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Trade policy, the price of capital goods and economic growth: An empirical test of a Solow-Swan model with capital variety

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**Trade Policy, the Price of Capital Goods
and Economic Growth**

An empirical test of a Solow-Swan model with capital variety

by

Rainer Maurer



Institut für Weltwirtschaft an der Universität Kiel
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Abstract

In this paper I test the hypothesis that trade policies leading to higher prices for capital goods have a negative influence on the steady state level and transitional growth rate of per capita GDP. I derive this hypothesis from a modified version of a Solow-Swan model, in which capital variety increases productivity.

This model has the implication that import restrictions on foreign capital goods reduce the steady state level and the transitional growth rate of per capita GDP. However, although I assume that technological progress spreads over different countries via the import of new capital goods, import restrictions do not reduce the steady state growth rate. A reduction of the steady state growth rate is only possible, if the number of varieties of imported capital goods were restricted.

The empirical results show that capital goods prices as well as the relative input ratios of domestic and foreign capital goods are significantly positively affected by the level of import tariffs on capital goods and the coverage ratio of non-tariff measures on capital goods. A test of the steady state version of the Solow-Swan model displays a statistically significant negative relation between import restrictions on foreign capital goods and the level of per capita GDP. A test of the transitional version of the Solow-Swan model displays a statistically significant negative relation between import restrictions on foreign capital goods and the transitional growth rate of per capita GDP.

Key words: Trade policy, economic growth of open economies, neoclassical growth theory, new growth theory, empirical test

JEL-Classification: C12, C21, F13, F43, O11, O12, O41

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1. Introduction

Trade policy in many developing countries intends to favour the development of a domestic capital goods industry. A primary instrument towards this end are import tariffs and import quotas on foreign capital goods. These import restrictions are to raise the demand for domestic capital goods subsidizing this way the domestic capital goods industry. Case studies on foreign trade regimes, such as Balassa (1971), Donges/Müller-Ohlsen (1978), and Balassa (1982), have shown that many developing countries have significant high rates of effective protection for producer durables.¹

There is still an ongoing debate in economic theory on the implications of this kind of trade policy for the economic development of a country. Several schools of thought have established.

Under the assumptions of the traditional neoclassical trade theory any restriction on foreign trade is pareto-inferior to free trade. Roughly spoken, free trade can improve welfare within the neoclassical trade model, because it allows to exploit country-specific differences in preferences, resource endowments and technologies.² This way free trade typically leads to an increase of the consumption possibility space of an economy. However, within neoclassical theory international trade does typically not change the production technologies itself. In this sense it does not lead to an increase of the production possibility space.³ This holds also in the typical neoclassical growth models (Solow (1956), Swan (1956), Cass (1965), Uzawa (1964)). In these models the production possibility space grows with an exogenous rate. Trade can only influence the transitional growth rate of real GDP if financial markets allow for international borrowing and lending.⁴

Contrary to the typical neoclassical model, under the assumptions of endogenous growth theory free trade can in general influence the growth rate of the production possibility space. Depending on the specification of the model, restrictions on foreign trade can increase as well

¹ (a) See Balassa (1971), pp. 28-29, Donges/Müller-Ohlsen (1978), p. 61 and Balassa (1982), p. 54. There are, however, differences between developing countries. Typically effective rates of protection in capital goods industries are higher in Latin American countries than in East Asian countries. An exception seems to South Korea that had rather high rates of effective protection for machinery until the end of the seventies (Ito/Krueger (1993), p. 368). (b) The effective rate of protection for a commodity is defined as the ratio of the domestic price of one unit value added to the world market price of one unit value added minus one.

² See e.g. Dixit/Norman (1980), chapter 3.

³ More technically spoken, trade does not change the shape and position of the transformation curve.

⁴ For a discussion of the effects of free trade within this type of model see Barro/Sala-i-Martin (1995), chapter 3.

as decrease the growth rate of per capita GDP. Rivera-Batiz/Romer (1991a) and (1991b) present an endogenous growth model, where free trade leading to higher profits in research and development stimulates the production of new technological knowledge and increases therefore the rate of economic growth. On the contrary, Grossman/Helpman (1991), chapter 8, present a model of trade hysteresis, where free trade may deteriorate the long run growth perspectives of a technologically backward country. Two assumptions are essential to derive this result: International immobility of technological knowledge and an income inelastic demand for traditional "low tech" goods.⁵ Hence, all in all, endogenous growth theory has been very successful in offering new insights in possible interactions between international trade and the mechanics of economic growth.

However, the standard models of endogenous growth generally have some implications that are not supported by the data. Typically endogenous growth models imply the steady state growth rate of per capita income to depend on the endowment of the economy with production factors that are not (or not solely) accumulated by market forces (such as the resource endowment of the economy, the labor force, the stock of human capital and the stock of public goods).⁶ Consequently, endogenous growth models imply the per capita growth rate to display a time trend given that one or more of these production factors display a time trend. However, although many of these production factors actually display a time

⁵ (a) International immobility of technological knowledge can lead to an ever increasing comparative advantage in the production of high tech goods in countries with a leading position in the production of these goods. An income inelastic demand for "low tech" goods can lead to a long term rise in the relative price of high tech goods. (b) Probably the first economist, who developed a theory of trade hysteresis as an explicit counter theory to the „classical“ free trade theory of Adam Smith (1776) was Friedrich List (1841). The trade hysteresis theory of List already contained many features of the modern trade hysteresis theory, which has now been formalized by the models of Krugman (1981) and Grossman/Helpman (1991). For a discussion of the Listian trade hysteresis theory see Maurer (1994).

⁶ Needless to say, production factors like human capital, public goods and even labour force can be modeled as accumulating production factors within model of endogenous growth. In this case they do not appear in the formula of the steady state growth rate. For a discussion of these points see Maurer (1995a).

trend, Maurer (1995a) finds that real per capita growth rates of most countries are mean-reverting processes and have no significant time trend.⁷

On the contrary, traditional neoclassical growth models do fit with this time series behaviour of the data. This is the case, because the traditional neoclassical growth model implies not the per capita *growth rate* but the *level* of per capita GDP to depend on production factors that are not accumulated by market forces. Furthermore, tests of the traditional neoclassical growth model, such as Mankiw/Romer/Weil (1992), Gundlach (1994), and Barro/Sala-i-Martin (1995), chapters 11 and 12, have shown its good empirical performance. Based on cross regional as well as cross country data sets these studies show that the transitional dynamics of the neoclassical growth model are able to explain a lot of the actual cross regional and cross country variation of growth rates.

Built on these studies the following empirical picture can be drawn: The rate of technological progress can be assumed to be exogenous.⁸ Technological knowledge is more or less mobile such that the rate of productivity growth is approximately equal across countries. Therefore, if all countries had reached their steady states, their per capita income would grow with the same rate. Consequently, the striking persistence and significant deviation of real per capita growth rates, which most countries exhibited over the last thirty years,⁹ is to be explained by their different distances to their steady states *and* by a corresponding change of the steady state variables. These steady state variables are the investment quota (resp. the corresponding preference parameters, which determine this quota) of physical and human capital, the steady state level of endowment with public goods (public infrastructure, political stability, etc.) and the population growth rate. For example, countries with an outstanding good growth performance like the East Asian NICs started from a comparatively low level of per capita income and have succeeded in enormously increasing their investment quotas (Maddison (1992), World Bank (1993), pp. 40-42) and their stocks of human capital (World

⁷ Of course, endogenous growth models can be reconciled with these empirical facts. To do so the "crucial production function" must not include non-accumulating production factors (The "crucial production function" is the production function that contains an accumulating production factor with non-diminishing marginal returns.). In this case the steady state per capita growth rate depends only on policy variables (such as taxes and tariffs) and the structural parameters of the economy (such as the rate of time preference, the parameter of relative risk aversion and certain production elasticities). An example for this type of model is the fiscal spending model of Barro (1990).

⁸ This is not to say that the rate of technological progress is actually exogenous. However, the mistake that is possibly implied by this assumption is probably empirically not that important. If it is important, the explanatory power of the model will be reduced.

⁹ Maurer (1995a).

Bank (1993), pp. 43-46 and Barro/Lee (1993)) while holding a high level of political stability.

Given this relative good empirical performance of the traditional neoclassical growth model in explaining cross country growth rates, it may be a useful first approach to base an empirical study of the influence of a protectionist capital goods trade policy on a model of this type. To do so, I modify the Solow-Swan model in such a way that international trade with capital goods does increase the production space. This model has the implication that restrictions on capital good imports lead to a lower steady state level of GDP and a lower transitional growth rate of per capita income. The fact that international trade effects the production space discriminates this model from the standard neoclassical foreign trade model.

2. A Solow/Swan model with capital variety.

Consider the production function of the economy to be represented by a Cobb-Douglas production function of the following type:

$$Y_t = L_t^\alpha H_t^\beta \left(\sum_i^{A_D} X_{i,t}^\gamma + \sum_j^{A_F} X_{j,t}^\gamma \right) \text{ where } \alpha + \beta + \gamma = 1, \quad 0 < \alpha, \beta, \gamma < 1 \quad (1)$$

The notation is conventional: 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, A_F is the set of foreign capital goods.

This way of modelling the stock of physical capital reaches back to Dixit/Stiglitz (1997) and Ethier (1982) and is used in the endogenous growth models of Rivera-Batiz/Romer (1991a), (1991b).¹⁰ It implies that the productivity of all inputs and hence the level of per capita GDP is the higher the larger the available set of capital goods, $A_D + A_F$. Behind this stands the simple idea that a worker who can make use of a larger set of specialized tools is more productive. If tools are specialized, they are imperfect substitutes. The technical elasticity of substitution between two different types of capital goods, which is implied by equation (1) equals $\sigma = 1/(1 - \gamma)$ (see appendix 5 for the derivation). Consequently, the assumption that $0 < \gamma < 1$ ensures that the elasticity of substitution is finite, i.e. $\sigma < \infty$, and capital goods are imperfect substitutes.¹¹

¹⁰ This assumption is used in the endogenous growth models of Rivera-Batiz/Romer (1991a), (1991b) and Grossman/Helpman (1991) to transfer the output of the R&D sector (i.e. blueprints to produce new varieties of capital goods) into the aggregated production function of the economy.

¹¹ Appendix 2 analyses the implications of the model if capital goods are perfect substitutes.

Given this modelling of the stock of physical capital, exogenous technological progress can be introduced in this model by assuming an exogenous growth rate of the available set of production goods:

$$A_{D,t} = A_{D,0} e^{gt} \quad (2)$$

$$A_{F,t} = A_{F,0} e^{gt} \quad (3)$$

Following these equations I assume the growth rate of productivity to be equal across countries. I interpret this kind of modelling exogenous technological progress in the following way: The knowledge of producing capital goods is internationally immobile. However, the productivity effect of this knowledge is internationally mobile, because it is embodied in capital goods. Therefore, countries can benefit from the technological knowledge of other countries by importing their capital goods. Consequently, even though technological knowledge is internationally immobile in this model, its productivity growth effect spills over to other countries through international trade.

Following the typical neoclassical growth model I assume that GDP can be used for consumption as well as for investment. This implies that there is a one-to-one pass-through technology that allows one unit of GDP to be transformed into one unit of a domestic capital good.

Following Mankiw/Romer/Weil (1992) and Barrow/Sala-i-Martin (1995), I assume that international financial markets are imperfect and do therefore not allow for international borrowing and lending. Without this assumption this Solow-Swan model would imply a contrafactual immediate convergence of per capita GDP of all countries.¹² Given this impossibility for international credits, the balance of trade of each country has to be equilibrated in each point of time. Consequently, countries that are net capital good importers had to export the corresponding amount of consumption goods in order to balance its foreign trade. International arbitrage ensures that this is possible. The assumption of the impossibility of international borrowing and lending is supported by the empirical findings that savings and investment quota (and export and import quota) typically display a cross country correlation coefficient close to one (Feldstein/Horioka (1980)).

¹² See Barro/Sala-i-Martin (1995), chapter 3, for a discussion. Strictly speaking this holds only, if the steady state variables of all countries (e.g. savings quota, endowment with public goods etc.) were identical *and* installed capital (physical and human) were perfectly mobile across countries.

In order to analyze the effect of trade policy within this model, I assume that the government levies an ad valorem import tariff of τ on foreign capital goods.¹³ Furthermore, I assume that technological knowledge is 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. This implies that the price of one unit GDP equals the price of one unit of a domestic capital good, because of the assumption of a one-to-one pass-through technology that allows one unit of GDP to be transformed into one unit of a domestic capital good. It is interesting to note that the alternative assumption of a monopolistic market structure on the domestic capital goods market (based on eternal patents for each type of capital good or local immobility of technological knowledge), does not qualitatively alter the trade policy implications of the model (see appendix 1 for a derivation of the model under the assumption of a monopolistic capital goods market structure).

The assumption of free entry to the production of capital goods within each country implies that the price of foreign capital goods equals the price of domestic capital goods times $(1+\tau)$.¹⁴ As the price for one unit domestic capital goods equals unity, the price of one unit foreign capital goods equals $(1+\tau)$. Given a price of domestic capital goods of unity and a domestic price of foreign capital goods of $(1+\tau)$ and an equilibrium market interest rate r , the equilibrium per period rent for the usage of one unit domestic capital goods equals r and the per period rent for the usage of one unit foreign capital goods equals $r(1+\tau)$. Under the assumption of a physical depreciation rate of capital goods of d , the per period opportunity costs of one unit domestic capital goods equals $(r+d)$ and the per period opportunity costs of one unit foreign capital goods equals $(r+d)(1+\tau)$. Consequently, the assumption of profit maximization of the representative firm implies:

$$\max_{L, H, X_i, X_j} F! \quad \text{with} \quad (4)$$

$$F = L_t^\alpha H_t^\beta \left(\sum_i^{\Delta_D} X_{i,t}^\gamma + \sum_j^{\Delta_F} X_{j,t}^\gamma \right) - L w_L - H w_H - \sum_i^{\Delta_D} X_{i,t} (r_t + d) - \sum_j^{\Delta_F} X_{j,t} (r_t + d)(1 + \tau)$$

¹³ In order to keep things computationally easy I assume that the government spends its import tax revenue for consumption and not for investment. If the government spend its import tax revenue for investment, this would partially reduce the negative effect of import taxes on capital goods on the level of per capita GDP, because it would increase the steady state investment quota.

