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Long-Term International Capital Movements and Technology: A Review

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Abstract

This paper reviews the theoretical literature on the question of how long-term international capital movements depend on the international distribution of technology. It focuses on long-term investment flows, as these are more affected by international differences in technologies than short-term financial flows. International capital movements are investigated in the context of various technology specifications, ranging from models with only one common technology to those with multiple and endogenous technologies. The paper demonstrates that the theoretical specification of technology is crucial to the prediction of the size and direction of international capital movements.

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Contents

I. Introduction

In the post-World War II era, the world economy has become increasingly interdependent as has been reflected in the surge in international trade and capital flows since the 1950s. The greater economic integration has also facilitated the flow of ideas and technologies across countries by extending the channels through which technologies can be transferred. It would be unthinkable these days for a major invention to take two hundred years to spread around the world, as in the case of gunpowder which was known to the Chinese in the eleventh century, but not to the Europeans until about the late thirteenth century. Although globalization may have facilitated the diffusion of technologies across the world, this has not led countries to become identical in the technologies they use or have access to. The implications of differences in technologies have been studied at length in the context of international trade and international growth comparisons. The implications of international differences in technologies for capital flows have received less attention, however. Yet, technologies matter as much to the pattern of capital flows as to the pattern of trade flows. For example, in the standard Heckscher-Ohlin-Samuelson (HOS) model with two countries, two factors of production (capital and labor) and two commodities—that is, there are two production processes, which are available to both countries—free trade in goods is a perfect substitute for international capital movements.[2] Factor prices are equalized through trade and the comparatively capital scarce-country indirectly imports capital by importing the capital-intensive commodity in exchange for the labor-intensive commodity, and vice versa for the comparatively labor-scarce country. In a less symmetric world, where countries use different technologies or specialize in the production of different commodities, factor price equalization is less likely to hold. Hence, differences in technologies are a source of international capital movements.[3]

This paper reviews the theoretical literature on the question of how long-term international capital movements depend on the international distribution of technology. It demonstrates that the theoretical specification of technology is of great relevance to the prediction of the size and direction of international capital movements.[4] The discussion applies to long-term investment flows, as these are mainly determined by economic fundamentals such as production technologies, in contrast to short-term financial flows,

[2] Provided the endowment structure of both countries is such that specialization in the production of a single commodity does not occur.

[3] This paper does not want to assert that international capital flows can be fully understood by just looking at the international distribution of technologies. There are, of course, other determinants of long-term capital flows, which are probably as important as differences in technologies.

[4] The concept of technology used here is that of the production function, or the production possibilities set. A technology incorporates one or more production processes, which are described by all the technologically feasible patterns of inputs and ouputs. Technologies are distinguished by the number of production processes they incorporate and by the parameters of these production processes, that is the slopes and intercepts of the production functions.

which tend to be determined more by short-run fluctuations in expected yield differentials. It is not the aim of this paper to present an exhaustive review of the relevant literature, it is merely an attempt to shed light on the issue of how the different distributions of technology might affect the direction of capital flows, and how capital flows affect welfare in each case.

The paper is organized as follows. Sections II and III investigate approaches to international capital mobility in which all countries have access to the same technologies. The approaches in Section II assume technologies with only one production process, whereas the approaches discussed in Section III assume technologies with multiple production processes. Section IV reviews approaches that assume countries do not have access to the same technologies. The models that are reviewed in Sections II-IV assume technologies are convex and do not change over time. Technology specifications that take account of such non-convexities as externalities and economies of scale, and that consider changes in technology over time are reviewed in Section V. The discussion in this section draws on the new endogenous growth literature. Though relatively little attention has been paid in this literature to open-economy models with international capital mobility, it will be interesting to investigate the predictions some of the endogenous growth models would yield when international capital mobility is introduced. Finally, Section VI draws some conclusions.

II. A SINGLE TECHNOLOGY ACROSS ALL COUNTRIES

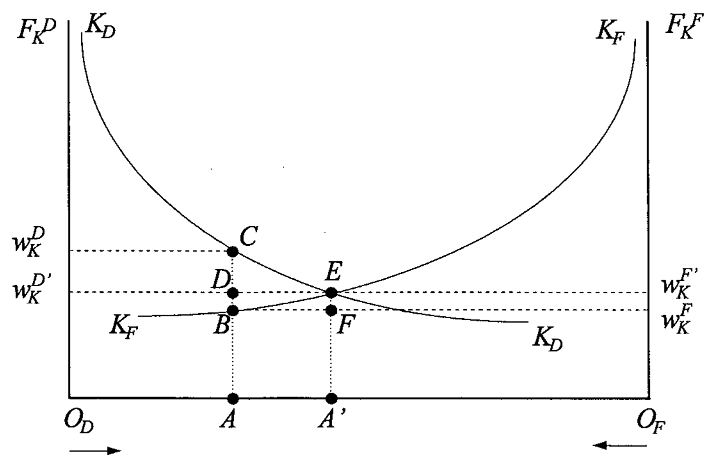
In the literature discussed in this section all countries are assumed to use the same technology. Countries only differ in their endowments of inputs. The discussion starts with the static approaches in which the endowments of the inputs are fixed.

A. Static models

The simplest and most stylized model of international capital movements is described in a paper by MacDougall (1960).[5] The technology in this model has two inputs, labor and capital, and one homogeneous output. The production function is homogeneous of degree one and exhibits positive and diminishing marginal returns to capital and labor. Let $F(K, L)$ denote a production function that satisfies these conditions, then constant returns to scale imply $F(K, L) = L \cdot F(K, 1) = L \cdot f(k)$, where $f(k)$ is the production function in *intensive form*. The neoclassical production function further

[5] See also Hobson (1914), Jasay (1960) and Kemp (1962).

