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Economic growth, leadership and capital flows: the leapfrogging effect

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Abstract

The leapfrogging effect has been analysed in a model without capital. However, history has shown numerous cases in which countries lost economic leadership at the same time as they were exporting capital. This work focuses on the interaction between international capital flows, economic growth and the transmission of leadership. We show that capital mobility is at the heart of the adoption of new technologies. Malfunctioning international capital markets that prevent capital imports may delay adoption of the new technology by the lagging country and may postpone or even prevent leapfrogging that would have occurred in the case of free flows of capital. The model shows that capital mobility smooths passing the baton in the relay race for economic leadership.

Keywords

Growth, international capital flows, leadership, leapfrogging, learning-by-doing, technological progress

1. INTRODUCTION

Modern growth theory has instilled new life into the literature on the convergence and divergence of income across countries. New growth models offer various mechanisms as engines of growth, ranging from direct incentives, through investment in knowledge and R&D, to external learning by doing.[1] Emphasizing country-specific increasing returns, the new growth theory postulates a constant (or even widening) gap between leading and less developed countries. The recent histories of Japan and other south-east Asia countries, as well as the less recent histories of the US and UK, cast doubt on this prediction. In history, both catching up and 'leapfrogging' in leadership exist.

Brezis *et al.* (1993) analyse this effect and suggest that the fact that technological change comes in two types can explain leapfrogging. Most of

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the time technical change is a gradual improvement of methods and is likely to proceed through learning-by-doing. This type of technical change is at least partly country-specific and does not spread rapidly.[2] Occasionally, however, a major invention can fundamentally change the nature of a technology. At first, such an invention is not necessarily better than the old technology, and for a nation that already enjoys a lead, adopting such a new technology might prove disadvantageous. Under such circumstances, the lagging country may very well be the first to adopt this invention.

The Brezis *et al.* (1993) (BKT) model, however, concentrates only on part of the picture. Table 1 displays the data on 200 years of growth. It shows that the leapfrogging effect is correlated with the direction of capital flows. Holland led during the 17th and early 18th centuries, and it was a lending country, particularly to Britain (Brezis, 1995). In the mid-18th century, Britain leapfrogged Holland and took the lead, remaining there throughout the 19th century; during its hegemony Britain was lending all over the world and particularly to the US. At the beginning of the 20th century Britain was overtaken by the US and these dynamics in leadership were accompanied by a change in direction of capital flows, from being a borrower in the 19th century, the US in the 20th century became a lender.

This correlation between outflows of capital and leapfrogging cannot be considered in the BKT model since it does not include capital or savings. Moreover, a feature of the new growth theory is to play down the role of the accumulation of physical capital as a determinant of growth. In part, this is done as a modelling strategy; but partly, it is based on the feeling that knowledge, being non-rival and non-excludable, can better explain non-diminishing returns during growth, while other, more conventional factors of production cannot. New growth theory, therefore, favours human capital or

Table 1 GDP and capital flows

	GDP per capita at US$ 1970				*Capital inflows (+) outflows (–) (millions of US$ 1970)*		
Year	*Holland*	*UK*	*US*	*Japan*	*Holland*	*UK*	*US*
1700	400	288			–1.1	1.98	
1770	410	400			–43.5	109	
1820	400	454	372	251		–220	76
1870	831	972	764	251		–1101	441
1950	1773	2094	3211	585			–586
1979	4396	3981	6055	4419			–6525

Sources: Columns 1–4, Maddison (1982); columns 5–6, Brezis (1995); column 7, Williamson (1964).

knowledge accumulation over capital formation: 'Analysis suggests that physical capital may play only a supporting role in the story of long-run growth' (Grossman and Helpman, 1991). However, without explicitly introducing capital in the model, the new growth theory cannot analyse the interaction between capital accumulation, international capital flows, and resultant worldwide spillover effects that seem part of the picture portrayed in Table 1. Furthermore, new-growth models that do discuss capital flows, end with the prediction that capital will flow from poor to rich countries (Lucas, 1990), a contention belied by the facts provided in Table 1.