¹⁴ As all countries use same production technologies (equation (1)), this is equal to say that the domestic price of foreign capital goods equals the world market price of foreign capital goods times $(1+\tau)$.

where w_t 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, i.a.:

$$\frac{\delta F}{\delta X_{i,t}} = \gamma L_i^\alpha H_i^\beta X_{i,t}^{\gamma-1} - r_t - d = 0 \quad (5)$$

$$X_{i,t} = \left(\gamma L_i^\alpha H_i^\beta (r_t + d)^{-1} \right)^{\frac{1}{1-\gamma}}$$

$$\frac{\delta F}{\delta X_{j,t}} = \gamma L_j^\alpha H_j^\beta X_{j,t}^{\gamma-1} - (r_t + d)(1 + \tau) = 0 \quad (6)$$

$$X_{j,t} = \left(\gamma L_j^\alpha H_j^\beta (r_t + d)^{-1} (1 + \tau)^{-1} \right)^{\frac{1}{1-\gamma}}$$

Consequently, the market equilibrium relation between domestic capital goods and foreign capital goods is given by:

$$X_{i,t} = X_{j,t} (1 + \tau)^{\frac{1}{1-\gamma}} \quad (7)$$

Hence, the higher import restrictions drive the price for foreign capital goods the higher is the quantity of each type of domestic capital good used in production in relation to the quantity of each type of foreign capital good used in production. For further calculations it is useful to notice that equation (5) implies the input quantities of all domestic capital goods to be identical:

$$X_{i,t} = \bar{X}_{i,t} \quad \forall i \in A_D \quad (8)$$

By the same argument equations (6) implies the input quantities of all foreign capital goods to be identical:

$$X_{j,t} = \bar{X}_{j,t} \quad \forall j \in A_F \quad (9)$$

The market equilibrium value of the capital stock equals:¹⁵

$$K_t = \sum_i^{A_D} X_{i,t} + \sum_j^{A_F} X_{j,t} (1 + \tau) \quad (10)$$

¹⁵ The market value of the capital stock is measured in GDP equivalent units and has to be distinguished from the physical amount of the real capital stock.

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 import tariff for foreign capital goods. In the following this is called the „income effect“ of import tariffs. Inserting equation (7) and using (8) and (9) this can be rewritten in two alternative ways:

$$K_t = X_{i,t} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) \quad (11)$$

$$K_t = X_{i,t} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) (1 + \tau)^{\frac{1}{1-\gamma}} \quad (12)$$

Inserting equations (5) resp. (6) these equations represent the total credit demand in dependence from the interest rate (see appendix 3 for an analysis of the capital market of this model). Based on (11) and (12) in a market equilibrium equation (1) implies:¹⁶

$$Y_t = L_t^\alpha H_t^\beta K_t^\gamma \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right)^{1-\gamma} \quad (13)$$

Consequently, if the physical quantities of capital goods in equation (1) are substituted by the market value of the capital stock, K_t , the production function has to include a factor determined by the available variety of capital goods (and the import tariff for capital goods) in order to reflect the real productivity of the capital stock. To derive the steady state levels of these variables in terms of the structural parameters of the economy, the following definitions are useful:

$$\begin{aligned} h_t &:= H_t / L_t \\ k_t &:= K_t / L_t \\ y_t &:= Y_t / L_t \end{aligned} \quad (14)$$

Now equation (13) can be rewritten:

$$y_t = h_t^\beta k_t^\gamma e^{s_t(1-\gamma)} \Psi^{(1-\gamma)} \quad \text{with} \quad \Psi := \left(A_{D,0} + A_{F,0} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) \quad (15)$$

Following Mankiw/Romer/Weil (1992) I use a version of the Solow/Swan model, where households save a fixed fraction of their income for investments in physical capital, s_t , and

¹⁶ For an explicit derivation of equation (13) see appendix 4.

for investments in human capital, s_h .¹⁷ Under the simplifying assumption of Mankiw/Romer/Weil (1992) that physical and human capital depreciates with the same rate, d , net investments in physical and human capital are given by the following equations:

$$\dot{K}_t = s_k Y_t - dK_t \quad (16)$$

$$\dot{H}_t = s_h Y_t - dH_t \quad (17)$$

From the definition of (14) follows:

$$\dot{k} = \frac{\dot{KL} - KL}{L^2} = \frac{\dot{K}}{L} - k \frac{\dot{L}}{L} \quad (18)$$

Following the assumptions of the neoclassical growth model, I assume the labor force L_t to grow exogenously at rate n :

$$L_t = L_0 e^{nt} \quad (19)$$

Consequently, inserting equation (16) into (18) yields:

$$\dot{k}_t = s_k y_t - k_t (d + n) \quad (20)$$

This implies by analogy:

$$\dot{h}_t = s_h y_t - h_t (d + n) \quad (21)$$

As in steady state all variables expressed in per capita units do not grow, the steady state levels of k_t and h_t are found by setting equation (20) and (21) equal to zero:

$$\dot{k}_t = 0 \Leftrightarrow k_t = \left(\frac{s_k h^\beta e^{s t (1-\gamma)} \Psi^{(1-\gamma)}}{n + d} \right)^{\frac{1}{1-\gamma}} \quad (22)$$

¹⁷ This assumption distinguishes the Solow-Swan model from the Cass-Ramsey model. The latter is build 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/Lawrence/Summers (1991), Campbell/Mankiw (1989), Giovannini (1983) and (1985)). Earlier empirical studies (Feldstein (1970), McKinnon (1973), Fry (1980) and (1978), Abe et al (1977) could not reject the hypothesis of a positive relation between real savings and the real interest rate.

$$\dot{h}_t = 0 \Leftrightarrow h_t = \left(\frac{s_h k^\gamma e^{\sigma t(1-\gamma)} \Psi^{(1-\gamma)}}{n+d} \right)^{\frac{1}{1-\beta}} \quad (23)$$

Inserting equation (22) into (23) and (23) into (22) yields the steady state levels of k and h in dependence from the structural parameters of the economy:

$$k^* = \Psi^{\frac{1-\gamma}{1-\beta-\gamma}} \left(\frac{s_k^{1-\beta} s_h^\beta e^{\sigma t(1-\gamma)}}{n+d} \right)^{\frac{1}{1-\beta-\gamma}} \quad (24)$$

$$h^* = \Psi^{\frac{1-\gamma}{1-\beta-\gamma}} \left(\frac{s_k^\gamma s_h^{1-\gamma} e^{\sigma t(1-\gamma)}}{n+d} \right)^{\frac{1}{1-\beta-\gamma}} \quad (25)$$

Based on equation (24) and (25) equation (15) can now be rewritten:

$$\left(\frac{Y}{L} \right)^* = e^{\frac{\sigma t(1-\gamma)}{1-\beta-\gamma}} (n+d)^{\frac{-\beta-\gamma}{1-\beta-\gamma}} \frac{\gamma}{s_k^{1-\beta-\gamma}} \frac{\beta}{s_h^{1-\beta-\gamma}} \Psi^{\frac{1-\gamma}{1-\beta-\gamma}} \text{ where } \Psi := \left(A_{D,0} + A_{F,0} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right) \quad (26)$$

Equation (26) predicts that the steady state level of per capita GDP negatively depends on the level of import tariffs on foreign capital goods, τ .¹⁸ This is caused by two effects: the „substitution effect“ of import restrictions for foreign capital goods and the „income effect“ of import restrictions on foreign capital goods. The intuition behind the substitution effect is revealed by equations (1) and (7). Equation (1) shows that both domestic and foreign capital goods display the same degree of 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, equation (7) shows that a profit maximizing enterprise 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. Consequently, the output level decreases as τ increases. 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 less use of foreign capital goods is made. The income effect of import restrictions has already been discussed looking at equation (10) above. It 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

¹⁸ This can be easily shown by taking the first derivation of per capita GDP with respect to τ .

capital goods. Therefore, the total input quantity of capital goods is reduced by import restrictions too.¹⁹

It is interesting to note that although the model assumes that a part of the productivity effect from the growth of technological knowledge is transferred into the domestic economy via imports of new varieties of foreign capital goods (equation (3)), import restrictions on foreign capital goods do not reduce the steady state growth rate of per capita GDP. The reason for this feature of the model is revealed by equation (7): Import restrictions such as import tariffs or quantitative restrictions²⁰ lead only to a reduction of the quantity of imported foreign capital goods but not to a reduction of the varieties of foreign capital goods. Therefore the productivity effect of the creation of new foreign capital goods influxes into the domestic economy despite of the existence of import restrictions on foreign capital goods. Indeed, within this model only import restrictions that restrict the varieties of imported capital goods can display negative effects on the steady state growth rate of per capita GDP.

The other predictions of equation (26) correspond to the standard predictions of the Solow/Swan model: The saving quotas of physical investment, s_k , and human capital, s_h , and the level of technological progress, $A_0 e^{g t}$, positively influence the level of per capita GDP, while the rate of population growth, n , and the depreciation rate, d , negatively influence the level of per capita GDP.

In order to test whether the data support the predictions of equation (26), I follow again Mankiw/Romer/Weil (1992) and assume that the rate of physical and human capital depreciation, d , is constant across countries. As implied by equations (2) and (3), I assume the growth rate of the domestic and foreign sets of capital goods to equal g . This implies that the g is constant across countries too. However, this may be a too restrictive assumption. Therefore I allow for country specific deviations from g . I assume however that these deviations net out on average such that the following relation holds:

$$\frac{1-\gamma}{1-\beta-\gamma} t g = a + \epsilon \quad (27)$$

¹⁹ Appendix 2 presents a Solow-Swan model with a closed oligopoly on the market for capital goods. Within this model import restrictions influence the steady state level of per capita GDP, because foreign capital good imports reduce the market power of the domestic oligopoly. As foreign and domestic capital goods are perfect substitutes within this model, import restrictions on foreign capital goods display only to an „income effect“. In a sense, this model offers an alternative „channel“ of influence of trade policy on the level of per capita GDP.

²⁰ As is shown in section 3, within this model equivalence of tariffs and quotas holds.

where ϵ is an independent, normally distributed shock.²¹ Consequently, taking logs of equation (26) and inserting equation (27) yields:

$$\ln\left(\frac{Y}{L}\right)^* = a - \frac{\beta + \gamma}{1 - \beta - \gamma} \ln(n) + \frac{\gamma}{1 - \beta - \gamma} \ln(s_k) + \frac{\beta}{1 - \beta - \gamma} \ln(s_h) + \frac{1 - \gamma}{1 - \beta - \gamma} \ln(\Psi) + \epsilon \quad (28)$$

In order to estimate equation (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 . Assuming this, I follow again Mankiw/Romer/Weil (1991). Without this assumption a simple OLS estimation would not yield an asymptotically unbiased estimate of the regression coefficients.²²

A test of equation (28) has to be based on the assumption that the economies of the cross section sample are close to their steady states. However, if most of the economies are significantly out of their steady states, the level of their current per capita GDP may not only be influenced by the steady state parameters (s_k , s_h , n , Ψ) of but also by the initial states of their per capita GDP. Given this were the case, the omission of the initial state of the level their per capita GDP implies a misspecification of the OLS-estimation. This can give rise to autocorrelated residuals resp. an estimation bias. Consequently, a sensitivity analysis of the steady state assumption may be right in place. Consider therefore the out-of-steady-state-implications of the Solow-Swan model.

If the 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. This is displayed by the following equation (for a formal derivation see Barro/Sala-i-Martin, 1995, p. 37 and 53):

²¹ Mankiw/Romer/Weil (1992), pp.410-411 make a similar assumption.

²² In a multivariate OLS regression the estimator of the regression coefficients corresponds to $\hat{\beta} = (X'X)^{-1} X'u$, 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, these kind of variables are difficult to find.

$$\ln\left(\frac{Y_t}{L_t}\right) = (1 - e^{-\lambda t}) \ln\left(\frac{Y}{L}\right)^* + e^{-\lambda t} \ln\left(\frac{Y}{L}\right)_0 \quad \text{where } \lambda = (1 - \beta - \gamma)(n + d) \quad (29)$$

Where $(Y/L)_0$ is the initial level of per capita GDP. As follows from equation (29), 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 is the transition from the initial level of per capita GDP to its steady state level. For a hypothetical $\lambda = 0$ no convergence towards the steady state level of per capita income takes place ($\ln(y_t) = \ln(y_0)$), while for a hypothetical $\lambda = \infty$ the economy is always in its steady state ($\ln(y_t) = \ln(y_t^*)$). Furthermore, equation (29) 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 equation (29) implies that the weight of the steady state level of per capita GDP is the higher the „older“ the economy (the higher t).

To derive an estimation equation, which can be used to test for the effects of the steady state assumption implied by an estimation of equation (28), equation (26) can be inserted into equation (29). In order to yield comparability with „growth regressions“ like Mankiw/Romer/Weil (1992) and Barro/Sala-i-Martin (1995), I subtract the initial level of per capita GDP from both sides of the equation and divide both sides by the number of years between the initial period and period t . As an OLS-estimation is invariant to linear transformations, this manipulation does not qualitatively influence the results: This means that only the value of regression coefficients may change but not their p -levels and not the value of „quality indicators“ like adjusted R-squared, p -value of regression F , standard error of estimate, Durbin Watson coefficient and so on.²³ After taking logs this yields the following equation:

$$\begin{aligned} \ln\left(\left(\frac{Y}{L}\right)_t / \left(\frac{Y}{L}\right)_0\right) t^{-1} &= (1 - e^{-\lambda t}) t^{-1} a - (1 - e^{-\lambda t}) t^{-1} \frac{\beta + \gamma}{1 - \beta - \gamma} \ln(n) + (1 - e^{-\lambda t}) t^{-1} \frac{\gamma}{1 - \beta - \gamma} \ln(s_k) \\ &+ (1 - e^{-\lambda t}) t^{-1} \frac{\beta}{1 - \beta - \gamma} \ln(s_h) + (1 - e^{-\lambda t}) t^{-1} \frac{1 - \gamma}{1 - \beta - \gamma} \ln(\Psi) \\ &- (1 - e^{-\lambda t}) t^{-1} \ln\left(\frac{Y}{L}\right)_0 + (1 - e^{-\lambda t}) t^{-1} \varepsilon \end{aligned} \quad (30)$$

²³ The subtraction of the initial value of per capita GDP implies that the model predicts then that coefficient of the initial level of per capita GDP displays a negative sign because $0 < e^{-\lambda t} < 1$.

Beside the linear transformation of coefficients the basic difference between equation (30) and equation (28) is the inclusion of the initial state level of per capita GDP. However, estimating equation (30) one problem arises: As the initial state level of per capita GDP is unknown it has to be approximated by the level of per capita GDP of some „base“ period. Following equation (29) this implies that the proxy for the level of the initial state per capita GDP is influenced by the steady state variables too. This implication of the model is also found in the data as shown in table 1, Maurer (1995c). This table shows that the level of per capita GDP of the base period 1960 is highly correlated with variables that are typically chosen to proxy the the steady state parameters of the model (even though these variables are computed as five years averages of the period 1980-85). Therefore, an estimation of equation (30) with the available proxies typically leads to multicollinearity problems. However, as OLS-estimators keep their BLUE-property even in the presence of multicollinearity, an OLS-estimation of equation (30) should yield reliable estimates (for a formal analysis of these issues see Maurer (1995b)).²⁴

3. Alternative measures of import restrictions on foreign capital goods

Before proceeding with an estimation of equations (28) and (30), it is necessary to derive empirical proxies for Ψ , the indicator of „openness“ for foreign capital goods. Ψ consists of three variables: The number of domestic capital goods, A_D , the number of foreign capital goods, A_F , and the percentage increase of the domestic price of foreign capital goods over their producer price, τ . In order to control for measurement errors, I construct several, independent, empirical proxies for these variables.²⁵ Furthermore, I test whether these proxies are consistently related to each other and to measures of import tariffs and quotas on capital goods.

