 that the regression coefficient in the line above the p-value equals zero. $p(F)$ is the p-value of the F-value in the line above the p-value. $\overline{R}^2$ is the adjusted R-squared value. SEE is the standard error of the regression. DW is the Durbin–Watson test of first-order serial correlation of the regression errors. (The sample is ranked according to the 1985 level of per capita GDP.) — [b]The country sample corresponds to the "big sample" (98 countries) of Barro and Sala-i-Martin (1991). This sample excludes all small islands economies, the major oil exporters and the former socialist countries. — [c]All "big sample" countries minus OECD countries. — [d]The restrictions urge the sum of the implicit values of the production elasticities to equal unity (i.e., $\alpha+\beta+\gamma=1$). F(restr.) is the F-value of a test of the H_0 that the restricted model is false and the unrestricted model is true. — [e]$(g+d)$ is assumed to be 0.05.

Table A.11.3 — Indicators of Import Tariffs and Quotas on Capital Goods and Relative Capital Goods Prices and Input Ratios

Country	WB-Code	Tariff	Quota	RIM65	RIM70	RIM75	RIM80	RIM85	RCGP80	RCGP85
Algeria	DZA	0.132	0.003		9.763	8.101				
Angola	AGO	0.092	0.051							
Benin	BEN	0.264	0.169							0.964
Botswana	BWA								0.193	0.295
Burkina Faso	HVO	0.482	0.682							
Burundi	BDI	0.221	0.006							
Cameroon	CMR	0.261	0.143		9.683	9.410	10.514		0.537	0.575
Cape Verde	CPV									
Centr. Afr. Rep.	CAF	0.200	0.037				15.306			
Chad	TCD									
Comoros	COM									
Congo	COG	0.198	0.035		9.423	11.281		9.850		0.439
Egypt	EGY	0.104	0.247	10.603	17.348	16.423	19.699			0.993
Ethiopia	ETH	0.200	0.174						0.923	0.456
Gabon	GAB			10.966						
Gambia	GMB									
Ghana	GHA	0.330	0.200		12.662	11.939				
Guinea	GIN	0.051								
Guinea-Bissau	GNB									
Côte d'Ivoire	CIV				11.023	8.270			0.549	0.217
Kenya	KEN	0.275	0.203		9.842	8.570	8.412	10.171	0.777	0.823
Lesotho	LSO									
Liberia	LBR									
Madagascar	MDG	0.255	0.007		10.502	12.123	9.918	10.256	0.682	0.789
Malawi	MWI	0.121	0.808	11.580	13.671	11.060	13.343	11.378	0.956	0.808
Mali	MLI				15.422	12.074			0.998	0.342
Mauritania	MRT									
Mauritius	MUS	0.347	0.337		14.959	7.530	10.321			0.842
Morocco	MOR	0.301	0.307				11.505	11.071	0.675	1.071
Mozambique	MOZ	0.106		13.817						
Niger	NER									
Nigeria	NGA	0.447	0.016					12.994	0.455	0.223
Rwanda	RWA	0.274	0.443							0.442
Senegal	SEN	0.189	0.049			7.866	8.342		0.747	0.647
Seychelles	SYC									
Sierra Leone	SLE	0.122								0.431
Somalia	SOM	0.204	0.024							
South Africa	ZAF				8.754	8.245	8.577	9.227		
Sudan	SDN	0.331	0.075							
Swaziland	SWZ									0.407
Tanzania	TZA	0.172	0.284						0.496	–0.380
Togo	TGO									
Tunisia	TUN	0.218	0.543	11.541	12.458	9.404	9.369	9.299	0.608	0.451
Uganda	UGA	0.103								
Zaire	ZAR	0.122	0.381							
Zambia	ZMB	0.183		12.364					0.461	0.555
Zimbabwe	ZWE	0.229	0.867	7.779		10.488	12.092	11.219	0.441	0.534