The purpose of the present paper is to analyse the effect of leapfrogging in an extended model that includes internationally mobile capital. We show that the correlation in the data is not pure hazard. Leapfrogging and the capital flows shown in Table 1 are endogenous to the process of growth. Capital flows from advanced to backward countries are crucial for the dynamics of development, and might even generate leapfrogging that could not have occurred in the absence of free capital flows.

Capital plays an important role in the leadership contest. If economic history can be depicted as a relay race, capital flows from a leader to its successor not only passes the baton smoothly but also accelerates the 'take-off' of the latter. Whether take-offs lead to catching-up or to leapfrogging depends on the features of knowledge.

This paper develops a simple model relating the cost of production and capital flows to the inability to switch to new sectors with higher productivity. We use a minimalist, two-country, overlapping generations model with trade and capital flows in order to endogenize savings and interest rates.

The paper is organized as follows. Section 2 describes the basic structure of a two-country overlapping generations model with endogenous growth. Section 3 examines the adoption of new technologies, depending on the exact nature of externalities and Section 4 concludes.

2. THE MODEL

Consider a perfectly competitive world consisting of two countries: one advanced (country a) and one backward (country b). Economic activity in each country is conducted over discrete time t, $t = 0, 1, ..., \infty$. Both countries produce the same good, using two factors of production: labour (L) and capital (K). Labour is inmobile, but capital is perfectly mobile. Thus, the rate of return to capital in both countries is equal. The country with the *ex-ante* higher return to capital attracts inflows of capital that are paid for with an outflow of goods.

In order to minimize the model and to abstract from wealth and capital distribution over time, we use an overlapping generations framework (Diamond, 1965) where capital depreciates totally at the end of each period.

2.1 Production and technology

Each country produces in each period the same single non-durable good using labour and capital. The difference is that the technology known and applied in each country is different and affects productivity.

We assume that the production function is of a Cobb–Douglas form and is subject to externalities. Two elements have positive external effects on productivity. One is the effect of the world stock of capital on the production function, which proxies for the basic knowledge embodied in capital; in the case of capital flows, this basic knowledge diffuses throughout the world so that the proper index of the knowledge embodied in capital is the world stock of capital. The second externality results from learning-by-doing effects, which we assume to be country-specific. The simplest form of such an externality is when the coefficient of technology in each country is an increasing function of accumulated production in that country alone. We assume that this dynamic externality increases at a decreasing rate, and that it is technology-specific. Thus, assuming technology was first used in each country i at time t_i, the production functions of countries a and b take the form:[3]

$$Y_{t,a} = [M(H_{t,a}, K_t)]^{1-\alpha} K_{t,a}^{\alpha} L_{t,a}^{1-\alpha} \quad Y_{t,b} = [M(H_{t,b}, K_t)]^{1-\alpha} K_{t,b}^{\alpha} L_{t,b}^{1-\alpha} \tag{1}$$

where:

$H_{t,i} = \sum_{\tau=t_i}^{t-1} Y_{\tau,i}$ for $i = a, b$

$K_{t,i}$ = capital stock at time t in country i for $i = a, b$

$K_t = K_{t,a} + K_{t,b}$

$M_1, M_2, M_{12} > 0; \quad M_{11}, M_{22} < 0$

Technological progress displays learning-by-doing effects specific to each country. These effects are positive and are subject to diminishing returns as each technological generation matures (Arrow, 1962). As noted, information embodied in capital diffuses throughout the world, but the capacity to implement such information obviously depends on each country's existing level of knowledge. Since both types of externalities interact, world capital stock affects both economies differently.

In this model, increasing returns are due to these externalities, and the model displays constant returns-to-scale for the firm. Therefore, the competitive equilibrium used in OLG remains appropriate to our case.[4] Also, since the size of the labour force plays no role in this model, we normalize the labour force in each country to 1. Without loss of generality we give country a the lead at the beginning by making the following assumption.

At time t_0,

$$H_{t_0,a} > H_{t_0,b}$$

That is, we assume that country a, the advanced country, was the first to start using the current technology in production. Thus, it has already produced more of the good. This assumption, together with (1), implies that country *a* has a more advanced technology $[M(H_{t,a}, K_t) > M(H_{t,b}, K_t)]$ as long as both countries continue to use the same technology. To simplify the notation, denote $A_t = M(H_{t,a}, K_t)$ and $B_t = M(H_{t,b}, K_t)$. A_t, B_t stand for the overall external effect in the advanced and backward countries respectively.