I choose two approaches to construct proxies for the number of domestic and foreign capital goods. First, as a „macroeconomic-oriented“ approach I choose $A_D = A_F = 1$. This implies the

²⁴ Another „problem“ of an estimation of equation (30) that is stressed by Quah (1993), is the fact that the Cauchy-Schwarz inequality implies that the estimated coefficient of the base period per capita GDP may display a negative sign (beta-convergence), although the cross section variance of the log of the level of per capita income grows (sigma-divergence). Hence, a negative coefficient from an estimation of equation (30) does not necessarily imply sigma-convergence (see also Maurer (1995b)) for a discussion of this and related issues).

²⁵ The absolute value of the exponent of the import tariff on foreign capital goods, $-\gamma/(1-\gamma)$, is set equal to unity. This implies a value of $\gamma = 0.5$. A sensitivity analysis of the estimation with values of γ close to zero and close to one exhibited no serious changes of the results (For γ close to zero the coefficient loses its significance, due to the smoothing effect (implied by this exponent magnitude) on the cross country variability of import tariffs.).

assumption that from a macroeconomic point of view it is sufficient to distinguish only two broad types of capital goods, domestic and foreign. Second, as a more "microeconomic-oriented" approach I choose A_D to equal the share of the domestic gross output of producer durables on world output of producer durables as published in the UNIDO database.²⁶ Correspondingly, I choose $A_F = 1 - A_D$. This way of approximating the number of domestic and foreign goods has the effect that Ψ is lower for a country with a low domestic production base for capital goods than for a country with a high domestic production base, even if τ is equal for both countries. This captures the implication of the Solow-Swan model with capital variety that import restrictions on capital goods have a larger negative impact on the level of per capita GDP, if the domestically available set of capital goods is low.

Now I turn to the construction of empirical proxies for τ . For the ease of exposition up to now I assumed that import restrictions were caused by an import tariff on foreign capital goods. However in reality quantitative restrictions are important instruments of trade policy too.²⁷ Therefore, before I construct empirical proxies for τ , I firstly analyse the effect of quantitative restrictions within this model. As it turns out, under the assumptions of this model τ captures the effect of quantitative restrictions too. Therefore, it is sufficient to construct empirical proxies for τ only.

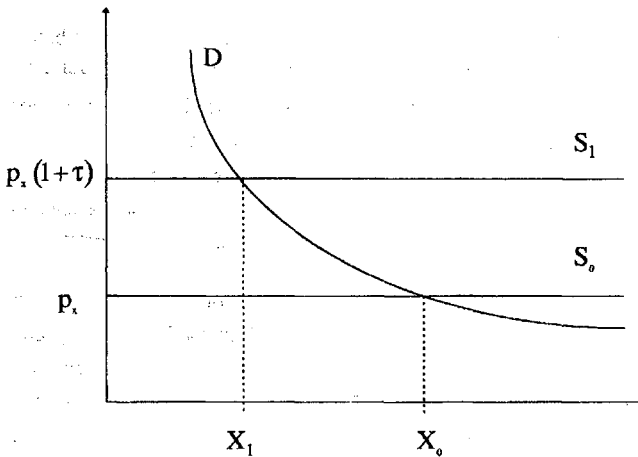
Within this model all assumptions necessary to yield equivalence of tariffs and quotas (Bhagwati (1969)) are fulfilled. Hence, for every import quota on foreign capital goods, there exists a tariff on foreign capital goods that yields the same import quantities as the quota and vice versa.²⁸ This is shown by the following figure:

²⁶ Gross output of producer durables equals the sum of gross output of machinery except electrical (UNIDO-ISIC 382), machinery electric (UNIDO-ISIC 383), transport equipment (UNIDO-ISIC 384), professional and scientific equipment (UNIDO-ISIC 385). I measure the share of domestic gross output of producer durables on world output of producer durables in US-dollar. I use the exchange rates from Summers/Heston (1991) (The Penn World Table Mark 5).

²⁷ For a survey see Erzan/Kuwahare/Marchese/Vossenaar (1988) and Maurer (1994b).

²⁸ Bhagwati defines the equivalence of tariffs and quotas in the following way: "...tariffs and quotas are equivalent in the sense that an explicit tariff rate will produce an import level which, if set alternatively as a quota, will produce an implicit tariff equal to the explicit tariff (and, pairwise, that a quota will produce an implicit tariff which, if set alternatively as an explicit tariff, will generate the same level of imports)." Bhagwati (1969), p. 248. For a discussion of conditions under which the equivalence of tariffs and quotas does not hold see Bhagwati (1969).

Figure 1 - Equivalence of tariffs and quotas on capital goods in the Solow-Swan model with capital variety



Here, D is the demand for a capital good. D follows from equation (5) for given input quantities of raw labour, L , and human capital, H . S is the supply of a foreign capital good without import restrictions on foreign capital goods. As there is perfect competition and capital goods are produced with a constant returns to scale production technology (equation (1)), the supply curve is flat and equals the marginal costs of production, p_x . p_x equals unity, because of the normalization of prices introduced above. Hence, without import restrictions on foreign capital goods prices of foreign capital goods and domestic capital goods are equal.

Within this scenario a quantitative restriction on imports of foreign capital goods that reduces the supply of foreign capital goods to X_1 leads to an increase of prices for foreign capital goods from p_x to $p_x(1+\tau)$. Consequently, an import tariff of $(1+\tau)$ is equivalent to this quantitative restriction. On the contrary, for every import tariff τ there exists of course a quantitative restriction that has the same effect as the import tariff. Hence, within this model equivalence of tariffs and quotas holds. Consequently, τ measures the effect of quantitative restrictions as well as the effect of import tariffs. It is therefore sufficient to restrict the empirical analysis on proxies for τ .

I choose two different approaches to construct proxies for τ : A price-based approach and a quantity-based approach. Ideally τ equals the percentage increase of the domestic prices of foreign capital goods over the producer price of foreign capital goods caused by import

restrictions on foreign capital goods. (see figure 1).²⁹ The price-based proxy for τ is intended to measure the difference between domestic price and the producer price of foreign capital goods.

Unfortunately, the empirical base of internationally comparable prices for capital goods is rather small. There exist, however, a large scale project of the UNSTAT and EUROSTAT, the International Comparison Programm (ICP), that delivers internationally comparable prices for all product categories of GDP, inclusive producer durables. Phase IV of the ICP delivers such prices for 60 countries (UNSTAT/EUROSTAT (1987)) collected for 1980 and and phase V of the ICP delivers such prices for 64 countries collected for 1985 (UNSTAT/EUROSTAT (1994)).³⁰ The quality of these data is outstanding. For example, the price level index for producer durables („equipment goods“) of phase IV is based on a precisely defined commodity basket of 150 „non-electrical 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 these definitions of 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 actually internationally comparable.³¹

I construct two types of proxies for $(1 + \tau)$ based on the ICP data for producer durables:

$$\text{NRPDP}_i = \frac{P_{X,i}}{P_{X,us}} / e_{i,us} \quad (31)$$

$$\text{RRPDP}_i = \frac{P_{X,i}}{P_{X,us}} / \frac{P_{GDP,i}}{P_{GDP,us}} \quad (32)$$

where $p_{X,i}$ is the ICP price index of country i capital goods in domestic currency, $p_{X,us}$ is the ICP price index of United States capital goods in US-dollar, $e_{i,us}$ is the yearly average of the nominal dollar exchange rate (domestic currency units per US-dollar), $p_{GDP,i}$ is the ICP price

²⁹ Producer prices of foreign and domestic capital goods are equivalent under the assumptions of this model. Therefore τ equals also the percentage increase of the domestic prices of foreign capital goods over the domestic price of domestic capital goods.

³⁰ Earlier phases of the ICP comprise not enough countries to deliver a reliable base for statistical inferences. For example the results of phase III (1975) comprise only 34 countries (Kravis/Heston/Summer (1982)).

³¹ The ICP data are an important ingredient of the widely used Summers/Heston Penn World Table data set (Summers/Heston (1991)).

index of country i GDP in domestic currency, $p_{GDP,US}$ is the ICP price index of United States GDP in US-dollar.

$NRPDP_i$ is the nominal relative producer durables price index of country i . For this index I use the nominal exchange rate as conversion factor. $RRPDP_i$ is the real relative producer durables price index of country i . For this index I use the purchasing power parity exchange rate as conversion factor. As empirical investigations show, nominal exchange rates often move far away from the purchasing power parity. However, these deviations are typically mean-reverting processes (Frankel/Rose (1995), Wei/Parsley (1995)).³² Therefore, in case that nominal exchange rates are driven by „speculative forces“ that lead to measurement errors of the relative producer durables price index the purchasing power parity exchange rate may be a more reliable conversion factor than the nominal exchange rate.

Both proxies for $(1+\tau)$, $NRPDP_i$ and $RRPDP_i$, are based on the United States producer durable price index as a proxy for the producer price of foreign capital goods. Of course, freight, insurance costs and import restrictions may cause the United States producer durable prices to be higher than the producer prices for producer durables. However, this effects the relative producer durables price index of every country in the same way. Hence, within a cross country regression framework it has only a scale effect that influences the magnitude of the regression coefficient but not its sign and significance.

A more relevant problem that arises with both, $NRPDP_i$ and $RRPDP_i$, stems from the fact that the ICP prices include domestic prices for foreign producer durables *and* domestic prices for domestic producer durables, while τ is intended to measure the difference between domestic price and the producer price of foreign capital goods only. Consequently, the fact that the ICP prices include the prices of domestic capital goods too reduces $NRPDP_i$ and $RRPDP_i$ below the true value of τ . Hence, $NRPDP_i$ and $RRPDP_i$ are lower boundaries for the true values of τ . Nevertheless, the above model implies that high import restrictions on foreign capital, i.e. high values of the true τ , lead to high values of $NRPDP_i$ and $RRPDP_i$. Consequently, the true τ and both, $NRPDP_i$ and $RRPDP_i$, should be positively correlated under the null hypothesis that the above Solow-Swan model is the true model.

Fortunately I can test this model implication also explicitly. Barro/Lee (1994) offer data on import tariff rates on intermediate inputs and capital goods and non-tariff frequencies on intermediate inputs and capital goods that refer to the period 1980-85. These data allow to

³² The estimated halfways of the deviation from purchasing power parity are about four years in the Frankel/Rose (1995) study and about four and three quarter years for the non-EMS countries and four and one-quarter years for the EMS countries in the Wei/Parsley (1995) study.

check the sign and significance of correlation between both NRPDP_i and RRPDP_i , and actual restrictions on foreign capital goods (for the results see the table 1, section 4.1).

Now I turn to the construction of a quantity-based proxy for τ . There are two reasons to have an alternative, quantity-based proxy for τ . First, appropriate ICP-data for capital goods prices are available only for two years, 1980 and 1985. This restricts empirical tests of equation (28) to two years only. Hence, it would be good to have an alternative proxy for τ , that is available for more years. Second, a quantity-based proxy may be more sensitive to quantitative restrictions than a price-based proxy, given the theoretical equivalence of tariffs and quotas does not hold exactly. Hence, a quantity-based proxy provides a mean to control for measurement errors of the price based proxy.

To construct a quantity-based proxy for τ , consider that in a market equilibrium equation (7) must hold. This implies taking the first derivation of equation (7) with respect to time:

$$\dot{X}_i = \dot{X}_j (1 - \tau)^{\frac{1}{1-\tau}} \quad (33)$$

Multiplying both sides with A_D/A_F and rearranging the terms this yields:

$$\frac{\dot{X}_i}{\dot{X}_j} \frac{A_D}{A_F} = \frac{A_D}{A_F} (1 + \tau)^{\frac{1}{1-\tau}} \quad (34)$$

As follows from equation (10) and (8) the market equilibrium per period increment of the capital stock with domestic goods, $K_D = A_D \dot{X}_i$, equals:

$$\dot{K}_D = A_D \dot{X}_i + \dot{A}_D X_i \quad (35)$$

By analogy the market equilibrium per period increment of the capital stock with foreign goods, $K_F = A_F \dot{X}_j (1 + \tau)$ equals:

$$\dot{K}_F = (A_F \dot{X}_j + \dot{A}_F X_j) (1 + \tau) \quad (36)$$

From equations (7) and (28) and from the first derivations of equations (2) and (3) with respect to time follows:

$$\frac{\dot{A}_D}{A_D} \frac{X_i}{\dot{X}_i} = \frac{\dot{A}_F}{A_F} \frac{X_j}{\dot{X}_j} := \omega \quad (37)$$

such that the following equation holds:

$$\frac{\dot{K}_D}{\dot{K}_F} = \frac{A_D \dot{X}_i + \dot{A}_D X_i}{A_F \dot{X}_j + \dot{A}_F X_j} (1 + \tau)^{-1} = \frac{(A_D \dot{X}_i)(1 + \omega)}{(A_F \dot{X}_j)(1 + \omega)} (1 + \tau)^{-1} = \frac{(A_D \dot{X}_i)}{(A_F \dot{X}_j)} (1 + \tau)^{-1} \quad (38)$$

Consequently, equation (34) can be rewritten:

$$(1 + \tau)^{\frac{\gamma}{1-\gamma}} = \frac{\dot{K}_D}{\dot{K}_F} \frac{A_D}{A_F} \quad (39)$$

\dot{K}_D equals the domestic production of capital goods minus exports of domestic capital goods. \dot{K}_F equals domestic imports of foreign capital goods. A_D is the number of the varieties of domestic capital goods. A_F is the number of the varieties of foreign capital goods. I approximate the ratio of A_D/A_F by the ratio of exports of domestic capital goods to the world production of capital goods minus domestic production of capital goods. I take the data of exports and imports on capital goods from UNCTAD (1992), table 4.1 and 4.2, machinery and equipment (SITC 7) and the data for production from UNIDO (1995), gross output of producer durables.³³ Consequently, my empirical proxy for equation (34) has the following dimension:

$$(1 + \tau)^{\frac{\gamma}{1-\gamma}} = \frac{\text{ratio of domestic capital goods to foreign capital goods in } \textit{domestic} \textit{ production}}{\text{ratio of domestic capital goods to foreign capital goods in } \textit{world} \textit{ production}} \quad (40)$$

I call this indicator the relative input mix-value (RIM-value). Equation (40) has a general intuitive interpretation: Given a world where all countries use the same production technologies (equation (1)), where all types of capital goods are perfectly tradeable and without transportation or other transaction costs the ratios of equation (40) should equal unity, if there are no restrictions to trade on capital goods. Within this world any deviations from unity must be caused by restrictions to trade on capital goods. The reason for this is the fact that given the production technology implied by production function (1) it is profit maximizing for enterprises all over the world to use the same „input mix“ of capital good varieties. However, given domestic import restrictions on foreign capital goods the ratio of domestic capital goods to foreign capital goods in domestic production increases above the technologically optimal value. Under the assumption that all other countries impose no import restrictions the ratio of domestic capital goods to foreign capital goods in world production can be used as a benchmark value for the technologically optimal „input mix“.