Figure 1: The MacDougall model



satisfies the well-known Inada conditions:

$$\lim_{k \to 0} f_k = \infty,$$
$$\lim_{k \to \infty} f_k = 0,$$

where f_k is the first derivative of the production function with respect to capital. Figure 1 gives a graphical presentation of the MacDougall model. Along the left vertical axis the marginal product of capital in country D, F_K^D, is given, while along the right vertical axis the marginal product of capital in country F, F_K^F, is given. The horizontal axis represents the total stock of capital in the two-country world. Initially, $O_D A$ of capital is allocated in country D and $O_F A$ is allocated in country F. The $K_D K_D$-curve and the $K_F K_F$-curve are the marginal product curves of capital installed in, respectively, country D and country F. The marginal product of capital in country D at the initial allocation can be read from the $K_D K_D$-curve and equals w_K^D, which is equal to the distance AC. The marginal product of capital in country F equals w_K^F, which is equal to the distance AB. Total capital income in country D is w_K^D times the stock of capital that is owned by investors in country D, $O_D A$. Labor income in country D is then the area under the $K_D K_D$-curve up to point A minus capital income $AC \times O_D A$. In country F, capital income equals $AB \times O_F A$ and, similarly, labor income is the area under the $K_F K_F$-curve up to point A minus $AB \times O_F A$.

Under the initial allocation, the marginal product of capital in country F is below that in country D, because the capital-labor ratio in country D is less than that in country

F.[6] Investors from country F, therefore, move their capital to country D, where they can earn a higher return, until the marginal products of capital in both countries are equalized. This is the case when investors in country F move $A'A$ of their capital to country D. After this capital flow, the international equilibrium rate of return to capital is $w_K^{D\prime}$, and O_DA' of the world capital stock is allocated in country D, while O_FA' is allocated in country F. But, investors in country F still own O_FA of the world capital stock. Their return per unit of capital has increased, as they now earn $AD \times O_FA$. Hence, investors in country F gain $BD \times O_FA$. The total return to the stock of capital that is allocated abroad $A'E \times A'A$ is remitted to the owners of this capital stock in country F. For investors in country D the return per unit of capital has dropped and so has their total capital income. Their loss is $DC \times O_DA$.

Labor in country D gains $DC \times O_DA$ plus the area DCE. Labor in country F looses $FE \times O_FA'$ plus the area EFB. Although in both countries the welfare gains for capital owners and labor have opposite signs, the net welfare gain from the international relocation of capital is positive for both countries. The net gain to country D is equal to the area DCE in, while the net gain to country F is equal to the area BDE.

When all countries have access to the an identical technology incorporating a single production process that uses capital and labor as inputs, countries with the highest capital-labor ratios will be exporters of capital, while countries with the lowest capital-labor ratios will be the recipients of foreign capital. The international relocation of capital is welfare improving for both capital exporting and capital importing countries. This simplest version of the neoclassical approach to international capital movements does not fit the empirical observations on international capital movements between rich and poor countries, however. The latter receive far less foreign capital than the standard neoclassical model predicts on the basis of the differences in capital-labor ratios between rich and poor countries.[7]

B. Dynamic models

Many dynamic approaches to international capital flows build on the neoclassical one-sector growth model. The dynamic structure of these models does not change the predictions of the static one-sector neoclassical model, discussed above. But without some additional assumptions about technology or preferences, perfect international capital mobility leads to peculiar results if technologies are identical across all countries. To understand what is behind these results, it will be helpful to discuss the one-sector

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[6]The position of the K_DK_D- and K_FK_F-curves is determined by the size of the labour force and the intercept of the production function. Both are assumed to be the same in each of the countries in this example. For example, a smaller labour force in country D would shift the K_DK_D-curve downward, thereby reducing the initial difference in the marginal products of capital and the incentive for international capital movements.

[7]See also Lucas (1990) and Zebregs (1998a) on this.

neoclassical growth model in some detail.

The domestic economy is assumed to be small compared to the world economy and, furthermore, to consist of households and firms. Households supply firms with labor and capital. Labor is supplied inelastically to domestic firms, while capital can be supplied to domestic as well as foreign firms. The household, which is both an investor and a consumer, is assumed to have an infinite time horizon and maximizes the following objective function:

$$U_t = \int_t^{\infty} u(c(\tau)) \exp(-\rho(\tau - t))\, d\tau, \tag{1}$$

where $u(\cdot)$ is an instantaneous utility function, $c(\tau)$ is per capita consumption at time τ and ρ is the household's rate of time preference. The objective function is maximized under the following intertemporal budget constraint:

$$\int_t^{\infty} p(\tau)c(\tau) \exp(-[R(\tau) - R(t)])\, d\tau = \int_t^{\infty} w_L(\tau) \exp(-[R(\tau) - R(t)])\, d\tau + W_t, \tag{2}$$

where $p(\tau)$ is the price of the consumption good, $R(\tau) \equiv \int_0^{\tau} r(s)\, ds$ is the household's discount rate and $w_L(\tau)$ is the wage rate at time τ. W_t represents the household's initial stock of wealth at time t. The intertemporal budget constraint in (2) says the household cannot consume more than its lifetime wage earnings plus the initial stock of wealth, which therefore rules out Ponzi schemes.

Without loss of generality $p(\tau)$ can be normalized to 1 for all τ. The first-order condition of the household's maximization problem is then given by:

$$u'(\cdot) \exp(-\rho(\tau - t)) = \mu(t) \exp(-[R(\tau) - R(t)]), \tag{3}$$

where $\mu(t)$ is Lagrange multiplier on the budget constraint. Differentiating both sides of (3) with respect to time and rearranging terms yields the following well-known consumption Euler equation:

$$\dot{c}(t) = \frac{1}{\theta}[r(t) - \rho]c(t), \tag{4}$$

where $\dot{c}(t) \equiv dc(t)/dt$, $r(t)$ is the real interest rate, at which the household can freely lend or borrow, and θ is the intertemporal elasticity of substitution.