Table A.11.3. continued

Country	WB-Code	Tariff	Quota	RIM65	RIM70	RIM75	RIM80	RIM85	RCGP80	RCGP85
Bahamas	BHS	0.177								
Barbados	BRB	0.095	0.093		9.235	9.474				
Canada	CAN	0.046	0.019	6.108	5.253	4.498	4.706	3.698	–0.051	0.191
Costa Rica	CRI	0.157	0.703	10.921	10.539	9.643	9.909	9.211	0.756	
Dominica	DMA	0.305								
Dominican Rep.	DOM					9.232	10.254	7.391	1.046	
El Salvador	SLV	0.133	0.043	9.381	9.916	8.690	9.604		0.944	
Grenada	GRD	0.182	0.094							
Guatemala	GTM	0.084	0.823			9.369	9.622	10.309	1.067	
Haiti	HTI	0.101	0.118							
Honduras	HND			11.248				13.142	0.879	
Jamaica	JAM	0.106	0.105	13.840	13.215	12.575	13.114	13.365		
Mexico	MEX	0.082	0.064		9.516	8.866	8.675			
Nicaragua	NIC	0.148	0.684	12.738	10.850	9.373	9.397	11.198		
Panama	PAN			10.961	9.015	8.889	12.736	13.429	0.944	
St. Lucia	LCA	0.141	0.031							
St. Vincent	VCT	0.100	0.031							
Trinidad & Tobago	TTO	0.293	0.245			9.442		8.803		
United States	USA	0.020	0.123	6.123	6.370	4.851	4.916	3.964		
Argentina	ARG	0.294	0.055						0.728	
Bolivia	BOL	0.129	0.042						1.332	
Brazil	BRA	0.159	0.047						0.663	
Chile	CHL	0.213	0.098	11.212	11.520	10.903	9.471	10.368	0.964	
Colombia	COL	0.310	0.520	11.472	11.610	10.253	9.961	11.091	1.216	
Ecuador	ECU	0.275	0.399	11.003		10.515		12.668	1.163	
Guyana	GUY	0.118	0.013							
Paraguay	PRY	0.463	0.013						1.127	
Peru	PER	0.409	0.370						1.418	
Surinam	SUR									
Uruguay	URY	0.207	0.030			11.821	10.740	11.766	0.610	
Venezuela	VEN	0.182	0.002	10.565	10.647	10.906	9.970	9.948	0.685	
Afghanistan	AFG									
Bahrain	BHR	0.048	0.020							
Bangladesh	BGD	0.409	0.497			13.987	10.630	10.477		1.232
Myanmar	BUR									
China	CHN	0.254	0.291					9.189		
Hong Kong	HKG		0.001			6.516	6.447	5.311	0.284	
India	IND	1.319	0.888	10.105	10.857	9.577	10.056	9.755	1.134	0.961
Indonesia	IDN	0.137	0.101		8.851	8.293	8.799	9.385	1.250	0.364
Iran	IRN	0.390	0.863	12.649	14.436	8.803	10.921			0.832
Iraq	IRQ	0.086	0.180	10.736						
Israel	ISR								0.617	
Japan	JPN	0.020	0.058	7.774	7.897	6.566	6.429	5.993	–0.040	0.104
Jordan	JOR	0.187	0.109	11.359		10.056	7.997	9.197		
Korea	KOR	0.137	0.100	11.192	9.264	6.880	6.597	5.150	0.458	0.460

Table A.11.3. continued

Country	WB-Code	Tariff	Quota	RIM65	RIM70	RIM75	RIM80	RIM85	RCGP80	RCGP85
Kuwait	KWT	0.027	0.053							
Malaysia	MYS	0.087	0.045		8.722	7.174	5.918	3.936		
Nepal	NPL	0.104	0.045							
Oman	OMN	0.013	0.020							
Pakistan	PAK	0.411	0.075	9.705	11.582	11.126	10.253	10.793	1.206	1.252
Philippines	PHL	0.221	0.467	14.511	12.891	10.481	9.582	8.405	1.177	0.514
Saudi Arabia	SAU	0.079	0.019							
Singapore	SGP	0.016	0.005		6.236	4.623				
Sri Lanka	LKA	0.280	0.080				10.427	10.191	1.958	1.542
Syria	SYR	0.163	0.538							
Taiwan	OAN	0.073	0.375				6.173	5.538		
Thailand	THA	0.294	0.055		14.007	10.373	8.790	7.989		0.897
Arab. Emirates	ARE	0.029	0.006							
Yemen	YEM	0.161	0.128			11.221				
Austria	AUT	0.047	0.021	6.841	7.401	6.279	6.150	5.850	0.267	0.005
Belgium	BEL	0.036	0.112	4.255	5.072	3.671	3.260		0.185	0.029
Cyprus	CAP	0.078	0.354	12.790			7.697	6.827		
Denmark	DNK	0.042	0.112	6.246	6.454	5.029	5.746	5.316	0.220	–0.018
Finland	FIN	0.059	0.067	7.163	7.609	6.506	6.677	6.227	0.376	0.041
France	FRA	0.019	0.050	15.030	6.362	5.043	5.052	4.917	0.257	0.047
Germany, West	DEU	0.039	0.119	5.341	5.570	4.308	4.353	4.108	0.184	–0.021
Greece	GRC	0.041	0.142	10.115	10.703	8.548	8.911	9.167	0.650	0.469
Hungary	HUN				6.855	5.107	6.695	6.787	0.645	0.421
Iceland	ISL				13.591	11.754	11.478	12.152		
Ireland	IRL	0.019	0.054	8.816	8.998	7.072	6.078	4.986	0.506	0.141
Italy	ITA	0.021	0.069		6.170	5.317	5.134	4.724	0.492	0.252
Luxembourg	LUX	0.036							0.213	–0.123
Malta	MLT			11.578	11.528	9.402	9.495	9.350		
Netherlands	NLD	0.040	0.126		5.659	4.438	4.495	4.039	0.216	0.049
Norway	NOR	0.014	0.041	6.423	6.893	5.560	6.873	6.504	0.322	0.126
Poland	POL								0.419	0.162
Portugal	PRT	0.047	0.194	9.046	8.679	7.872	7.805	7.098	0.659	0.777
Spain	ESP	0.042	0.123	8.562	8.317	6.896	7.259	6.432	0.253	0.425
Sweden	SWE	0.033	0.028	5.772	6.109	4.937	5.121	4.601		–0.049
Switzerland	CHE	0.012	0.176							
Turkey	TUR	0.133	0.872	14.333	13.124	11.125	11.112	8.298		0.191
United Kingdom	GBR	0.018	0.044		6.040	4.864	4.866	4.375	0.392	0.126
Yugoslavia	YUG	0.091	0.370		8.474	7.281	7.849	7.392	0.332	0.432
Australia	AUS			8.464	9.102	8.072	8.126	8.264		–0.022
Fiji	FJI				13.974			11.961		
New Zealand	NZL	0.176		20.126	11.053	9.630	9.546	9.251		0.483
Papua New Guinea	PNG	0.106	0.002					13.110		
Solomon Islands	SLB									
Tonga	TON									
Vanuatu	VUT									
Western Samoa	WSM									

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