³³ For definition of producer durables see footnote 18. As the UNCTAD data on machinery and equipment are classified to the SITC code and the UNIDO data on producer durables are classified to the ISIC code, they are only approximately compatible.

Of course the above assumptions, under which the RIM-value exactly indicates import restrictions on foreign capital goods, are surely violated in reality. Nevertheless there is good reason to believe that the relative magnitudes of RIM-values of different countries contains information on the different degree of import restrictions on foreign capitals of these countries:

First, given the fact that not all varieties of capital goods are perfectly tradeable and that there are significant transportation and other transaction costs for capital goods, the RIM-value of all countries should typically be significantly higher than unity. However, it is most likely that the degree on non-tradeability of capital goods and the level of transportation costs influences the magnitude of the RIM-values of most countries in a similar way. Therefore, the RIM-value of most countries should be upward biased to the same degree. Consequently, the relative magnitude of the RIM-values of different countries should indeed contain information on different import restrictions on capital goods.

Second, given the fact that import restrictions on foreign capital goods are imposed in many countries the ratio of domestic capital goods on foreign capital goods in world production should typically be downward biased, such that the RIM-value is upward biased. However, as import restrictions on capital goods are typically not country-specific, it is - again - most likely that this upward bias influences the RIM-values of most countries in a similar way. Consequently, the relative magnitude of the RIM-values of different countries should therefore nevertheless contain information on different import restrictions on capital goods.

Fortunately, (whatever degree of trust one is willing to invest in these a priori arguments) the Barro/Lee (1994) data on import tariff rates on intermediate inputs and capital goods and non-tariff frequencies on intermediate inputs and capital goods for the period 1980-85 allow a check of sign and significance of correlation between the RIM-values and actual restrictions on imports of foreign capital goods.

4. Empirical results

4.1. The correlation structure of measures of import restrictions on capital goods

In this section I present the empirical correlations of the measures of import restrictions on capital goods (NRPDP-, RRPDP- and RIM-values) with the Barro/Lee (1994) data on import tariff rates on intermediate inputs and capital goods and non-tariff frequencies on intermediate inputs and capital goods for the period 1980-85. I derive these correlations based on the following regression equation:

$$\ln(A_k) = a + \beta_1 \ln(OWTI_k) + \beta_2 \ln(OWQI_k) + \varepsilon_k \quad (41)$$

where Λ_k equals the NRPDP-, the RRPDP- or the RIM-value and OWTI equals the own-import weighted tariff rates on intermediate inputs and capital goods and OWQI equals the own-import weighted non-tariff frequency on intermediate inputs and capital goods from Barro/Lee (1994). According to Lee (1993) these data have been assembled to the greatest part based on the Customs Cooperation Council Nomenclature (CCCN) of the UNCTAD for the period 1980-85. If my measures of import restrictions of capital goods actually measure import restrictions on capital goods, an estimation of equation (41) should yield significant and positive regression coefficients, β_1 and β_2 . Table 1 presents the results of an estimation of equation (41).

Table 1 - The correlation structure of measures of import restrictions on capital goods(a)

	NRPDP80			NRPDP85			RRPDP80			RRPDP85		
CONST	0.372 (0.000)	0.43 (0.000)	0.344 (0.000)	-0.535 (0.000)	-0.433 (0.000)	-0.47 (0.000)	1.306 (0.000)	1.234 (0.000)	0.85 (0.000)	1.0471 (0.000)	1.033 (0.000)	0.687 (0.000)
OWTI	0.037 (0.226)	0.028 (0.33)	-	-0.044 (0.273)	-0.075 (0.052)	-	0.254 (0.000)	0.261 (0.000)	-	0.247 (0.000)	0.265 (0.000)	-
OWQI	-0.034 (0.176)	-	-0.007 (0762)	-0.087 (0.028)	-	-0.104 (0.004)	0.0325 (0.000)	-	0.073 (0.079)	0.011 (0.797)	-	0.106 (0.046)
\bar{R}^2	0.018	-0.000	-0.019	0.155	0.058	0.15	0.432	0.434	0.044	0.435	0.46	0.068
p-value(F)	0.249	0.330	0.011	0.011	0.000	0.002	0.004	0.000	0.025	0.000	0.000	0.023
No. Obs.	48	50	49	45	49	45	48	50	49	45	49	45

	RIM65			RIM70			RIM75			RIM80			RIM85		
CONST	13.203 (0.000)	13.806 (0.000)	11.505 (0.000)	14.752 (0.000)	14.277 (0.000)	11.65 (0.000)	12.851 (0.000)	12.815 (0.000)	9.746 (0.000)	13.047 (0.000)	12.769 (0.000)	9.955 (0.000)	12.581 (0.000)	12.749 (0.000)	8.926 (0.000)
OWTI	1.012 (0.032)	1.504 (0.002)	-	1.749 (0.000)	1.947 (0.000)	-	1.845 (0.000)	1.869 (0.000)	-	1.725 (0.000)	1.823 (0.000)	-	2.030 (0.000)	1.988 (0.000)	-
OWQI	0.489 (0.171)	-	0.865 (0.011)	0.408 (0.000)	-	0.875 (0.002)	0.036 (0.855)	-	0.522 (0.025)	0.24 (0.366)	-	0.631 (0.023)	-0.122 (0.534)	-	0.308 (0.221)
\bar{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
No. Obs.	36	39	36	48	49	48	57	58	58	54	55	55	51	52	52

(a) OLS estimation of equation (41). Variables as defined in text. Numbers in parenthesis = 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. \bar{R}^2 = adjusted R-squared value. No. Obs. = Number of observations.

The overall impression from table 1 is that most of the above measures of import restrictions on capital goods are significantly and positively correlated to the Barro/Lee (1994) indices of import tariffs and quantitative restrictions. There is, however, one exception: The NRPDP displays only a weak correlation both in terms of significance (high p-values) and in terms explanatory power (low \bar{R}^2) of the Barro/Lee indices. Only the the Barro/Lee index of non-tariff measures (OWQI) shows a significant, but negative correlation for the year 1985. On the contrary, the RRPDP seems to be closely correlated to the Barro/Lee indices of import restrictions on capital goods. In both years, 1980 and 1985, the overall correlation as measured by the regression F-value is significant, positive and the explanatory power, as measured by the \bar{R}^2 , is high. However, as the single variable regressions show, most of this close correlation is to be attributed to the Barro/Lee index of import tariffs (OWTI). The Barro/Lee index of non-tariff measures (OWQI) displays a significant correlation only for the year 1985.

From these results I draw the conclusion that the NRPDP might be disturbed by „speculative“ fluctuations of nominal exchange rates (see the discussion in section 3). This conclusion is also confirmed by a regression of NRPDP85 on NRPDP80. The regression coefficient is not significantly (at a significance level of 5%) larger than zero and the \bar{R}^2 equals 0.05. At the same time a regression of RRPDP85 on RRPDP80 yields a highly significant regression coefficient (a p-value of 0.000001%) with a magnitude around unity and an \bar{R}^2 -value of 0.55. This indicates that NRPDP-values are severely exposed to short run fluctuations of nominal exchange rates, while RRPDP-values are much more resistant against such disturbances. Therefore, I hold the RRPDP to be the more appropriate index for the measurement of import restrictions on capital goods.

The regressions with the RIM-values display a similar picture as the regression of the RRPDP. As there are more data available, it is possible to construct RIM-values back to the year 1965. In order to check how persistent import restrictions on capital goods have been, I present estimations of equation (41) from 1965 to 1985. Three basic conclusions can be drawn from these estimations: *First*, the significant and positive correlations and the relatively high explanatory power over the years 1965-1985 exhibits a relative high persistence of import restrictions on capital goods (The Barro/Lee indices refer to the years 1980-85 only.). Single regressions of the RIM-value of 1985 on the other RIM-values confirm these results: In all cases the regression coefficient is significant with a magnitude around unity. The \bar{R}^2 values monotonically increase from 0.21 in 1965 to 0,88 in 1980.³⁴ *Second*, the high, positive and significant values of the regression constants confirm the above

³⁴ Results are available upon request.

a priori arguments in favour of a high upward bias of the RIM-values (see the discussion in section 3). *Third*, the relatively better performance (compared to the RRPDP regressions) of the Barro/Lee index of non-tariff measures (OWQI) in the single regressions indicates that the RIM-value might indeed be closer related to quantitative restrictions. However, as a comparison of the \bar{R}^2 values displays, the Barro/Lee index of tariff measures has always a higher explanatory power. The fact that the regression coefficient of OWQI always becomes insignificant as OWTI is included in the regression indicates that there might be multicollinearity between OWQI and OWTI. This is confirmed by a single regression of OWTI on OWQI, which exhibits indeed a strong positive correlation between both indicators.³⁵

To sum up, these regression results support the implication of the above Solow/Swan model with capital variety that import restrictions on foreign capital goods lead to high RRPDP- and RIM-values. Therefore, there is good reason to believe that these values actually measure import restrictions on capital goods. I argue that this justifies their use as proxies for $(1+\tau)$. However, the NRPDP-value seems not to be closely correlated to import restrictions on foreign capital goods. I explain this by possible disturbances stemming from short run „speculative“ fluctuations of nominal exchange rates. Therefore, I do not use the NRPDP-value as a proxy for $(1+\tau)$. As the OWTI displays a very high correlation to both, the price-based and the quantity based proxies, I use this indicator as a third proxy for import restrictions on foreign capital goods.

4.2. Test of the Solow-Swan model with capital variety

Before I start with an estimation of equations (28) and (30) empirical proxies for the savings quotas of physical and human capital, s_k resp. s_h , and the rate of the labor force growth, n , have to be determined. As a proxy for the savings quota of physical capital I use - following again Mankiw/Romer/Weil (1991) - the investment quota (the share of real investments in real GDP) from the Summers/Heston (1991) data). However, contrary to Mankiw/Romer/Weil (1991) I do not use the 1960-1985 average of the investment quota, but a five years average. I do so, because the investment quota of most countries of the Summers/Heston (1991) data displays a significant positive or negative time trend.

As a proxy for the savings quota of human capital I use the percentage of secondary school attained in the total population from the Barro/Lee (1993) data. In order to check for the

³⁵ This confirms the results of Erzan/Kuwahara/Marchese/Vossenaar (1988), who find a significant positive correlation between import tariffs and non-tariff measures across countries as well as across commodity groups within countries.

sensitivity of the regression results with respect to the human capital data, I also estimate the following version of equation (28), which is derived under the assumption of a given steady state level of the human capital stock, h^* :³⁶

$$\ln\left(\frac{Y}{L}\right) = a - \frac{\gamma}{1-\gamma} \ln(n) + \frac{\gamma}{1-\gamma} \ln(s_k) + \frac{\beta}{1-\gamma} \ln(h^*) + \ln(\Psi) + \varepsilon \quad (42)$$

Based on the same procedure equation (30) can be rewritten in the following way:

$$\begin{aligned} \ln\left(\left(\frac{Y}{L}\right)_t / \left(\frac{Y}{L}\right)_0\right) t^{-1} &= (1 - e^{-\lambda t}) t^{-1} a - (1 - e^{-\lambda t}) t^{-1} \frac{\gamma}{1-\gamma} \ln(n) + (1 - e^{-\lambda t}) t^{-1} \frac{\gamma}{1-\gamma} \ln(s_k) \\ &+ (1 - e^{-\lambda t}) t^{-1} \frac{\beta}{1-\gamma} \ln(h^*) + (1 - e^{-\lambda t}) t^{-1} \ln(\Psi) \\ &- (1 - e^{-\lambda t}) t^{-1} \ln\left(\frac{Y}{L}\right)_0 + (1 - e^{-\lambda t}) t^{-1} \varepsilon \end{aligned} \quad (43)$$

These versions of equations (28) and (30) allow to use the average schooling years in the total population over age 25 (which has a stock dimension) from Barro/Lee (1993) as a proxy for human capital under the assumption that the actual realization of this value, h_t , is sufficiently close to its steady state value, h^* .³⁷

As a proxy for the rate of labor force growth I use the growth rate of the total population. Again, I take a five years average of this growth rate, because the population growth rate of most countries of the Summers/Heston (1991) data displays a significant positive or negative time trend.

Of course, much more variables than those of equations (28) and (30) could be included into the regression. For example the production function of the Solow-Swan model only had to be extended to include public goods, such as infrastructure and political stability, as inputs. However, as table 2 shows, these type of public goods variables are typically highly

³⁶ To derive equation (37) insert equation (24) into equation (15) and take logs.

³⁷ Actually this assumption can be weakened, because within the framework of a cross country regression it is only necessary for h_t to display the same relative cross country variation as h^* .

correlated with each other and with human capital, such that their inclusion could result in multicollinearity problems.

Table 2 - Correlation matrix of typical steady state parameters 1985¹

	n	S _k	h*	S _h	ROA	RAIL	GOV
n	1,00						
S _k	-0,32	1,00					
h*	-0,57	0,60	1,00				
S _h	-0,61	0,47	0,77	1,00			
ROA	-0,54	0,42	0,57	0,49	1,00		
RAIL	-0,55	0,27	0,52	0,46	0,77	1,00	
GOV	0,30	-0,37	-0,50	-0,34	-0,42	-0,36	1,00

¹ The numbers are correlation coefficients. 'S_k' = share of real investments in GDP 1985, 'S_h' = percentage of „secondary school attained“ in the total population in 1985, 'h*' = average schooling years in the total population over age 25 in 1985, 'ROAD' = length of road network per km² of country area in 1985, 'RAIL' = length of rail network per km² of country area in 1985, 'GOV' = share of government expenditures on GDP in 1985. Source: Summers/Heston (1991), Barro/Lee (1993) and IRTU (1990).

The positive intercorrelations indicate that countries, which succeed in establishing public institutions for the formation of human capital, typically succeed also in establishing public institutions for the formation of other kind of public goods. Therefore, I plead for a broad interpretation of the physical and human capital proxies: As a lot of public good variables are positively correlated with these proxies, their regression coefficients reflect also the general productivity effects of the supply with public goods.