Firms operate in markets that are characterized by perfect competition and zero profits. Labor is hired by firms up to the point where the marginal product of labor equals the wage rate, w_L. Firms borrow from households to finance the purchase of capital goods. They will do this until the interest rate on their debt, $r(t)$, equals the net return on a capital good, which is the capital good's marginal product $f_k(\cdot)$ minus the depreciation rate, δ. Hence, $r(t) = f_k(k(t) + z(t)) - \delta$, where $z(t)$ is the amount of foreign capital that is invested in the domestic economy. If $z(t)$ is positive, capital is imported from abroad; capital is exported when $z(t)$ is negative. Foreign investors will relocate capital to the domestic economy until the rate of return abroad equals the rate of return in the domestic economy. Hence $f_k(k(t) + z(t)) = r_F(t) + \delta$, with r_F being the foreign interest rate on debt.[8]

Because both consumption goods and capital goods are produced with the same technology, it holds that:

$$\dot{k} + \dot{z} = f(k(t) + z(t)) - r_F z(t) - c(t) - \delta k(t). \tag{5}$$

The steady-state equilibrium of the domestic economy is found by solving equations (4) and (5) for $\dot{c} = 0$ and $\dot{k} = \dot{z} = 0$, but such a long-run equilibrium may not always be feasible. Since the domestic economy is small compared to the foreign economy, it takes r_F as given, which implies that an internationally stable steady-state equilibrium requires that $\rho = r_F$. The fact that the domestic economy is small also implies that the supply of foreign capital is perfectly elastic. Thus, if k' is the amount of capital that sets r equal to r_F and k_0 is the initial capital stock, the amount of foreign investment that immediately flows into the domestic economy under free capital mobility is equal to $k' - k_0$. The domestic economy, therefore, immediately jumps to its steady state without a transition period, and the amount of foreign capital in the steady state is entirely determined by the initial domestic capital stock, k_0.[9]

If the domestic economy is less patient than the foreign economy ($\rho > r_F$), domestic consumption will eventually become zero and all capital in the domestic economy will be owned by foreigners. Domestic firms will rent capital goods from foreign investors, because domestic investors require a higher interest rate. Domestic households are only willing to accumulate wealth if the interest rate is higher than or equal to ρ. Hence, when the interest rate falls below ρ domestic households will consume more than their income, and borrow abroad to finance their consumption after they have consumed their initial wealth. Ultimately, domestic output is produced with only foreign capital, and all labor income is transferred to abroad to pay for the interest on foreign debt.

If on the other hand, the domestic economy is more patient than the foreign economy ($\rho < r_F$), per capita consumption in the domestic economy steadily rises. Domestic households will keep lending to abroad, while their wealth continues to accumulate. In the long-run, domestic households will own all the wealth in the domestic

[8] This is equivalent to a situation where domestic investors borrow abroad to finance the purchase of capital goods.

[9] These conclusions do not depend on the small country assumption. See, for example, Lipton and Sachs (1983) who have developed a two-country version of this model.

and foreign economies, which means that the small country assumption cannot be sustained. At some point the domestic interest rate must become the world interest rate, for otherwise the domestic economy would accumulate more than all the wealth in the world.

The results described above are not very meaningful and they do not reflect empirical observations.[10] One way out of the stringent conditions for a stable long-run equilibrium, is to assume that households have a variable rate of time preference. To obtain more realistic results the rate of time preference should decrease as consumption tends to zero—that is, households should become less impatient as they become poorer. This appears to be counterintuitive, however. Models that proceed along this line build on Uzawa (1968) and have been developed by Obstfeld (1982) and Engel and Kletzer (1986a), (1986b), among others. Another possibility is to assume a finite horizon, as in overlapping generations models (Blanchard 1985; Matsuyama 1987). These modifications resolve the problematic result that all but the most patient country will have zero consumption in the long-run if countries differ in their rates of time preference. They do not resolve the problem that small, capital-scarce countries converge to their long-run steady state at infinite speed.

Assuming installation costs for investment in the above model of optimal savings introduces a transition period, so that the economy does not immediately jump to its steady state under free capital mobility (Blanchard 1983; Matsuyama 1987). Barro et al. (1995) introduce human capital in the production function and further assume that human capital cannot be used as a collateral for international loans. Human capital must, therefore, be entirely financed by domestic savings. Under this specification and perfect mobility of physical capital, the speed of convergence is not infinite and, moreover, in line with empirical observations on cross-country convergence rates of output per worker.

Finally, an important feature of the technology in the neoclassical growth model is that the elasticity of substitution between capital and labor is larger than minus infinity. It is, therefore, possible to increase output if only one of the inputs is increased and the other is not zero. Because of this, both labor and capital are fully employed at any point in time. Under a Leontief technology, however, the incremental capital output ratio is fixed and there is only one growth rate that sustains full employment of capital and labor. Such a growth model has been proposed by Domar (1946) and has been the basis for the so called two-gap models (Chenery and Strout 1966). According to these models, the absence of foreign exchange and sufficient domestic capital are bottlenecks to economic development. The two-gap models, however, do not predict or explain international capital movements.

[10]See, for example, King and Rebelo (1993).

III. Technologies with Multiple Production Processes

This section investigates international capital movements under technologies that incorporate more than one production process. As in the previous section, it is assumed that all countries have access to the same technologies. This assumption does not imply, as will be shown, that every production process will be employed in each country.

A. Static models

In the standard $2 \times 2 \times 2$ HOS model, there are two countries, two factors of production (capital and labor), and two commodities that are produced with different production processes. The production functions that represent both production techniques are assumed to be homogeneous of degree one, and increasing and concave in both capital and labor. The production processes are distinguished by the intensity with which they use different factors of production. One of them is more intensive in capital, whereas the other is more intensive in labor. The only difference between the two countries in the HOS model is in the relative endowments of the factors of production.[11] The difference in relative endowments leads to different factor prices and, hence, different commodity prices in both countries under autarky. Free trade equalizes commodity prices and, because both countries employ the same technologies, also leads to factor price equalization.[12]

If free trade equalizes rates of return between countries, it eliminates international factor movements, in which case the capital-scarce country imports capital by importing the commodity that is produced with the capital intensive technology. This result depends on several non-trivial assumptions. First of all, distortions such as tariffs should be absent, because even the smallest tariff will result in a difference in factor prices and trigger capital flows until one of the countries has become specialized in the labor intensive commodity and the other in the capital intensive commodity (Mundell 1957).[13]

The conclusions from the HOS model also depend on the number of commodities relative to the number of factors or inputs. When there are more factors than commodities, factor price equalization is, in principle, not possible. This is, for example, the case in the one-sector models that were discussed in Section II. If, on the other hand, the number of commodities is larger than or equal to the number of inputs, factor price equalization is possible.[14]

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[11] Preferences are also assumed to be identical in both countries.