Since capital is perfectly mobile, the rates of return to capital are equal in both countries. Thus, capital is allocated for production at the same proportion as the relative level of productivity:

$$\frac{A_t}{B_t} = \frac{K_{t,a}}{K_{t,b}} \tag{2}$$

Wages are equal to the marginal product of labour:

$$W_{t,a} = (1-\alpha)\, A_t^{1-\alpha}\, K_{t,a}^{\alpha} \quad \text{and} \quad W_{t,b} = (1-\alpha)\, B_t^{1-\alpha}\, K_{t,b}^{\alpha} \tag{3}$$

Therefore, relative wages are equal to relative stocks of capital:

$$\frac{W_{t,a}}{W_{t,b}} = \frac{K_{t,a}}{K_{t,b}} = \frac{A_t}{B_t} \tag{4}$$

Since technology is more productive in country *a* than in country *b*, wages in country *a* are higher than in country *b*, and the ratio of capital used in country *a* to worldwide capital stock is greater than half.

2.2 Consumption

The demand for goods is given by the standard overlapping generations model combined with the fact that there are two countries. A generation, consisting of a continuum of individuals of size 1, is born in each country in each period. Individuals are the same both within and between countries. They live two periods and are endowed with one unit of labour in the first period and zero in the second. Output can be used for consumption or saved to form the next period's capital stock. People can invest in their own country and in the other country. In the second period, when old, they consume what they have invested in both countries. They have the same log-utility function:

$$U_{t,i} = (1-\beta)\log C_{t,i} + \beta \log C_{t+1,i}, \quad \text{where } i = a, b \tag{5}$$

The first-order condition of an individual's maximization problem yields the saving function for each country, $S_{t,a}$ and $S_{t,b}$:

$$S_{t,a} = \beta W_{t,a} = \beta(1-\alpha)\, A_t^{1-\alpha}\, K_{t,a}^{\alpha}; \quad S_{t,b} = \beta W_{t,b} = \beta(1-\alpha)\, B_t^{1-\alpha}\, K_{t,b}^{\alpha} \tag{6}$$

Note that in spite of the external effects, there are no pure profits in this model; the value of output equals the cost of inputs.

2.3 Short-run-equilibrium and dynamics

A two-country dynamic general equilibrium with perfect capital mobility is a sequence of K_t that satisfies equations (1)–(6) in each period. Moreover, world savings have to equal world investment. Thus:

$$K_{t+1} = S_{t,a} + S_{t,b} = \beta(1-\alpha)(A_t + B_t)^{1-\alpha} K_t^{\alpha} > 0 \tag{7}$$

One immediately observes that $\mathrm{d}K_{t+1}/\mathrm{d}K_t$ is positive. Since our focus is on a model with perpetual growth, we assume further that this derivative is greater than or equal to 1. Note, however, that since A_t, and B_t, are increasing functions of K_t (at a decreasing rate) a sufficient condition for perpetual growth is that for all t, $\mathrm{d}(A_t + B_t)/\mathrm{d}K_t \geq 1$ holds, together with some technical restrictions on the parameters.

2.4 Capital flows

Section 2.3 fully characterized the two-country dynamic equilibrium with perfect capital mobility. This dynamic characterization implies that there may be capital flows between the two countries. We now determine which country exports capital. Consider country a: at the end of period t, individuals have saved $S_{t,a}$. In the following period the quantity of capital used in production is $K_{t+1,a}$. The capital exports of country a are therefore $S_{t,a} - K_{t+1,a}$ and are given by:

$$\begin{aligned} NK_{t,a} &= S_{t,a} - K_{t+1,a} \\ &= \beta(1-\alpha) K_t^{\alpha} (A_t + B_t)^{1-\alpha} \left[\frac{A_t}{A_t + B_t} - \frac{A_{t+1}}{A_{t+1} + B_{t+1}} \right] \end{aligned} \tag{8}$$

This expression is positive when country a exports capital and imports consumption services, and negative when it imports capital and exports consumption services.