Table 3 and 4 display the results of the tests of equation (28) resp. (42). The results refer to all the years the Barro/Lee (1993) data set presents human capital data. The first column of each year gives the estimation results without an indicator of openness for foreign capital goods. The results in the first column are comparable to the results of the second column (where Ψ is based on the RIM-value), because the samples of both columns are restricted to be identical.

Table 3 - Estimation of equation (28)¹

	(Y/L) 1985				(Y/L) 1980				(Y/L) 1975			(Y/L) 1970			(Y/L) 1965		
CONST	4.308	5.331	3.584	4.137	4.641	6.185	5.759	4.1	4.251	5.72	4.68	4.93	6.99	5.868	5.41	7.012	5.17
p-value($\beta=0$)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
n	-0.266	-0.209	-0.268	-0.159	-0.222	-0.134	-0.192	-0.235	-0.282	-0.238	-0.222	-0.159	-0.139	-0.15	-0.1	-0.061	0.665
p-value($\beta=0$)	(0.000)	(0.007)	(0.003)	(0.036)	(0.019)	(0.162)	(.0049)	(0.011)	(0.001)	(0.004)	(0.026)	(0.271)	(0.28)	(0.379)	(0.624)	(0.748)	(0.665)
S _k	0.292	0.198	0.618	0.49	0.366	0.18	0.033	0.523	0.586	0.448	0.363	0.434	0.139	-0.086	0.425	0.304	0.557
p-value($\beta=0$)	(0.121)	(0.291)	(0.054)	(0.002)	(0.057)	(0.355)	(0.888)	(0.000)	(0.001)	(0.009)	(0.022)	(0.271)	(0.588)	(0.637)	(0.279)	(0.406)	(0.086)
h*	1.058	0.996	0.85	0.751	0.861	0.845	1.051	0.419	0.51	0.396	0.437	0.665	0.527	0.4936	0.485	0.307	0.463
p-value($\beta=0$)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.004)	(0.065)	(0.00)
Ψ (RIM)	-	0.058	-	-	-	0.087	-	-	-	0.107	-	-	0.128	-	-	0.119	-
p-value($\beta=0$)		(0.058)				(0.015)				(0.003)			(0.001)			(0.014)	
Ψ (RRPDP)	-	-	0.775	-	-	-	0.519	-	-	-	-	-	-	-	-	-	-
p-value($\beta=0$)			(0.766)				(0.011)										
Ψ (OW Π)	-	-	-	0.243	-	-	-	0.283	-	-	0.264	-	-	0.386	-	-	0.274
p-value($\beta=0$)				(0.009)				(0.001)			(0.005)			(0.002)			(0.051)
\bar{R}^2	0.76	0.774	0.781	0.765	0.736	0.761	0.766	0.758	0.679	0.721	0.703	0.578	0.666	0.575	0.38	0.471	0.484
p-value regr. 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	0.000	0.000	0.000	0.000	0.000
p-value macro	-	0.058	0.766	n.d.	-	0.019	n.d.	0.52	-	0.033	0.6	-	0.014	0.79	-	0.03	0.818
s.e.e.	0.43	0.416	0.528	0.478	0.471	0.447	0.479	0.466	0.528	0.493	0.498	0.605	0.539	0.6	0.664	0.616	0.66
D.W.	1.95	1.953	1.65	1.54	1.483	1.52	1.377	1.5	1.557	1.69	1.625	1.315	1.64	1.07	1.55	1.64	1.58
Observations	51	51	37	61	54	54	45	61	61	61	62	48	48	57	39	39	46

¹ Variables as defined in text. Numbers in parenthesis = p-values of corresponding t-values of regression coefficients. 'P-value regr. F' = p-value of an F-test of the null-hypothesis that all regression coefficients are jointly zero. 'P-value macro' = p-value of an F-test of the null-hypothesis that the macro economic version of Ψ performs better than the microeconomic version of Ψ . \bar{R}^2 = adjusted R-squared value. N.d. = not defined (F-value smaller 0). 'S.e.e.' Standard error of estimate. 'D.W.' Durbin Watson Test of serial correlation of the regression errors (The sample is ranked according to its per capita GDP.).

Table 4 - Estimation of equation (42)¹

	(Y/L) 1985				(Y/L) 1980				(Y/L) 1975			(Y/L) 1970			(Y/L) 1965		
CONST	4.545	5.617	3.639	4.555	3.91	5.387	4.703	4.493	3.91	5.615	4.974	4.175	6.169	6.322	4.96	6.56	4.921
p-value($\beta=0$)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
n	-0.323	-0.267	-0.279	-0.128	-0.362	-0.287	-0.341	-0.168	-0.314	-0.253	-0.144	-0.205	-0.181	0.102	-0.14	-0.84	0.135
p-value($\beta=0$)	(0.000)	(0.002)	(0.001)	(0.085)	(0.000)	(0.000)	(0.000)	(0.068)	(0.000)	(0.001)	(0.142)	(0.151)	(0.155)	(0.512)	(0.45)	(0.64)	(0.527)
S _k	0.564	0.467	0.886	0.597	0.757	0.591	0.592	0.518	0.726	0.553	0.379	0.752	0.468	0.102	0.57	0.431	0.731
p-value($\beta=0$)	(0.007)	(0.025)	(0.002)	(0.000)	(0.000)	(0.000)	(0.01)	(0.001)	(0.000)	(0.000)	(0.012)	(0.002)	(0.036)	(0.813)	(0.1)	(0.186)	0.0145
S _h	0.045	0.038	0.049	0.046	0.03	0.024	0.038	0.032	0.059	0.043	0.058	0.067	0.0467	0.065	0.068	0.0462	0.075
p-value($\beta=0$)	(0.000)	(0.001)	(0.000)	(0.000)	(0.002)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Ψ (RIM)	-	0.068	-	-	-	0.091	-	-	-	0.12	-	-	0.126	-	-	0.111	-
p-value($\beta=0$)		(0.053)				(0.015)				(0.000)			(0.001)			(0.009)	
Ψ (RRPDP)	-	-	0.128	-	-	-	0.512	-	-	-	-	-	-	-	-	-	-
p-value($\beta=0$)			(0.628)				(0.012)										
Ψ (OWTI)	-	-	-	0.312	-	-	-	0.388	-	-	0.317	-	-	0.553	-	-	0.275
p-value($\beta=0$)				(0.001)			(0.000)			(0.001)			(0.000)			(0.032)	
\bar{R}^2	0.685	0.703	0.777	0.726	0.688	0.717	0.685	0.708	0.684	0.743	0.664	0.595	0.677	0.587	0.482	0.561	0.571
p-value regr. 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	0.000	0.000	0.000	0.000	0.000
p-value macro	-	0.262	n.d.	0.62	-	0.02	n.d.	0.503	-	0.005	-	-	0.001	-	-	n.d.	n.d.
s.e.c.	0.505	0.49	0.544	0.543	0.522	0.497	0.569	0.54	0.534	0.481	0.562	0.606	0.541	0.663	0.625	0.576	0.618
D.W.	1.484	1.485	1.735	1.372	1.615	1.598	1.34	1.403	1.39	1.553	1.408	1.32	1.546	1.07	1.508	1.68	1.325
Observations	53	53	39	65	56	56	47	64	64	64	66	52	52	64	41	41	48

¹ Variables as defined in text. Numbers in parenthesis = p-values of corresponding t-values of regression coefficients. 'P-value regr. F' = p-value of an F-test of the null-hypothesis that all regression coefficients are jointly zero. 'P-value macro' = p-value of an F-test of the null-hypothesis that the macro economic version of Ψ performs better than the microeconomic version of Ψ . \bar{R}^2 = adjusted R-squared value. N.d. = not defined (F-value smaller 0). 'S.e.c.' Standard error of estimate. 'D.W.' Durbin Watson Test of serial correlation of the regression errors (The sample is ranked according to its per capita GDP).

The overall impression is that the model is not rejected by the data: No matter what specification is used (equation (28) or (42)) an F-test of the null-hypothesis that all regression coefficients except the constant are zero is rejected at conventional levels (the p-values are close to zero). The explanatory power of the model is quite satisfying: The adjusted R-squared values fluctuate around 0.7 with a slight tendency to decrease as the year of estimation decreases. However, this effect may be caused by the decreasing sample sizes. The Durbin Watson statistic (the data set is ranked according to the level of per capita GDP) indicates that there may be some positive autocorrelation of the residuals in some years. However, as the values mostly lay between the lower and upper bounds of the Durbin Watson test, a decisive test is typically not possible.

Adding an indicator of openness for foreign capital goods typically leads to an increase of the adjusted R-squared value. The regression coefficients of these indicators display always the sign predicted by the model indicating that lower import restrictions on foreign capital goods increase the level of per capita GDP. With exception of the $\Psi(\text{RRPDP})$ value for 1985 all indicators are significant at conventional levels.³⁸ I do not present an additional F-test of the null-hypothesis that the true model does not include an indicator of openness for foreign capital goods, because the p-value of such a test equals the p-value of a t-test of the null-hypothesis of a zero regression coefficient. An F-test of the null-hypothesis that the macroeconomic oriented version of Ψ performs better than the microeconomic version can only in 8 of 24 cases be rejected at conventional significance values (see 'p-value macro').

Table 5 and 6 display the results of the tests of equation (30) resp. (43). The results refer to the per capita GDP growth rates over the years 1960-85, 1960-80 and 1960-75. Easterly/Kremer/Pritchett (1993) present graphical evidence that per capita growth rates of most countries lack persistence and are primarily influenced by temporary shocks. Given this were the case, an estimation of equation (30) resp. (43) over such long spans of time would scarcely yield significant results. However, Maurer (1995a) finds (based on the Summers/Heston (1991) data) that per capita growth rates of most countries are mean reverting processes and display no time trend. Hence, typically temporary shocks do not lead to long run deviations of the growth rates from their mean. Furthermore, based on an estimation of an error correction model Maurer (1995a) finds that the simple arithmetic mean („compound rate“) of the growth rates does not significantly deviate from the estimated mean of the mean reverting process. Consequently, it makes sense to base a test of equation (30) and (43) on the per capita growth rates over such long spans of time.

³⁸ By tautology the p-value of a t-test of the null-hypothesis of a zero regression coefficient equals the p-value of a F-test of the null-hypothesis of a zero regression coefficient.

Table 5 - Tests for equation (30)¹

	d(Y/L) 1960-85				d(Y/L) 1960-80				d(Y/L) 1960-75		
CONST	0.051 (0.001)	0.089 (0.000)	0.009 (0.702)	0.053 (0.005)	0.025 (0.215)	0.057 (0.047)	0.021 (0.423)	0.04 (0.036)	0.007 (0.729)	0.048 (0.084)	0.032 (0.126)
y_0	-0.013 (0.000)	-0.014 (0.000)	-0.007 (0.068)	0.017 (0.000)	-0.01 (0.004)	-0.011 (0.001)	-0.007 (0.056)	-0.016 (0.000)	-0.01 (0.002)	-0.013 (0.000)	-0.014 (0.000)
n	-0.004 (0.000)	-0.002 (0.225)	-0.003 (0.188)	-0.005 (0.01)	-0.002 (0.338)	-0.002 (0.509)	-0.000 (0.949)	-0.005 (0.029)	-0.005 (0.035)	-0.005 (0.042)	-0.005 (0.028)
s_k	0.016 (0.001)	0.013 (0.007)	0.019 (0.003)	0.019 (0.000)	0.022 (0.000)	0.02 (0.000)	0.024 (0.000)	0.022 (0.000)	0.025 (0.000)	-0.023 (0.000)	0.022 (0.000)
s_h	0.001 (0.003)	0.001 (0.02)	0.000 (0.727)	0.001 (0.061)	0.000 (0.232)	0.000 (0.319)	0.000 (0.634)	0.000 (0.444)	0.000 (0.156)	0.000 (0.261)	0.000 (0.341)
$\Psi(\text{RIM})$	-	0.002 (0.004)	-	-	-	0.002 (0.116)	-	-	-	0.002 (0.038)	-
$\Psi(\text{RRPDP})$	-	-	-0.000 (0.99)	-	-	-	0.015 (0.013)	-	-	-	-
$\Psi(\text{OWTT})$	-	-	-	0.005 (0.065)	-	-	-	0.008 (0.002)	-	-	0.006 (0.018)
\bar{R}^2	0.431	0.512	0.191	0.53	0.349	0.368	0.378	0.557	0.389	0.424	0.516
p-value regr. F	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
p-value macro	-	0.01	n.a.	n.a.	-	0.167	n.a.	0.613	-	0.059	0.857
s.e.e.	0.012	0.011	0.012	0.014	0.014	0.013	0.014	0.013	0.014	0.014	0.014
D.W.	2.184	2.018	1.468	1.851	1.976	1.91	2.151	2.51	2.395	2.495	2.56
Observations	53	53	39	63	56	56	47	63	63	63	65

¹ Variables as defined in text. Numbers in paranthesis = p-values of corresponding t-values of regression coefficients. 'P-value regr. F' = p-value of an F-test of the null-hypothesis that all regression coefficients are jointly zero. 'P-value macro' = p-value of an F-test of the null-hypothesis that the macro economic version of Ψ performs better than the microeconomic version of Ψ . \bar{R}^2 = adjusted R-squared value. N.d. = not defined (F-value smaller 0). 'S.e.e.' Standard error of estimate. 'D.W.' Durbin Watson Test of serial correlation of the regression errors (The sample is ranked according to its growth rate per capita GDP.).