[12] Whether factor price equalization is feasible depends on the initial distribution of relative endowments between the two countries. This is discussed by Dixit and Norman (1980) in a more general context.

[13] It is of course also possible that labor is mobile, but as the interest here is in capital movements only the case of capital mobility is considered. For a thorough treatment on the welfare effects of capital movements in the presence of tariffs see Markusen and Melvin (1979).

[14] See Chapter 4 of Dixit and Norman (1980).

Other important assumptions of the HOS model, without which trade and factor mobility are not perfect substitutes, have been investigated by Markusen (1983) and Wong (1995), among others. Besides the absence of distortions like tariffs, as discussed above, the HOS model assumes identical technologies in all countries, production characterized by constant returns to scale, perfect competition in commodity and factor markets, and identical homothetic demand in all countries. Except for the last one, the implications of these assumptions for international capital flows will be discussed in subsequent sections. If one or more of the assumptions are relaxed, factor price equalization cannot occur through trade alone and, hence, there exists an incentive to move factors—in this case capital—across borders.[15] Countries that export the capital intensive commodity will import capital until the rate of return on capital is equalized across all countries.

Section II has investigated models with a single production process and two inputs. In such a set-up, factor price equalization does not occur, in principle, and hence capital has to move across borders to equalize rates of return. When commodities are produced with different technologies, factor price equalization is possible when the number of commodities is larger than or equal to the number of factors, in which case the incentive for international capital movements is eliminated. The possibility of factor price equalization further depends on a set of assumptions that will be relaxed in the sections that follow. The welfare implications of international capital flows depend on which of the assumptions is relaxed.

B. Dynamic models

One way to model international capital flows in a two-sector model with capital accumulation is to assume that one of the sectors produces consumption goods, while the other sector produces investment goods.[16] Capital is accumulated through the purchase of investment goods that are produced at home or abroad. The country that at a given point in time is relatively most capital abundant exports investment goods, but this is not the same as an international capital flow. The latter generates claims on the income of the capital importing country. Such claims are not generated when a country buys investment goods abroad. Further, the maximum amount of investment goods that can be imported is limited by current income, while international capital flows are limited by current and future income of the capital importing country. In this class of models, trade in consumption and investment goods, and international capital movements are substitutes so long as factor prices are equalized through trade.

[15]It is also possible that all the above assumptions of the HOS model hold, but that the initial endowment structure is such that specialization occurs. In that case free trade does not lead to factor price equalization, either.

[16]See, for example, Oniki and Uzawa (1965), and Smith (1977), who constructed models with fixed savings rates, and Stiglitz (1970), for a model with optimal savings.

One of the first dynamic two-sector models of an open economy with international capital flows was developed by Fischer and Frenkel (1972). They added a separate investment-demand function to the above dynamic two-sector models. Savings—a fixed share of national income—are equal to the demand for investment goods plus the net demand for international assets. Investment demand depends on the present size of the capital stock and the given rental rate.[17] In a relatively capital scarce country savings may fall short of investment demand, so that international assets have to be exported to finance the purchase of investment goods. As the economy grows, investment demand will drop and eventually become smaller than savings. From then on, the economy will buy international assets and gradually become a net creditor country. Because savings are always less than total national income there is no risk that economies will borrow in excess of the net present value of their future income and the current stock of wealth. The Fischer and Frenkel (1972) model has been influential in studying the stages of the balance of payments, though a short coming may be the reliance on a fixed savings rate. On the other hand, introducing optimal savings behavior would greatly complicate the model.

There are not many papers that investigate two-sector models of open economies with optimal savings and international capital mobility. The first to extend the two-sector optimal growth model to analyze international capital flows was Bazdarich (1978), who assumed that both sectors produce tradeable commodities. Others who have studied these types of models have in most cases assumed one of the two sectors produces a non-tradeable. Murphy (1986) presents an example of such a model with overlapping generations. Obstfeld (1989) has constructed a similar model with an infinitely-lived household. Engel and Kletzer (1989) investigate a model with non-tradeables and a variable rate of time preference. Finally, Brock (1988) proposes a model in which installation costs of investment are non-tradable.

IV. DIFFERENT TECHNOLOGIES ACROSS COUNTRIES

In the previous sections it was assumed that countries had equal access to the same technologies. This section reviews part of a literature that relaxes this assumption. When countries use different technologies, factor price equalization through trade is generally not possible and, as discussed above, this gives rise to factor movements. Kemp (1966) and Jones (1967) developed models with international differences in factor intensities in sectors that produce the same commodity.[18] Their models have two countries that both have an agricultural and a manufacturing sector. Production techniques in the agricultural sectors are identical, but the production process in the manufacturing sector in the advanced country is more capital-intensive than that in the less advanced country.

[17] The country is assumed to be small and is therefore a price taker.

[18] Markusen (1983) also investigates differences in production technologies between countries, but instead of factor intensities, he focusses on differences in the intercepts of the production functions. His results, though, correspond with those discussed in this section.

Assume, initially both countries have the same capital-labor ratios, and labor and capital are immobile. Further, assume that commodity prices are equalized through trade and let the advanced country be the exporter of manufactures and the less advanced country be the exporter of agricultural products. Because both countries have the same capital-labor ratios and the production process in the manufacturing sector in the advanced country is most capital-intensive, the rental rate on capital in this country is higher, at given commodity prices, than in the less advanced country. Hence, if capital becomes mobile it will flow from the less advanced to the advanced country. This flow increases the relative abundance of capital in the advanced country, so that its comparative advantage in the production of the capital intensive commodity is enlarged, thus resulting in more trade. Capital mobility and trade are complements in this case. If the advanced country had initially been the exporter of agricultural products, capital mobility would have reduced the comparative advantage of this country and capital flows would have reduced trade.