Note that the only source of actual flows of capital in this model is technological progress. In the absence of such progress neither A nor B change and no capital will flow across countries in equilibrium. In such a case, given our simple structure, each country saves exactly the necessary amount to satisfy its own demand for investment at the world-determined interest rates. Capital will flow from the slowly technologically progressing economy to the rapidly technologically progressing economy regardless of whether the latter is rich or poor. The richer country (country a) exports capital only if the technology in the poorer country improves at a faster rate, i.e. the following condition holds:

Condition 1 (C1) Country a exports capital if and only if $(B_{t+1}/B_t) > (A_{t+1}/A_t)$.

Remark While C1 depends on the specifics of the functional form, the result is much more general. The direction of capital flows depends on the properties of both the production function and the utility function (saving rates). Nonetheless, it can be shown that under fairly general conditions the country that exhibits a faster rate of a Hicks-neutral technological progress will see more inflow (or less outflow) of capital than otherwise. In a way this result is fairly intuitive. In the OLG set-up the distribution of wealth is one to one related to the distribution of income. Savings are a function of the permanent income only. At any point in time a Hicks-neutral technological progress in one country increases both the marginal product of capital and permanent income. As long as income does not obtain a strong and positive effect on the saving rate, holding everything else equal, a Hicks-neutral change attracts more capital from the other country. This intuition holds true for differences in the rate of technological progress as well.

3. ADOPTION OF A TECHNICAL BREAKTHROUGH

This section investigates the two-country dynamic equilibrium at the time a new invention is introduced. As stated in the introduction, we make a clear distinction between innovations and inventions. Innovations result from (i) each country accumulating experience in using current technology and (ii) from the knowledge embodied in the formation of new capital worldwide. Innovations, therefore, are fully identified with technological progress. Inventions, however, are far less frequent. An invention changes the production structure as a whole, and therefore depletes (part of) the efficacy of the experience accumulated in the previously-used ('old') technology. Weighing this depletion of accumulated knowledge, which is merely a variant of the Schumpeterian concept of creative destruction, against the expected benefits from adopting a new technology, lies at the heart of the decision whether to adopt the latter or to ignore it. Since gross future benefits are similar, while accumulated experience is different across countries, it is immediately apparent that the decision whether or not to adopt a new technology does not bear the same consequences for both countries at any point in time. This section shows that cost considerations, even in a world with perfect capital mobility, may cause the backward country to adopt a new invention while the advanced country does not. Since the decision to adopt or reject the new technology hinges solely on entrepreneurs' private return, the decision to reject the new technology may, in terms of output, prove wrong in the long run.[5]

Adoption of a new technology is therefore a decision to be made. In this paper we assume that in each country the young are the entrepreneurs who decide whether or not to adopt a new technology. They borrow capital from the old who have saved for their later days. Once they choose a production process, they work at the going wage. When deciding whether to adopt a new invention or not, they maximize their utility.[6] Last, but not least, the timing of the decision must be specified: we assume that the new technology arrives unexpectedly after all markets clear. Prior to its arrival, therefore, the new invention has no effect; upon arrival it immediately becomes ready for use for all young agents in both countries.

We examine the process for adoption in two steps. The first step focuses on the effect of the world capital externality. A new invention may create an opportunity for the backward country, country *b*, to adopt the new technology first, and consequently to catch up with country *a*. The final result of such an event is, however, that both countries converge to a similar level of output and a similar rate of growth. In the second step we analyse the effect of the country-specific externality, i.e. the learning-by-doing effect. We show that this effect can lead country *b* not only to catch up with country *a* but actually to overtake it and assume economic leadership.

3.1 Static externalities and dynamic convergence

Suppose this two-country world is on a dynamic equilibrium path and assume that a new technology becomes available to both in period t_1. In this subsection we assume that the increase in productivity resulting from the implementation of the new technology is due to a change that affects only the world capital externality. The dynamic externality through learning-by-doing will be reintroduced shortly. This is done for expository purposes only: it highlights the importance of the world stock of capital for the decision about adoption (and therefore for the mechanics of catching up), and helps distinguish between this mechanism and the one that produces leapfrogging.

The analysis is done in three steps: (1) the new technology is defined, (2) output dynamics are displayed, (3) the role of capital flows is discussed.