Table 6 - Tests for equation (43)¹

	d(Y/L) 1960-85				d(Y/L) 1960-80				d(Y/L) 1960-75		
CONST	0.049 (0.029)	0.093 (0.000)	0.006 (0.791)	0.048 (0.009)	0.052 (0.027)	0.088 (0.005)	0.042 (0.216)	0.063 (0.001)	0.028 (0.229)	0.065 (0.028)	0.055 (0.015)
y ₀	-0.015 (0.000)	-0.018 (0.000)	-0.008 (0.036)	-0.018 (0.000)	-0.013 (0.000)	-0.015 (0.000)	-0.01 (0.034)	-0.018 (0.000)	-0.012 (0.000)	-0.014 (0.000)	-0.016 (0.000)
n	-0.007 (0.009)	-0.006 (0.011)	-0.006 (0.098)	-0.007 (0.024)	-0.001 (0.749)	0.000 (0.981)	-0.000 (0.983)	-0.002 (0.287)	-0.004 (0.078)	-0.004 (0.086)	-0.004 (0.111)
s _k	0.016 (0.001)	0.01 (0.032)	0.018 (0.007)	0.017 (0.000)	0.016 (0.002)	0.014 (0.01)	0.019 (0.005)	0.018 (0.000)	0.022 (0.000)	0.02 (0.000)	0.018 (0.000)
h*	0.01 (0.015)	0.015 (0.004)	0.003 (0.64)	0.014 (0.003)	0.015 (0.017)	0.015 (0.016)	0.008 (0.282)	0.012 (0.006)	0.009 (0.031)	0.008 (0.048)	0.008 (0.024)
Ψ(RIM) _t	-	0.002 (0.002)	-	-	-	0.002 (0.079)	-	-	-	0.002 (0.047)	-
Ψ(RRPDP)	-	-	-0.000 (0.984)	-	-	-	0.015 (0.009)	-	-	-	-
Ψ(OWT) _t	-	-	-	0.005 (0.026)	-	-	-	0.008 (0.001)	-	-	0.007 (0.000)
\bar{R}^2	0.437	0.56	0.22	0.588	0.401	0.426	0.392	0.61	0.419	0.45	0.552
p-value regr. F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
p-value macro	-	0.006	n.a.	n.a.	-	0.12	0.622	0.546	-	0.067	0.014
s.e.e.	0.012	0.01	0.011	0.013	0.013	0.013	0.014	0.013	0.014	0.014	0.014
D.W.	2.253	2.164	1.463	1.966	1.974	1.925	2.068	2.466	2.159	2.328	2.322
Observations	55	55	41	65	56	56	47	63	62	62	64

¹ Variables as defined in text. Numbers in paranthesis = p-values of corresponding t-values of regression coefficients. 'P-value regr. F' = p-value of an F-test of the null-hypothesis that all regression coefficients are jointly zero. 'P-value macro' = p-value of an F-test of the null-hypothesis that the macro economic version of Ψ performs better than the microeconomic version of Ψ. \bar{R}^2 = adjusted R-squared value. N.d. = not defined (F-value smaller 0). 'S.e.e.' Standard error of estimate. 'D.W.' Durbin Watson Test of serial correlation of the regression errors (The sample is ranked according to its growth rate of per capita GDP.).

In tables 5 and 6 the first column of each year gives again the estimation results without an indicator of openness for foreign capital goods. The results in the first column are again comparable to the results of the second column (where Ψ is based on the RIM-value), because the samples of both columns are restricted to be identical.

The overall impression is again that the model is not rejected by the data: No matter what specification is used (equation (30) or (43)) an F-test of the null-hypothesis that all regression coefficients except the constant are zero is always rejected at conventional levels. However, now the explanatory power of the model is remarkable lower: The adjusted R-squared values typically lay in the interval 0.4 - 0.5. This difference of the estimation results of equations (28), (42) and (30), (43) is also found in the corresponding results of Mankiw/Romer/Weil (1992). It is however interesting to note that now the Durbin Watson statistic is generally close to 2.0, indicating that there is no AR(1) autocorrelation in the residuals (the data set is ranked according to the growth rate of per capita GDP)³⁹ An explanation for the lower adjusted R-squared values in combination with the better Durbin Watson statistics may be the well known fact that autocorrelated residuals may generate seriously understated estimation variances, such that R-squared values are overstated. This indicates that a regression based on equations (28) and (42) is probably misspecified: The omission of the value of the level of per capita GDP of the base period may give rise to the autocorrelation of the residuals, indicating that without the information of the GDP level of the base period an important part of the level of per capita GDP remains unexplained and generates therefore autocorrelated residuals. Consequently, the assumption that the economies are close to their steady states, which is implied by a regression based on equations (28) and (42), is probably wrong.

Adding an indicator of openness for foreign capital goods typically leads again to an increase of the adjusted R-squared value (with one exception: the $\Psi(\text{RRPDP})$ value for 1985). The regression coefficients of these indicators display always the sign predicted by the model indicating that lower import restrictions on foreign capital goods increase the steady state level of per capita GDP and lead therefore to a higher transitional growth rate. With exception of $\Psi(\text{RRPDP})$ for 1985 and $\Psi(\text{RIM})$ for 1980 all indicators are significant at conventional levels.⁴⁰ An F-test of the null-hypothesis that the macroeconomic oriented version of Ψ performs better than the microeconomic version can only in 4 of 16 cases be rejected at conventional significance values (see 'p-value macro').

³⁹ Similar Durbin Watson values are obtained, if the data are ranked according to the *level* of per capita GDP.

⁴⁰ The p-value of a t-test of the null-hypothesis of a zero regression coefficient equals the p-value of a F-test of the null-hypothesis of a zero regression coefficient.

From these results I draw the conclusion that the data do not reject the Solow-Swan model with capital variety. Adding an indicator of openness for foreign capital goods typically increases the performance of the model. The low p-values of the coefficient of the openness indicator implies that an estimation of the model without the openness indicator would typically lead to significantly higher estimation errors. Hence, these results confirm the findings of Lee (1993) and DeLong/Summers (1992), who find that policy measures increasing the price of capital goods are negatively related to the level resp. growth rate of per capita GDP.

5. Conclusions

In this paper I derived a Solow-Swan model with capital variety. This model has the implication that import restrictions on foreign capital goods reduce the steady state level of and the transitional growth rate of per capita GDP.

The empirical test of this model was based on two independent indicators of import restrictions of foreign capital goods, a price based indicator and a quantity based indicator. As displayed by a cross country regression, both indicators are significantly positively affected by the level of import tariffs on capital goods and the coverage ratio of non-tariff measures on capital goods.

Two versions of the Solow-Swan model were tested: the steady state version and the transitional version. The test results of both versions did not reject the model. However, some evidence was found that the steady state version may be misspecified. The addition of the indicators of import restriction on foreign capital goods did typically improve the explanatory power of the model. The coefficients of the indicators of import restrictions on foreign capital goods were typically significant and had the predicted sign.

Whether these results actually indicate that the „capital variety effect“ implied by the model is the primary „channel“ of influence of import restrictions on foreign capital goods on the steady state level of per capita GDP, or whether other „channels“ also play an important role, is a question that is left open for further investigation.⁴¹

⁴¹ Appendix 2 presents a Solow-Swan model with a closed oligopoly on the domestic market for capital goods. Within this model import restrictions reduce the steady state level of per capita GDP, because foreign capital good imports reduce the market power of the domestic oligopolists. In a sense, this model offers an alternative „channel“ of influence of trade policy on the level of per capita GDP.

Appendix 1 - A Solow-Swan model with capital variety and a monopolistic competition on the market for capital goods

In this appendix I show that the assumption of monopolistic competition on the market for capital goods does not basically alter the results of the Solow-Swan model with capital variety. I assume that for each type of domestic capital good an eternal patent is granted to a domestic inhabitant, such that there is no longer free entry to the production of capital goods.⁴² In order to accommodate this assumption with the assumption of an exogenous growth rate of the set of available domestic capital goods, I assume that the probability of obtaining the knowledge to produce one new type of capital good is equally randomly distributed over the domestic population. Hence, each inhabitant is an innovator with a equal probability of success that is not influenced by him. Everybody, who has the luck to win the knowledge to produce a new type of capital good is granted an eternal patent. Therefore, the chance of becoming owner of an eternal patent for a new type of capital good at one moment in time equals $A_{D,t} g/L_{D,t}$. As this process of knowledge distribution is exogenous and perfectly random, it has no allocative implications for the behavior of economic agents.⁴³

The knowledge to produce a capital good enables its owner to transform one unit of GDP with the help of an one-to-one pass-through technology into one unit of a capital good. As the entry to the production of a specific capital good is now blocked by an eternal patent, the owner of this patent is able to charge a price that is higher than the price for one unit of GDP (which, due to normalization, equals unity). To determine the profit maximizing price of a capital goods producer it is necessary to derive the demand for capital goods first. This demand follows from the profit maximization conditions of the representative GDP-producer:

$$\begin{aligned} \max_{L, H, X_i, X_j} F & \quad \text{with} & \quad (A1) \\ F = L_t^\alpha H_t^\beta & \left(\sum_i^{A_D} X_{i,t}^\gamma + \sum_j^{A_F} X_{j,t}^\gamma \right) - L w_L - H w_H - \sum_i^{A_D} X_{i,t} p_{i,t} (\tau_t + d) - \sum_j^{A_F} X_{j,t} p_{j,t} (\tau_t + d) (1 + \tau) \end{aligned}$$

⁴² An equivalent, alternative assumption is local immobility of technological knowledge. Local immobility implies that potential entrants are not able to obtain the technological knowledge to produce the type of capital good of the incumbent.

⁴³ Remember that the savings quota is independent of the level of income. Consequently even if income distribution becomes unequal, because some inhabitants had the luck to win more patents than others, the total amount of savings does not change. This would not be the case in a Ramsey-Cass model.

where $p_{i,t}$ equals the price for a domestic capital good to be determined and $p_{j,t}$ equals the price for a foreign capital good to be determined.⁴⁴ The import tariff for foreign capital goods equals again τ . (For the definitions of the other variables see section 2). The first order conditions yield i.a.:

$$\frac{\delta F}{\delta X_{i,t}} = \gamma L_t^\alpha H_t^\beta X_{i,t}^{\gamma-1} - p_{i,t} (\tau + d) = 0 \quad (A2)$$

$$X_{i,t} = \left(\gamma L_t^\alpha H_t^\beta p_{i,t}^{-1} (\tau + d)^{-1} \right)^{\frac{1}{1-\gamma}}$$

$$\frac{\delta F}{\delta X_{j,t}} = \gamma L_t^\alpha H_t^\beta X_{j,t}^{\gamma-1} - p_{j,t} (\tau + d) (1 + \tau) = 0 \quad (A3)$$

$$X_{j,t} = \left(\gamma L_t^\alpha H_t^\beta p_{j,t}^{-1} (\tau + d)^{-1} (1 + \tau)^{-1} \right)^{\frac{1}{1-\gamma}}$$

Consequently, the market equilibrium relation between domestic capital goods and foreign capital goods is given by:

$$X_{i,t} = X_{j,t} \left(\frac{p_{j,t}}{p_{i,t}} \right)^{\frac{1}{1-\gamma}} (1 + \tau)^{\frac{1}{1-\gamma}} \quad (A4)$$

Hence, the higher the price for a foreign capital good, $p_{j,t}$, and the higher the import restriction for foreign capital goods, τ , the lower is the input of foreign capital goods, $X_{j,t}$, in relation to the input of domestic capital goods, $X_{i,t}$. From equation (A2) follows the world demand for a domestic capital good:

$$\sum_n X_{n,i,t} = \sum_n \left(\gamma L_{n,t}^\alpha H_{n,t}^\beta p_{i,t} (\tau_{n,t} + d)^{-1} (1 + \tau_n)^{-1} \right)^{\frac{1}{1-\gamma}} \quad (A5)$$

where N is the set of all countries and the index „ n “ refers the corresponding variable of country $n \in N$. I assume that there is a world market for capital goods, such that a domestic capital goods producer is not able to discriminate between the demands of single countries.

⁴⁴ To be explicit: Contrary to the model with free entry to the production of capital goods, this price does equal no longer the price of one unit GDP (which, due to normalization, equals unity), because of the monopolistic price setting behavior of the owner of capital goods patents.

Hence, no country specific price discrimination is possible. Therefore, a domestic capital goods producer maximizes his profit over the aggregated world demand for his capital good. Rearranging equation (A5) yields then the price of a capital good in dependence from the sold quantity.

$$p_{i,t} = \left(\sum_n^N \gamma L_{n,t}^\alpha H_{n,t}^\beta (r_{n,t} + d)^{-1} (1 + \tau_n)^{-1} \right) \left(\sum_n^N X_{n,i,t} \right)^{-(1-\gamma)} \quad (\text{A6})$$

For convenience, define the sold quantity:

$$\hat{X}_{i,t} := \left(\sum_n^N X_{n,i,t} \right) \quad (\text{A7})$$

As a capital goods producer buys one unit of GDP at a price of unity and sells this unit GDP transformed into one unit capital good at a price of $p_{i,t}$, the profit maximization of a capital goods producer implies:

$$\max_{\hat{X}_{i,t}} \Pi_{i,t}! \quad \text{with} \quad \Pi_{i,t} = \hat{X}_{i,t} p_{i,t} - \hat{X}_{i,t} \quad (\text{A8})$$

With respect to equation (A6), the first order condition for a profit maximum yields:

$$\frac{\delta \Pi_{i,t}}{\delta \hat{X}_{i,t}} = p_{i,t} - 1 - \hat{X}_{i,t} (1-\gamma) \left(\sum_n^N \gamma L_{n,t}^\alpha H_{n,t}^\beta (r_{n,t} + d)^{-1} (1 + \tau_n)^{-1} \right) \hat{X}_{i,t}^{-(2-\gamma)} = 0 \quad (\text{A9})$$

Using (A6) this can be rewritten:

$$\frac{\delta \Pi_{i,t}}{\delta \hat{X}_{i,t}} = p_{i,t} - 1 - (1-\gamma) p_{i,t} = 0 \quad (\text{A10})$$

From this follows the profit maximizing price of a monopolistic capital goods producer:

$$p_{i,t} = \frac{1}{\gamma} \quad (\text{A11})$$

This is the well known „mark up“ formula for monopolistic pricing of intermediate products (see e.g. Tirole (1988), chap. 7.5.2., Rivera-Batiz/Romer (1991a), (1991b)⁴⁵). Following this

⁴⁵ Comparing this result with that of Rivera-Batiz/Romer (1991a) and (1991b), remember that - contrary to Rivera-Batiz/Romer (1991a) and (1991b) - this price is not the per period rental rate for a capital good, but the price for its eternal property right.

formula the profit maximizing price for a capital good is the higher the lower γ . The intuition for this relation follows from the elasticity of substitution between two types of capital goods, which equals $\sigma = 1/(1-\gamma)$ (see appendix 5 for a derivation). As this formula displays, for $\gamma = 1$ the elasticity of substitution approaches infinity and consequently all capital goods are perfect substitutes.⁴⁶ Therefore, if $\gamma = 1$, a capital goods producer has despite of his eternal patent no monopolistic price setting power, but faces perfect competition by the other capital goods producers. Consequently, if $\gamma = 1$, a capital goods producer has to equate his price to his marginal costs, which equal unity, such that $p_{i,t} = 1$. If, to the contrary, $\gamma < 1$, the elasticity of substitution is smaller than infinity, and capital goods are less than perfect substitutes.⁴⁷ Therefore, in this case, a capital goods producer has monopolistic price setting power and can chose a price that is higher than his marginal costs, such that $p_{i,t} > 1$.