The Kemp-Jones model has helped to explain the enormous increase in international trade as well as capital flows between the industrial countries in the post-World War II era. When applied to trade and capital flows between industrial and developing countries, the model either predicts capital flows from developing to industrial countries and a growing volume of international trade, or capital flows in the other direction with developing countries specializing in agriculture and/or industrial countries specializing in manufacturing. The second case prevails when the relative factor endowments in two groups of countries are outside the diversification cone, rendering commodity price equalization through trade impossible. Both these cases do not accurately describe the actual patterns of trade and capital flows between most developing and industrial countries. Clearly, capital is not flowing from poor to rich countries as the first case would suggest.[19] The second case may hold for some developing countries that are indeed specialized in agricultural production, and which trade their output for manufactured commodities from industrial countries. It, however, does not appear to provide a satisfactory description of the trade pattern between the Asian Tiger economies and industrial countries, between which there is much intra-industry trade in manufactures. This trade pattern cannot be explained with the help of the HOS or Kemp-Jones models; it requires different assumptions about market structure and production technology.

[19] Although there has been a net resource transfer from several severely indebted developing countries to industrial creditor countries since the second half of the 1980s, this does not reflect a relocation of capital in response to productivity differences. It is rather the aftermath of a period in which many developing countries borrowed extensively and that was ended abruptly by the debt crisis in the 1980s.

Dynamic models

Examples of dynamic models with different technologies across countries have been developed by Onitsuka (1974) and Ruffin (1979), among others. They have extended the Solow growth model with international capital movements.[20] Onitsuka (1974) did the exercise for a small economy, while Ruffin (1979) investigated the two country case.

In the one-sector Solow growth model with two large countries, as developed by Ruffin (1979), short-run capital movements and welfare gains are determined by the contemporaneous rates of return to capital, which are a function of the capital-labor ratios and the technologies in both countries. As in the MacDougall model, both countries gain in the short-run. In the long-run, capital flows are determined by the steady-state rates of return to capital, which are a function of technologies, savings and depreciation rates, and population growth. Because the two countries would have different rates of return to capital in a steady state without capital mobility, they also benefit in the long-run from capital mobility.[21] Hence, free capital mobility is unambiguously welfare improving for both debtor and creditor countries.[22]

Apart from technologies and initial capital-labor ratios, the countries in Ruffin's model are completely symmetric. Some authors, therefore, felt that the model was not suited to investigate the welfare implications of capital flows from the capital-rich, industrial countries (the North) to the capital-scarce, developing countries (the South). Quibria (1986) has amended Ruffin's approach by assuming that savings behavior in the South differs from that in the North. As before, agents in the North save a fixed share of per capita income, but agents in the South only save out of capital income, and consume all labor income. This Kaleckian approach to the South's savings behavior overturns Ruffin's results. The import of capital in the South has two effects on income: it reduces the rate of return to capital and has, therefore, a negative effect on capital income; but, it raises labor income. The income shift from capital owners to labor leads to a reduction in savings and hence a lower long-run capital-labor ratio. From a marginal increase in per capita income in the South, resulting from the import of capital, a smaller part is saved than the average savings rate in the South and it is this decline in the average savings rate that makes the welfare effects of international capital movements between North and South ambiguous. The assumed asymmetry in savings behavior may be valid for the short-run, but why would labor in the South continue to consume its entire income even

[20]See also Hamada (1966) and Negishi (1965).

[21]If both countries would have the same technology, they would also have the same steady-state capital-labor ratios in the absence of capital mobility, provided savings rates, depreciation rates, and population growth are also the same. In that case, there are no international capital flows in the long-run open-economy steady state, as the long-run rates of return to capital are the same in both countries.

[22]The positive welfare gains do not necessarily apply to each of the groups of capital owners and labor in both countries. For example, capital owners in the debtor country might loose, but as in the static MacDougall model, their loss is offset by the gain of labor in the same country.

after it has risen beyond a subsistence level? Quibria's long-run results therefore do not appear to be robust when savings out of labor income are allowed to become positive in the future.

Burgstaller and Saavedra-Rivano (1984) investigate an additional asymmetry between North and South. In their model the North is characterized by full employment; the South, on the other hand, is characterized by an infinitely elastic supply of labor at a subsistence wage level à la Lewis (1954). Moving from capital immobility to free capital mobility is in this case even more detrimental to the South's welfare, as the positive effect on the wage rate is now absent.

The models that have been discussed in this section assume that countries do not have access to the same set of technologies. This is an important assumption, because international technology differences are a reason for international capital movements. A shortcoming, perhaps, is that the differences in technology were assumed to be fixed. The next section discusses a range of models in which technologies are endogenous.

V. International Technology Transfers

Until now, technologies were assumed to be fixed, as each country was endowed with a given set of production techniques. This section relaxes that assumption and investigates capital movements under international diffusion of technologies. In addition, most of the models reviewed below also focus on the creation of new technologies.

Technological knowledge can be accumulated in several ways, such as through learning by doing (Arrow 1962; Sheshinski 1967; Romer 1986), scientific research (Shell 1967), or R&D (Romer 1990; Grossman and Helpman 1991; Aghion and Howitt 1992). For the accumulation of knowledge it matters whether knowledge is considered to be a pure public good or an excludable, but non-rival good. In the first case, there are no firms that want to engage in R&D, because the knowledge that it will create immediately flows into the public domain. Hence, knowledge creation only occurs as the accidental by-product of investment decisions of firms or as the output of research by public sectors as investigated by Shell (1967). If, on the other hand, knowledge can be made excludable, for instance by means of a patent, firms have an incentive to do research, and develop new products or production techniques that give them an advantage over their competitors. Once a blueprint for a new product or production process has been developed it does not, unlike rival inputs such as capital and labor, have to be reproduced if the firm wants to increase its output. Because a firm can double its output without doubling its cost, after it has invested in a blueprint, there exist increasing returns to scale that are internal to the firm. Under such a cost structure profits need to be positive, as firms have to recover their investment in blueprints. In order to make positive profits, firms need to have some monopoly power, which is not the case under perfect competition. Several market structures allow for profit making firms, but one that has proven to be very useful and tractable is monopolistic competition.[23]

The next section reviews international capital movements in models that take knowledge as a pure public good. The section thereafter considers international capital movements in models where knowledge is an excludable, but non-rival good.

A. Knowledge as a pure public good

Models with knowledge as a pure public good have been developed by Arrow (1962), Sheshinski (1967), and Romer (1986). In these models, private investment has positive spillovers to the public stock of knowledge in a country. This section investigates the implications of foreign investment that introduces foreign knowledge that is not yet available in the domestic economy. Knowledge accumulation is considered as an accidental by-product of private investment by domestic and foreign firms, which operate in a market that is characterized by perfect competition. Firms, indexed i, work with the following production function in intensive form

$$q_i(t) = A[X(t)]^{\alpha_1}[k_i(t) + z_i(t)]^{\alpha_2}, \quad 0 < \alpha_1 < 1,\ 0 < \alpha_2 < 1, \tag{6}$$

with

$$X(t) = \sum_i K_i(t) + \widetilde{Z}_i(t), \text{ and } \widetilde{Z}_i(t) = \max_{0 \le \tau \le t} \{Z_i(\tau), 0\},$$

where q_i is the output per worker of firm i, and k_i and z_i are, respectively, domestic and foreign capital per worker in firm i. The parameter A captures country specific characteristics, such as government policies, services from public investment, maintenance of property rights, and climate. The stock of knowledge $X(t)$ is identical to all firms in the same country and a function of the total stock of domestic and foreign capital in the economy, respectively K_i and $\tilde{Z}_i$. It is assumed that the economy is below its long-run steady state, so that the total stock of capital (the sum of the domestic and foreign capital stocks) is not decreasing. Furthermore, it is assumed that the domestic stock of knowledge does not decrease when the stock of foreign capital in the domestic economy decreases. Foreign knowledge will always remain available once it has been introduced. The production function in (6) assumes that when new foreign knowledge is introduced in the capital-importing economy it immediately spills over to all other firms in this economy. Likewise, the stock of knowledge of the country that exports capital is not affected by the capital outflow, for knowledge is a non-rival good.

[23]See Spence (1976) and Dixit and Stiglitz (1977) for the original papers on monopolistic competition, and Helpman and Krugman (1985) for applications to trade theory and other market structures in which firms have (some) monopoly power.

The *private* rate of return to capital, which is the relevant rate to private investors, is given by[24]

$$w_K = \alpha_2 A X^{\alpha_1} (k_i + z_i)^{\alpha_2 - 1}. \tag{7}$$

The right-hand side of equation (7) is the partial derivative of equation (6) with respect to k_i.[25] In this case, capital inflows have two effects on the private rate of return to capital in the host economy: they lower the private marginal product of capital; and they increase the stock of technical knowledge in the host economy. The increase in the host economy's stock of knowledge is reflected in an outward shift of the private marginal product curve. This outward shift causes additional capital inflows and further increases in the host economy's stock of knowledge. Whether this process will ever stop depends on the sum of α_1 and α_2. When $\alpha_1 + \alpha_2 < 1$, positive stocks of capital will be allocated in the host economy and abroad. When on the other hand $\alpha_1 + \alpha_2 \geq 1$, all capital will be allocated in the economy with the highest marginal product of capital.

For a given differential between the private marginal rates of return to capital, capital flows to the host economy are, due to the positive externality, larger than those that would prevail in the simple MacDougall model. Because knowledge is a non-rival good, the positive externality in the host economy is not offset by negative externalities in capital exporting economies. In the models developed by Arrow (1962) and Sheshinski (1967), $\alpha_1 + \alpha_2 < 1$. When free international capital mobility is introduced in these models, all countries will maintain a positive GDP in equilibrium, and the world capital stock will be allocated to more than one country. In the endogenous growth model developed by Romer (1986), $\alpha_1 + \alpha_2 = 1$ in which case the *social* rate of return to capital is linear—and hence non-decreasing—in k and z.[26] Assuming that α_1 and α_2 are the same for all countries, the introduction of free capital mobility in this case leads to the extreme result that all capital flows to the country where A is highest, or when all countries have the same A, there will be no capital flows.

Romer (1986) and Lucas (1988) have revived the interest of economists and policy makers in the determinants of economic growth and have triggered a large number of publications that try to explain prolonged differences in the growth rates of per capita income between countries. The simplest model of endogenous growth, as described in a paper by Rebelo (1991), is the linear growth model, also known as the Ak-model. In this model capital is broadly defined, which means it captures both human and physical capital. The private and social rates of return to capital are both equal to A.

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[24]Time arguments are henceforth omitted for ease of notation.

[25]Note, that because domestic and foreign capital are perfect substitutes, the derivatives with respect to k_i and z_i are identical.

[26]The social rate of return to capital is the sum of the private rate of return to capital and the increase in the public knowledge stock resulting from a marginal increase in the capital stock. Technically, it is the *total derivative* of the production function $F(X, K, Z, L)$ with respect to K (or Z).

The Ak-model is not very well suited to describe international capital movements. In an economy with a representative household that maximizes lifetime utility (1) under the intertemporal budget constraint (2), the following consumption Euler equation would prevail

$$\dot{c}(t) = \frac{1}{\theta}[A - \rho]c(t).$$

Assuming $A > \rho$, per capita consumption grows at a constant rate $\gamma = \theta^{-1}[A - \rho]$ in the balanced-growth equilibrium.[27] This model has no transition dynamics and immediately jumps to its long-run balanced-growth path.

The parameter A affects the productivity of capital and so long as economies are closed, differences in A can explain prolonged differences in per capita income growth between countries.[28] However, if economies are open and capital can flow freely between countries, the country with the highest A will ultimately be the host to all of the world's capital; it will be the only country with a GDP larger than zero. While GDP in countries with a lower A will be equal to zero, their GNPs will be positive as these countries live from the return on their foreign investments.[29]

The unrealistic long-run predictions of the open-economy Ak-model are also reflected in the predictions of the direction and size of capital flows between industrial and developing countries. The slope parameter A, which represents total factor productivity in the Ak-model, is likely to be lower in developing than in industrial countries. This suggests that while developing countries are capital scarce compared to industrial countries, capital in the Ak-model will flow from the former to the latter.