Another implication of equation (A11) is that all capital goods are sold at the same price. Remember the basic assumption of the Solow-Swan model with capital variety that all countries have the same production technologies. Consequently, γ is identical for all countries. Therefore, capital goods producer of all countries set the same capital goods price:

$$p_{i,t} = p_{j,t} = \frac{1}{\gamma} \quad (\text{A12})$$

Following equation (A12) equation (A4) can be rewritten:

$$X_{i,t} = X_{j,t} (1+\tau)^{\frac{1}{1-\gamma}} \quad (\text{A13})$$

This equals again equation (7) of the Solow-Swan model with capital variety and perfect competition on the market for capital goods. For further calculations it is useful to notice that equations (A2) and (A12) imply the input quantities of all domestic capital goods to be identical:

$$X_{i,t} = \bar{X}_{i,t} \quad \forall i \in A_D \quad (\text{A14})$$

⁴⁶ If the elasticity of substitution between two production factors approaches infinity, $\sigma \rightarrow \infty$, the isoquant between this production factors becomes a straight line and not the usual convex curve. If, to the contrary, the elasticity of substitution between to production factors is zero, $\sigma = 0$, the isoquant between this production factors degenerates towards a 90°- angle, i.e. the production factors are limitational.

⁴⁷ Remember that the constant returns to scale assumptions of equation (1) imply $0 < \gamma < 1$.

By the same argument equations (A3) and (A12) imply the input quantities of all foreign capital goods to be identical:

$$X_{j,t} = \bar{X}_{j,t} \quad \forall j \in A_F \quad (A15)$$

To derive the steady state level of per capita GDP consider the market value of the stock of physical capital with respect to the price of capital goods given by equation (A12):

$$K_t = \sum_i^{A_{D,t}} X_{i,t} P_{i,t} + \sum_j^{A_{F,t}} X_{j,t} P_{j,t} (1 + \tau) \quad (A16)$$

This equation already 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 prices for capital goods (resp. the import tariff for capital goods). Given equations (A14) and (A15) this can be rewritten in two alternative ways:

$$K_t = X_{i,t} P_{i,t} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) \quad (A17)$$

$$K_t = X_{j,t} P_{j,t} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) (1 + \tau)^{\frac{1}{1-\gamma}} \quad (A18)$$

Remember that (A14) and (A15) imply that equation (1) can be rewritten in the following way:

$$Y_t = L_t^\alpha H_t^\beta (A_{D,t} X_{i,t}^\gamma + A_{F,t} X_{j,t}^\gamma) \quad (A19)$$

Inserting equations (A17) and (A18) yields:

$$Y_t = L_t^\alpha H_t^\beta \left(A_D \left(K_t P_{i,t}^{-1} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-1} \right)^\gamma + A_F \left(K_t P_{j,t}^{-1} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-1} (1 + \tau)^{\frac{-1}{1-\gamma}} \right)^\gamma \right) \quad (A20)$$

This equals:

$$Y_t = L_t^\alpha H_t^\beta K_t^\gamma P_{i,t}^{-\gamma} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-\gamma} \quad (A21)$$

This equals:

$$Y_t = L_t^\alpha H_t^\beta K_t^\gamma p_{i,t}^{-\gamma} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{\gamma}{1-\gamma}} \right)^{1-\lambda} \quad (\text{A22})$$

This can be rewritten in terms of per capita intensities (see equation (14)):

$$y_t = h_t^\beta k_t^\gamma p_{i,t}^{-\gamma} e^{g t(1-\gamma)} \Psi^{(1-\gamma)} \quad \text{with} \quad \Psi := \left(A_{D,0} + A_{F,0} (1 + \tau)^{\frac{\gamma}{1-\gamma}} \right) \quad (\text{A23})$$

Given the same assumptions concerning savings behavior as in the Solow-Swan model with capital variety and perfect competition on the market for capital goods (see equation (16) and (17)) the steady state values of the stocks of physical and human capital now equal:

$$\dot{k}_t = 0 \Leftrightarrow k_t = \left(\frac{s_k p_i^{-\gamma} h_t^\beta e^{g t(1-\gamma)} \Psi^{(1-\gamma)}}{n + d} \right)^{\frac{1}{1-\gamma}} \quad (\text{A24})$$

$$\dot{h}_t = 0 \Leftrightarrow h_t = \left(\frac{s_h p_i^{-\gamma} k_t^\gamma e^{g t(1-\gamma)} \Psi^{(1-\gamma)}}{n + d} \right)^{\frac{1}{1-\beta}} \quad (\text{A25})$$

Inserting equation (A24) into (A25) and (A25) into (A24) yields the steady state levels of k and h in dependence from the structural parameters of the economy:

$$k^* = \Psi^{\frac{1-\gamma}{1-\beta-\gamma}} p_i^{-\frac{\gamma}{1-\beta-\gamma}} \left(\frac{s_k^{1-\beta} s_h^\beta e^{g t(1-\gamma)}}{n + d} \right)^{\frac{1}{1-\beta-\gamma}} \quad (\text{A26})$$

$$h^* = \Psi^{\frac{1-\gamma}{1-\beta-\gamma}} p_i^{-\frac{\gamma}{1-\beta-\gamma}} \left(\frac{s_k^\gamma s_h^{1-\gamma} e^{g t(1-\gamma)}}{n + d} \right)^{\frac{1}{1-\beta-\gamma}} \quad (\text{A27})$$

Based on equation (A26) and (A27) equation (A23) can now be rewritten:

$$\left(\frac{Y}{L} \right)^* = e^{\frac{g t(1-\gamma)}{1-\beta-\gamma}} (n + d)^{\frac{-\beta-\gamma}{1-\beta-\gamma}} s_k^{\frac{\gamma}{1-\beta-\gamma}} s_h^{\frac{\beta}{1-\beta-\gamma}} p_i^{-\frac{\gamma}{1-\beta-\gamma}} \Psi^{\frac{1-\gamma}{1-\beta-\gamma}} \quad \text{where} \quad \Psi := \left(A_{D,0} + A_{F,0} (1 + \tau)^{\frac{\gamma}{1-\gamma}} \right) \quad (\text{A28})$$

Equation (A28) shows that a monopolistic market structure on the market for capital goods leads to a reduction of the steady state level of per capita GDP by the factor $p_i^{-\frac{\gamma}{1-\beta-\gamma}}$. Remember that p_i equals γ^1 . Consider for the purpose of illustration a value of $\gamma = \beta = 0.3$.

This yields: $p_i^{\frac{-\gamma}{1-\beta-\gamma}} \approx 0.4$. Consequently a monopolistic structure on the market for capital goods can lead to a reduction of the steady state level of per capita GDP of 60 per cent compared to the steady state level of per capita GDP of the model with perfect competition on the market for capital goods (see equation (26)).

The intuitive explanation for the effect of a monopolistic market structure on the market for capital goods has already been revealed by equation (A17):⁴⁸ 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 prices for capital goods. As (A17) shows for $\gamma = 0.3$ the real value of nominal accumulated capital, K_t , is reduced by 70 per cent compared to the model with perfect competition on the market for capital goods (see equation (11)). The effect on per capita GDP (only 60 per cent instead of 70 per cent) is then damped by the diminishing marginal returns of capital.

To analyze the possible effect of a monopolistic market structure on the market for capital goods on an OLS-estimation of equation (A28) take the logs of (A28) and remember the assumption of equation (27), $\frac{1-\gamma}{1-\beta-\gamma} \ln g = a + \varepsilon$ (see section 2). This yields:

$$\begin{aligned} \ln\left(\frac{Y}{L}\right)^* &= a - \frac{\gamma}{1-\beta-\gamma} \ln(p_i) - \frac{\beta+\gamma}{1-\beta-\gamma} \ln(n) + \frac{\gamma}{1-\beta-\gamma} \ln(s_k) \\ &+ \frac{\beta}{1-\beta-\gamma} \ln(s_h) + \frac{1-\gamma}{1-\beta-\gamma} \ln(\Psi) + \varepsilon \end{aligned} \quad (\text{A29})$$

Equation (A29) shows that in case the market structure for capital goods of the sample countries is actually monopolistic, the omission of the price for capital goods, p_i , in an OLS-estimation of equation (A29) does only lead to a reduction of the regression constant by $\frac{\gamma}{1-\beta-\gamma} \ln(p_i)$. As the model implies that the price of capital goods is equal across all countries (see equation (A12)), the omission of p_i has no systematic effect on ε , the unexplained residuum of the regression. Consequently, under the null-hypothesis that the Solow-Swan model is the true model, the regression results presented in section 4 are not biased by the existence of a monopolistic market structure on the markets for capital goods. The only effect of a monopolistic market structure on the markets for capital goods is a reduction of the regression constant.

It is interesting to note that trade policy does not influence the price setting behavior of capital good producers within this model. Even if there are no import restrictions on capital

⁴⁸ Equation (A17) is equivalent to equation (A18), because of equation (A13).

goods, foreign competition does not lead to a reduction of monopolistic capital goods prices. Hence, the „conventional intuition“, according to which free trade improves productivity through increased competition for domestic producers, does not hold within this model. The reason for this is the special version of the Cobb-Douglas production function (equation (1)). As is derived in appendix 5 this functional form implies that capital goods are no perfect substitutes as long as $\gamma < 1$, such that the elasticity of substitution between capital goods is smaller than infinity, $\sigma < \infty$. Hence, the price setting power of a capital goods producer is not restricted as long as $\gamma < 1$, if the supply with other types of capital goods grows, caused by additional imports of foreign capital goods. Consequently foreign trade can not increase competition on the market for capital goods within this model. Appendix 2 analyses the influence of foreign trade on steady state per capita GDP, if all capital goods are perfect substitutes.

Appendix 2 - A Solow-Swan model with homogenous capital goods and a closed oligopoly on the domestic market for capital goods

In this appendix I analyze the influence of foreign trade on per capita GDP, if $\gamma = 1$, i.e. if capital goods are perfect substitutes. This version of the Solow-Swan model represents in a sense the contrary extreme to the Solow-Swan model with capital variety, because on one hand the assumption of $\gamma = 1$ excludes any positive effect of capital variety on per capita GDP but - as will be seen - allows on the other hand for a positive effect of foreign competition on per capita GDP. Hence, if $\gamma = 1$, foreign trade effects the level of per capita GDP not via the capital variety effect but via a competition effect.

Consider first the following production function, which allows to compare the differences of the production function of the Solow-Swan model with capital variety to the Solow-Swan model with homogenous capital goods:

$$Y_t = L_t^\alpha H_t^\beta \left(\sum_i^{A_D} X_{i,t}^\gamma + \sum_{j,i}^{A_E} X_{j,i}^\gamma \right)^\lambda \quad \text{where } \alpha + \beta + \lambda = 1, \quad 0 < \alpha, \beta, \lambda < 1 \text{ and } 0 < \gamma \leq 1 \quad (A30)$$

For $\gamma = \lambda$ this production function equals the production function of the Solow-Swan model with capital variety (see equation (1)) and for $\gamma = 1$ this production function equals the typical production function of the Solow-Swan model with homogenous capital goods, which will be analyzed in the following.

If capital goods are homogenous (resp. $\gamma = 1$) and there is atomistic competition on the domestic market for capital goods, prices will always equal marginal costs, such that imports of capital goods can not further increase competition. Therefore, in this case import

restrictions on capital goods can have no negative steady state effect on per capita GDP. Consequently, a necessary condition to derive a negative relation between import restrictions on capital goods and steady state per capita GDP is some kind of imperfect competition on the domestic capital goods market. Thus 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. I 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 I assume that the number of foreign capital goods producers, N_F , is finite but large.⁴⁹ Hence, equation (A30) can be rewritten in the following way:

$$Y_t = L_t^\alpha H_t^\beta \left(\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t} \right)^\lambda \quad \text{where } \alpha + \beta + \lambda = 1, \quad 0 < \alpha, \beta, \lambda < 1 \quad (\text{A31})$$

As it turns out, given these assumptions concerning the market structure the market result depends essentially on the assumptions concerning the market conduct. Two different scenarios have to be distinguished. *First scenario*: the oligopolists choose prices as interaction parameters. *Second scenario*: the oligopolists choose quantities as interaction parameters.

If the domestic oligopolists choose the price as interaction parameter *and* the demand for capital goods has perfect information on the price of each oligopolist, the market result is Bertrand competition and all existing Nash equilibria imply a market price that equals marginal costs. A capital goods price higher than marginal costs can be no Nash equilibrium, because in this case each oligopolist has an incentive to lower his price marginally, attract the hole demand and realize thus a positive profit. Consequently, as in the case of atomistic competition, imports of capital goods can not further increase competition. Therefore, if prices are chosen as interaction parameters, import restrictions on capital goods do not have a negative steady state effect on per capita GDP.⁵⁰

If, however, the domestic oligopolists choose quantities as interaction parameters, a Nash equilibrium with prices higher than marginal costs may evolve and additional competition by imports of capital goods can influence the steady state level of per capita GDP. To derive this

⁴⁹ This assumption will be used later on.

⁵⁰ To prevent the outcome of Bertrand competition within this scenario, some demand inertia has to be introduced. For example due to asymmetric information or transportation costs, each oligopolist may face a declining demand curve and may thus have some price setting power. I do not follow this approach here, because I suppose that the result does not differ much from the result of the second scenario.

result analytically, the demand for capital goods has to be determined first. Consider therefore the profit maximization problem of the representative firm:

$$\max_{L, H, \bar{X}} F! \text{ with } F = L_t^\alpha H_t^\beta \bar{X}_t^{\lambda-1} - L_t w_L - H_t w_H - \hat{X}_t p_t \text{ and } \bar{X}_t := \left(\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t} \right) \quad (\text{A32})$$

From the first order conditions for a profit maximum follows i.a.:

$$\frac{\delta F}{\delta \bar{X}} = \gamma L_t^\alpha H_t^\beta \bar{X}_t^{\lambda-1} - p_t = 0 \quad (\text{A33})$$

Hence the price for capital goods in dependence from the total supply, \bar{X}_t , equals:

$$p_t = \gamma L_t^\alpha H_t^\beta \bar{X}_t^{\lambda-1} \text{ with } \bar{X}_t := \left(\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t} \right) \quad (\text{A34})$$

Under the assumption that the domestic capital good producers choose quantities as interaction parameters and play an uncooperative Nash strategy, the Nash equilibrium quantity of capital goods can be derived by maximizing the profit of each domestic capital good producer under the assumption that the supply of the other capital goods producers is given. This leads to the following maximization approach:

$$\Pi_{i,t} = \hat{X}_{i,t} p_{i,t} - \hat{X}_{i,t} \text{ where } \hat{X}_{i,t} \text{ equals the supply of each capital good producer.} \quad (\text{A35})$$

With respect to equation (A34) the first order conditions yield:

$$\frac{\delta \Pi_{i,t}}{\delta \hat{X}_{i,t}} = p_{i,t} - 1 - \hat{X}_{i,t} (1-\gamma) \lambda L_t^\alpha H_t^\beta \left(\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t} \right)^{\lambda-2} = 0 \quad (\text{A36})$$

⇔

$$\frac{\delta \Pi_{i,t}}{\delta \hat{X}_{i,t}} = p_{i,t} - 1 - \hat{X}_{i,t} (1-\lambda) p_{i,t} \left(\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t} \right)^{-1} = 0$$

Solving equation (A36) for the price yields:

$$p_{i,t} = \left(1 - (1-\lambda) \frac{\hat{X}_{i,t}}{\sum_i^{N_D} X_{i,t} + \sum_j^{N_F} X_{j,t}} \right)^{-1} \quad (\text{A37})$$

Under the assumption that the per period imports of capital goods is restricted by the government on a market share of q of the domestic capital goods market this can be rewritten in the following way:

$$p_t = \left(1 - (1-\lambda) \frac{(1-q)}{N_D} \right)^{-1} \quad \text{where} \quad q = \frac{\sum_i^{N_F} X_{j,t}}{\sum_i^{N_D} X_{i,t} + \sum_i^{N_F} X_{j,t}} \quad (\text{A38})$$

Consequently, the domestic price for capital goods is the lower, the higher the number of domestic oligopolists, N_D , and the lower the import restrictions on foreign capital goods, $(1-q)$. This is most obviously seen by taking the limits: If the number of domestic oligopolists approaches infinity $N_D \rightarrow \infty$, the domestic price of capital goods approaches unity, $p \rightarrow 1$, which equals the price in the case of atomistic competition. If foreign capital goods producers are free to supply the whole domestic capital goods market, $q = 1$, the price for capital goods equals again unity, $p = 1$.⁵¹ 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 $p_t = (1 - (1-\lambda)/N_D)^{-1}$. Consequently, the domestic price for capital goods is now determined by the import restrictions on foreign capital goods, q . I assume that q is chosen by the government due to a exogenous political bargaining process.