Rebelo (1992) reviews open economy versions of a number of endogenous growth models and proposes a modification of preferences in which utility is only derived from consumption above a given subsistence level. With this modification, the elasticity of intertemporal substitution is lower in poor countries than in rich countries. Therefore, at a given interest rate, poor countries have lower savings rates than rich countries. Rebelo (1992) starts his analysis from a situation in which the productivity parameter A is lower in poor, capital-scarce countries than in rich countries. In such a setting, opening up to free capital mobility offers investors in capital-scarce countries better investment opportunities abroad. However, free capital mobility does not raise the level of the savings rate in these capital-scarce countries to that in rich countries, because the elasticity of

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[27]See, for example, Barro and Sala-i-Martin (1995, Ch.4) for a derivation of the balanced-growth path of the Ak-model.

[28]In the Solow growth model and in the optimal savings model, government policies have no effect on per capita income growth in the long-run steady state. In most endogenous growth models, however, government policies matter for per capita income growth in the balanced-growth equilibrium. See, for example, Rebelo (1991) and Jones and Manuelli (1990).

[29]This assumes identical rates of time preference across countries.

intertemporal substitution is still the lowest in the poor, capital-scarce countries. A key difference with the Ak-model is that the growth rate of per capita income in the poor economies will not immediately jump to that of the rest of the world, yielding slow convergence which is more in line with empirical observations (Barro et al. 1995).

Finally, Razin and Yuen (1995) provide empirical evidence that in absence of capital mobility there is divergence in growth rates of per capita income, which is in line with the predictions of endogenous growth models of closed economies. However, if capital mobility is introduced, the predictions of the endogenous growth models that were described in this section do not correspond with empirical observations.[30]

B. Knowledge as a non-rival good

In the previous section, a firm that had accumulated knowledge through investment could not prevent other firms from using this knowledge. In that case, firms do not actively invest in the accumulation of knowledge; it is merely a by-product of investment. While learning-by-doing may capture part of the actual accumulation of knowledge, firms do actively invest in the development of new or improved products and production processes. Romer (1987, 1990) was the first to develop a model in which technological change was driven by the intentional search for new knowledge by firms.[31] Two classes of models have subsequently been developed and further explored. The first considers expanding product variety in either consumer goods (Grossman and Helpman 1991) or intermediates (Romer 1987; Romer 1990). The second class of models considers improvements in the quality of products (Aghion and Howitt 1992; Grossman and Helpman 1991). This section looks at the implications of international capital mobility in the first class of models.

In models of horizontal product differentiation in intermediates, some variant of the following production function, that was originated by Ethier (1982), is mostly used:[32]

$$Q = AL^{\xi} \sum_{h=1}^{H} (M_h)^{\xi}, \qquad 0 < \xi < 1, \tag{8}$$

where Q is aggregate output, L is labor, and M_h is the employment of intermediate h used in the production of the final good. The total number of intermediates that are used in the production of final goods is H. The productivity of the final goods sector rises as the number of intermediates increases. This captures Adam Smith's notion of the increase in

[30] An interesting exception is provided by Buiter and Kletzer (1993) who construct an overlapping generations model in which the equilibrium growth rates can differ between countries, even if interest rates are equalized through international capital movements.

[31] Shell (1967) presented a model with a separate research sector, but this was a public sector that did not have to make a profit.

[32] Romer (1990) includes human capital instead of labour in this production function.

the division labor: when a production process can be divided into a larger number of subprocesses it becomes easier to assign laborers to particular subprocesses in which they are comparatively efficient.

The market structure in the final goods sector is characterized by perfect competition, while the intermediate sector is characterized by monopolistic competition. The final good is the numeraire and it can be either consumed or used to produce one unit of a particular intermediate. Each type of intermediate is produced by a different firm and, hence, there are H intermediate producers. Before an intermediate producer can start operating she has to incur a set-up cost, ϕ,which is determined by the amount of resources that have to be devoted to developing a new intermediate.[33] The intermediate producer can only recover this sunk cost if she is able to set the price of the intermediate above the marginal cost of producing the intermediate. The profits of intermediate firms depend on the size of the market—which in this model is the volume of demand for intermediates by the final goods sector—and firms will enter the intermediate sector until the set-up cost that each firm has to incur equals the discounted value of the future stream of profits. Any firm that would enter the intermediate sector after the maximum sustainable number of firms has entered will not be able to recover its set-up costs. The model is completed with the same representative household as before. Household savings are equal to investment in the development of new intermediates, $\phi\dot{H}$, and the total return on these investments are the profits made by intermediate producers. Profits are maximized by setting the price of intermediates at a fixed margin above the cost of producing an intermediate and since this cost is fixed, profits are constant through out.[34]

It can be shown that in the model described above, the rate of return to investment is constant, rendering its dynamic behavior similar to that of the Ak-model.[35] Also the introduction of international capital mobility yields results similar to those of the open-economy Ak-model: international differences in the rate of return to investment can explain differences in per capita income growth so long as capital is immobile, but when this restriction is lifted growth rates rapidly converge and all capital in the world is invested in the country where the constant rate of return is highest. Capital flows do not generate the same spillovers to the stock of knowledge as in the model with learning-by-doing. When in the present model a country opens up to trade and international capita flows it will benefit from the foreign intermediates that were not

[33]For the model to yield endogenous growth this set-up cost should either be constant or when it depends on the return to labour or human capital, it should be falling as more intermediates are invented. In the second case, which is proposed by Romer (1990), there is an additional externality as the invention of new goods reduces the cost of inventing new intermediates in the future. Today's researchers are standing on the shoulders of their predecessors.

[34]It is assumed to take one unit of the final good, the numeraire, to produce an intermediate.

[35]See, for example, Chapter 6 of Barro and Sala-i-Martin (1995) who work out the algebra of two endogenous growth models with expanding product variety: one with fixed R&D costs; and one with declining R&D costs (Romer 1990). The rate of return to investment is constant, because both the cost of inventing new intermediates and the return on these inventions are constant.

available under autarky. This welfare gain is only a one time level effect—there is a discrete jump in H—but it does not lead to higher long-run growth. The growth rate may increase if the rate of return to investment is higher abroad than in the domestic economy. In that case, the domestic economy stops doing its own R&D research, because other countries have more efficient R&D sectors. The domestic economy would then have access to the new intermediates by importing them.

In the production function (8) the only inputs are intermediates and labor; there is no durable input such as capital. If durable capital is introduced, however, the rate of return to investment is no longer fixed, yielding transitional dynamics toward a balanced-growth path.[36] In case of free capital mobility, a small economy, to which the world rate of return to capital is given, will immediately jump to the long-run growth path that prevails in the rest of the world. Capital-scarce countries that do not have the most efficient R&D sectors will not invest in the development of new products, but they may still receive foreign capital to produce existing intermediates. Again, when the rate of time preference is the same across countries, to each country a positive stock of capital will be allocated. If on the other hand, the rates of time preference differ, the same difficulties arise as in the case of the open-economy Ramsey model (see Section II.B).

Although much of the endogenous growth literature assigns an important role to the accumulation of knowledge and the potential international spillovers of knowledge, it remains somewhat vague as to how knowledge is actually transferred between countries. The usual assumption is that when two countries interact with each other—for example, through trade or foreign direct investment (FDI)—they will also be able to use all knowledge that has been accumulated in both countries. This is not a very precise description of the actual transfer of knowledge. For instance, a technologically less advanced country may not be able to make use of the latest technological developments in advanced countries. Besides that, a country may not immediately have access to all knowledge that has been accumulated by its trading partner. It is very likely that foreign knowledge becomes gradually available over a period of time.

Vernon (1966) and Findlay (1978) have studied the adoption and transfer of technology through international capital movements.[37] Findlay (1978) postulates that the rate of technological progress in the host economy is increased by FDI through a "contagion" or demonstration effect. The presence of advanced foreign technologies has a positive spillover effect on the productivity of firms in the host economy. However, to be

[36]Rivera-Batiz and Romer (1991) interpret the intermediates as capital goods, but they also assume a rate of depreciation of 100 percent, so that the capital goods are still not durable.

[37]Other papers that investigate the transfer of technology are Krugman (1979), and Flam and Helpman (1987), whose concern is the effect of technological diffusion on the pattern of trade and income distribution. Grossman and Helpman (1991; Chs.11,12), and Barro and Sala-i-Martin (1997) endogenize the rate of innovation and imitation. None of these papers, however, describes the channel through which the technology transfer takes place and they do not explicitly model international capital movements.

able to adopt the advanced foreign technologies and management practises the host economy should have a minimum level of technological development. Thus, foreign investment closes the technology gap between an advanced and a less advanced economy if the initial gap is not too large.[38] Findlay shows that in the steady state of his model the rate of technological progress is the same in both countries, while the technology gap and the ratio of foreign to domestic capital remain constant.[39] Countries may benefit from technology spillovers through foreign investment, but they are not necessarily using identical technologies in the long-run.

VI. Concluding Remarks

This paper has demonstrated that the specification of technology is of great relevance to the prediction of the size and direction of long-term international capital movements. In the simplest specification with only one technology for all countries, capital moves to the country with the lowest capital-labor ratio. This is the simplest version of the standard neoclassical approach to international capital movements and it overestimates the capital flows from rich to poor countries. However, when more sectors are added that use different production processes, capital movements may not exist when the initial distribution of endowments between countries is such that free trade leads to factor price equalization. Hence, approaches that assume all countries have access to the same technology do not, in general, generate accurate predictions of international capital movements, unless capital market imperfections are added.[40]

When technologies differ across countries, trade and factor movements tend to become complements rather than substitutes. Hence, differences in technology are a source of international capital movements. Therefore, in order to understand international capital movements, approaches that assume unequal access to technologies between countries seem a more natural starting point. Kemp (1966) and Jones (1967) were the first to address this issue explicitly. However, their approach was static and, thus, implicitly assumed technology differences between countries were permanent. This assumption may be too strict, as several Asian economies have substantially narrowed their technology gap with industrial countries over the past 45 years. The recent literature on endogenous growth explores international differences in technologies, and the transfer of technologies,

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[38]Nelson and Phelps (1966), Benhabib and Spiegel (1994), and Borensztein, De Gregorio, and Lee (1998) show that the stock of human capital in the host economy limits the ability to absorb new foreign technologies.

[39]Wang (1990) extends Findlay's model to a two country general equilibrium setting and investigates the welfare implications of foreign investment in the less advanced country. Both Wang and Findlay assume a fixed savings rate and exogenous technological change. Zebregs (1998b, Ch.4) builds on Findlay's model in an endogenous growth setting and investigates international capital movements in the presence of endogenous technology gaps between countries.

[40]See, for example, Barro, Mankiw, and Sala-i-Martin (1995) who introduce a capital market imperfection by assuming that human capital can be used as colateral for domestic loans, but not for international loans.

but has not paid much attention to international capital movements. This review has explored the implications for international capital movements of two types of endogenous growth models. In models of the first type, often referred to as Ak-models, knowledge is a pure public good and they imply large capital flows to the country with the most advanced technology. In these models the bias in the predictions of capital movements is in the other direction, as Ak-models imply that capital moves from poor to rich countries. In the second type of endogenous growth model that was investigated, knowledge is non-rival, but excludable. The dynamics in these models are, in principle, the same as in the Ak-models if capital is not included in the production function, or if the rate of depreciation is 100 percent. Relaxing these assumptions on capital introduces transitional dynamics similar to those in the open-economy Ramsey model discussed in Section II.B. It, thus, seems that although endogenous growth models address differences in technologies across countries and over time, they are not always better in giving more accurate predictions regarding international capital flows than the standard neoclassical growth model.[41]

In the endogenous growth literature much attention has been devoted to trade and international knowledge spillovers and this has resulted in many new insights in the dynamics of international trade. So far, international capital movements have not received the same attention in this literature. Yet, this seems to be a fruitful area for future research. It would be interesting to have a better understanding of how long-term capital movements are affected by differences in technologies, and of the effect of these movements on technology gaps between countries.

[41] It must be said that most of the endogenous growth models reviewed in this paper were not designed to address international capital movements, but introducing international capital mobility is illustrative for understanding how the specification of technology in these models affects international capital movements.

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