Given the domestic price for capital goods, $p_{i,t}$, the real input quantity of the domestic capital stock equals:

$$\bar{X}_t = K_t p_{i,t}^{-1} \quad (\text{A39})$$

where K_t equals the value of accumulated savings measured in GDP units. Inserting this in production function (A31) yields:

$$Y_t = L_t^\alpha H_t^\beta K_t^\lambda p_{i,t}^{-\lambda}$$

Given the assumptions of savings behavior of the Solow-Swan model (see section 2, equation (16) and (17)) and the assumption of labor augmenting technological progress ($A_t = A e^{\mu t}$) the steady state level of per capita GDP is given by the following equation:

⁵¹ Strictly speaking this holds only if the total number of foreign capital 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.

$$\left(\frac{Y}{L}\right)^* = A e^{gt} (g+n+d)^{\frac{-\beta-\lambda}{1-\beta-\lambda}} s_k^{\frac{\lambda}{1-\beta-\lambda}} s_h^{\frac{\beta}{1-\beta-\lambda}} p_i^{\frac{-\lambda}{1-\beta-\lambda}} \quad (A40)$$

Inserting equation (A38) yields then:

$$\left(\frac{Y}{L}\right)^* = A e^{gt} (g+n+d)^{\frac{-\beta-\lambda}{1-\beta-\lambda}} s_k^{\frac{\lambda}{1-\beta-\lambda}} s_h^{\frac{\beta}{1-\beta-\lambda}} \left(\left(1 - (1-\lambda) \frac{(1-q)}{N_D} \right)^{-1} \right)^{\frac{-\lambda}{1-\beta-\lambda}} \quad (A40)$$

Consequently, the steady state level of per capita GDP is the lower the higher the domestic price for capital goods, p_i . Given the formula for the domestic price of capital goods, equation (A38) implies that the steady state level of per capita GDP is the lower the higher the import restrictions on foreign capital goods, $1-q$. Hence, - contrary to the Solow-Swan model with capital variety - now trade policy influences the steady state level of per capita GDP via its impact on the degree of competition on the domestic capital goods market.

Appendix 3 - Analysis of the credit market in the Solow-Swan model with capital variety

In this appendix I analyze the implications of the Solow-Swan model with capital variety for the equilibrium on the domestic credit market. The motivation for this analysis is the question, whether the assumption of an exogenous growth rate of the available set of capital goods has some implausible implications for the credit market equilibrium: As within this model an ever growing set of capital goods permanently increases the productivity of the capital stock, it may induce an implausible and counterfactual permanent increase of the steady state interest rate.

1. Determination of the steady state interest rate

As a basic assumption of the Solow-Swan model with capital variety is existence of international immobility of capital, which precludes international borrowing and lending (see section 2). Consequently, the following analysis can be restricted to the domestic capital market only. To derive the steady state interest rate of the credit market in the Solow-Swan model with capital variety, consider first the credit demand. The total credit demand follows from the demanded quantity of each domestic and foreign capital good, which is given by equations (5) resp. (6), times the available number of different capital good types, which equals A_{D_i} resp. A_{F_i} . This yields the following equation (which corresponds to equations (11) resp. (12)):

$$K_t^D = \left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-1} \right)^{\frac{1}{1-\gamma}} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) \quad (A41)$$

Hence, the total domestic credit demand is the higher the lower the interest rate and the larger the available set of different capital goods, A_D and A_F . The investment demand follows from the total credit demand by subtracting the accumulated credit stock, K_t , minus per period capital depreciation, $K_t d$. This yields the following equation:

$$I_t = K_t^D - K_t (1 - d) \quad (A42)$$

In steady state total credit demand equals the accumulated credit stock:

$$K_t^D = K_t \quad (A43)$$

Consequently, in steady state investment demand equals capital depreciation:

$$I_t = K_t d \quad (A44)$$

Inserting equation (A41) yields the steady state investment demand:

$$I_t = \left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-1} \right)^{\frac{1}{1-\gamma}} \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right) d \quad (A45)$$

To determine the savings supply remember that the Solow-Swan model states a fixed savings quota such that savings supply equals (see equation (16)):

$$S_t = s Y_t \quad (A46)$$

Inserting the formula for total GDP from equation (13) yields:

$$S_t = s L_t^\alpha H_t^\beta K_t^\gamma \left(A_{D,t} + A_{F,t} (1 + \tau)^{\frac{-\gamma}{1-\gamma}} \right)^{1-\gamma} \quad (A47)$$

Equating investment demand and savings supply and solving for the interest rate yields the formula for the steady state interest rate, r^* :

$$I_t = S_t \quad (A48)$$

↔

$$\left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-1}\right)^{\frac{1}{1-\gamma}} \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}}\right) d = s L_t^\alpha H_t^\beta K_t^\gamma \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}}\right)^{1-\gamma}$$

⇔

$$\left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-1}\right)^{\frac{1}{1-\gamma}} \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}}\right) d = s \left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-\gamma}\right)^{\frac{1}{1-\gamma}} \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}}\right)$$

⇔

$$r^* = d \left(\frac{\gamma}{s} - 1\right)$$

Hence, the steady state interest rate depends only on the structural parameters of the economy. Consequently, it is time invariant. It is the higher, the higher the productivity of capital (as implied by the production elasticity of capital, γ), the higher the rate of capital depreciation, d , and the lower the savings quota, s . The economic reason for the constancy of the steady state interest rate follows from the fact that the steady state credit demand growth with the same rate as the steady state capital supply (see the third line of equation (A48)).

2. Determination of the transitional interest rate

To determine the behavior of the interest rate out of steady state, consider that out of steady state capital demand as given by equation (A41) is higher than the existing capital stock:

$$K_t^D > K_t \tag{A48}$$

Define therefore:

$$1 + \omega_t := \frac{K_t^D}{K_t} \tag{A49}$$

Inserting this in equation (A42) yields:

$$I_t = K_t (\omega_t + d) \tag{A50}$$

Equating again investment demand and savings supply and solving for the interest rate yields the formula for the interest rate out of steady state, r_t :

$$I_t = S_t \tag{A51}$$

⇔

$$r_t = d \left(\frac{Y}{s} - 1 \right) + \omega_t \frac{Y}{s}$$

\Leftrightarrow

$$r_t = r_t^* + \omega_t \frac{Y}{s}$$

Consequently, the out of steady state interest rate, r_t , is higher than the steady state interest rate, r^* , and decreases towards the steady state interest rate as the economy moves towards its steady state, i.e. $\omega_t \rightarrow 0$.

3. Graphical exposition of the credit market

To derive a graphical exposition of the credit market, consider that the total credit supply equals the accumulated savings, $K_t(1-d)$, plus per period savings $S_t = sY_t$:

$$K_t^S = S_t + K_t(1-d) \quad (\text{A52})$$

Inserting equation (A47) yields:

$$K_t^S = s L_t^\alpha H_t^\beta K_t^\gamma \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{1-\gamma} + K_t(1-d) \quad (\text{A53})$$

Inserting equation (A41) and (A43) yields:

$$K_t^S = \left(\gamma L_t^\alpha H_t^\beta (r_t + d)^{-1} \right)^{\frac{1}{1-\gamma}} \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right) (1-d + s(r+d)) \quad (\text{A54})$$

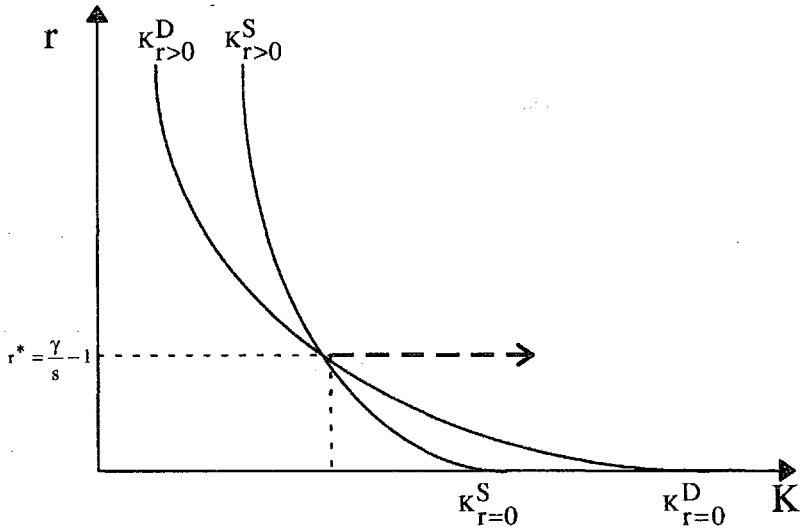
As follows from the first derivation of equation (A54) with respect to the interest rate, total credit supply depends negatively on the interest rate, $\delta K_t^S / \delta r_t < 1$. The economic reason for this behavior of credit supply is the assumption that savings are a constant fraction of GDP. Consequently, on one hand households do not save more when the interest rate increases (contrary to the Ramsey-Cass model), while on the other hand the level of GDP depends negatively on the interest rate, because capital input depends negatively on the interest rate (see equation (A41)).

Using equation (A41) this can be rewritten in the following way:

$$K_t^S = K_t^D (1-d + s(r+d)) \quad (\text{A55})$$

As $d > s d$, this implies that $K^D > K^S$, if $r = 0$. However, as r grows the expression $(1-d + s(r+d))$ becomes greater than unity, $(1-d + s(r+d)) > 1$, such that finally $K^D < K^S$ holds. Consequently the following graph results:

Figure 2 - The credit market of the Solow-Swan model with capital variety



The intersection point of steady state credit demand, K^D , and credit supply, K^S , determines the steady state interest rate, r^* . As credit demand and credit supply grow proportionately with the available set of production goods (see equation (A48)), they move both with the same speed to the right, such that the steady state interest rate stays constant.

Appendix 4: Derivation of equation (13)

In this appendix I derive equation (13), based on equation (1), (8), (9), (11) and (12):

$$Y_t = L_t^\alpha H_t^\beta \left(\sum_i^{A_D} X_{i,t}^\gamma + \sum_j^{A_F} X_{j,t}^\gamma \right) \quad (1)$$

$$X_{i,t} = \bar{X}_{i,t} \quad \forall i \in A_D \quad (8)$$

$$X_{j,t} = \bar{X}_{j,t} \quad \forall j \in A_F \quad (9)$$

$$K_t = X_{i,t} \cdot \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right) \quad (11)$$

$$K_t = X_{j,t} \cdot \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right) (1+\tau)^{\frac{1}{1-\gamma}} \quad (12)$$

Inserting equation (8) and (9) in equation (1) yields:

$$Y_t = L_t^\alpha H_t^\beta \left(A_D X_{i,t}^\gamma + A_F X_{j,t}^\gamma \right) \quad (A56)$$

Solving equation (11) and (12) for $X_{i,t}$ resp. $X_{j,t}$ and inserting the resulting expressions in equation (A57) yields:

$$Y_t = L_t^\alpha H_t^\beta \left[A_D \left(K_t \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-1} \right)^\gamma + A_F \left(K_t \left(A_{D,t} + A_{F,t} (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-1} (1+\tau)^{\frac{-1}{1-\gamma}} \right)^\gamma \right] \quad (A57)$$

\Leftrightarrow

$$Y_t = L_t^\alpha H_t^\beta K_t^\gamma \left(A_D + A_F (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right) \left(A_D + A_F (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{-\gamma}$$

\Leftrightarrow

$$Y_t = L_t^\alpha H_t^\beta K_t^\gamma \left(A_D + A_F (1+\tau)^{\frac{-\gamma}{1-\gamma}} \right)^{1-\gamma}$$

This equals equation (13).

Appendix 5 - Derivation of the technical elasticity of substitution between capital goods.

In this appendix I derive the technical elasticity of substitution between capital goods for the production function with capital variety (equation (1)). Consider production function (1) with $A=A_D+A_P$:

$$Y_t = I_t^\alpha H_t^\beta \left(\sum_i X_{i,t}^\gamma \right) \text{ where } \alpha + \beta + \gamma = 1, \quad 0 < \alpha, \beta, \gamma < 1 \quad (\text{A58})$$

Hence, for two arbitrary types of capital goods, $k, l \in A$, the elasticity of substitution is defined in the following way:

$$\sigma = \frac{\delta(X_k/X_l) \cdot (Y_{X_l}/Y_{X_k})}{\delta(Y_{X_l}/Y_{X_k}) \cdot (X_k/X_l)} \quad (\text{A59})$$

where Y_{X_k} is the first derivation of the production function with respect to capital good X_k and $\delta(X_k/X_l)/\delta(Y_{X_l}/Y_{X_k})$ is inverse of the first derivation of the marginal rate of technical substitution with respect to X_k/X_l . Inserting the corresponding terms derived from equation A(A58) in the formula of the elasticity of substitution yields:

$$\frac{\delta(X_k/X_l)}{\delta(Y_{X_l}/Y_{X_{kl}})} = \frac{1}{1-\gamma} \left(\frac{X_k}{X_l} \right)^\gamma \quad (\text{A60})$$

$$\frac{(Y_{X_l}/Y_{X_{kl}})}{(X_k/X_l)} = \left(\frac{X_k}{X_l} \right)^{-\gamma} \quad (\text{A61})$$

Such that:

$$\sigma = \frac{1}{1-\gamma} \quad (\text{A62})$$

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