Technology

The new technology, when adopted by country *i*, is characterized by the following production function, N:

$$Y_{t,i} = [N(K_t)]^{1-\alpha} K_{t,i}^{\alpha} L_{t,i}^{1-\alpha} \tag{9}$$

where

$$N(0) > 0, \text{ and } N_1 > 0.$$

Consider now the case of country *b* adopting the new technology at time t_1 while country *a* does not. The sufficient condition for this event to occur at time t_1 is summarized in the following condition.[7]

Condition 2 (C2)

(i) $M(H_{t,a}, K_t) > N(K_t)$ for $t = t_1, t_1 + 1$

(ii) $N(K_{t_1}) > M(H_{t_1,b}, K_{t_1})$

(iii) $$\frac{N(K_{t+1})}{N(K_t)} > \frac{M^N(H_{t+1,a}, K_{t+1})}{M(H^N_{t,a}, K_t)} \forall t \geq t_1$$

(iv) $$\frac{N(K_{t+1})}{N(K_t)} > \frac{M(H_{t+1,b}, K_{t+1})}{M(H_{t,b}, K_t)} \forall t \geq t_1$$

The superscript N in (iii) on both M and H denotes that country b has already adopted the new technology N.

Condition 2 stipulates only very simple requirements regarding the new technology. Inequality (i) at time t_1 states that for country a the external effect of the world stock of capital upon adoption of the new technology is weaker than the total combined enhancing effect of experience and capital formation in the old technology. The young entrepreneur in country a, if concerned solely with her wage, would find it counter-productive to switch to the new technology. Inequality (i) at time $t_1 + 1$ ensures that productivity growth is not dramatic enough to mean that, in one period, the new technology more than compensates for the forgone wage-income while young. A milder condition could be used instead of (i): condition (i), however, is sufficient for country a not to adopt the new technology at time t_1.

Inequality (ii) states that for the young in country b, wages increase upon adoption of the new technology. Inequality (iv) ensures that the following period's interest rate will increase. Since both the wage and the next period's rate of interest increase, there is no doubt that entrepreneurs in country b choose to adopt the new technology.

Inequality (iii) states that, given the current stock of capital around the world and current accumulated experience, productivity growth in the leading country is slower than in the laggard country, which has just adopted the new technology, and slower than it would have been if technology N had been adopted in the leading country (against its entrepreneurs' will). The superscript N denotes that for country a we consider the actual path (the path of production and learning that prevailed when country b switched to technology N). It is only due to capital outflows that the actual path in country a differs from the one that would have prevailed if no switch in technology b had occurred. As shown below, upon adoption of the new technology in country b, capital flows out of country a.[8]

Output dynamics

When a new technology that satisfies C2 appears at time t_1, country b adopts the new technology while country a does not. This technology has a higher rate of productivity growth and will eventually become more productive than the technology used in the leader country. As long as C2 is satisfied, country

a will continue to use technology M while country b uses technology N. As world output and the world stock of capital continue to grow, wages implied by technology N grow faster than do wages implied by technology M. When the world capital stock is large enough, country a's output when using technology N exceeds output when using technology M (C2(i) is reversed). At this point country a also switches to technology N, and both countries are now on a new and stable growth path. Once N is adopted by a, the two-country world becomes symmetric and growth will persist forever if the externality is strong enough. This extreme form of symmetry is merely an artefact created by ignoring the effect of learning-by-doing. In the next section we account for this form of externality as well. Case 1 in Figure 1 displays these dynamics when t_1 is the time the new invention arrives, and t_2 is the time country a also switches to the new technology and convergence occurs.[9]

Capital flows

Two issues about the relation between capital flows and technological changes emerge. (a) Are capital flows affected by the adoption of the new invention by the laggard country? And (b) do capital flows affect the decision made? The answers to both are yes. We discuss the two issues sequentially.

Capital flows are described by (8). We can sign the direction of this flow by analysing the expression in the square brackets on the right-hand side of (8):

$$\text{Sign}\,(NK_{t_1-1,a}) = \text{Sign}\left[\frac{M(H_{t_1-1,a},\ K_{t_1-1})}{M(H_{t_1-1,a},\ K_{t_1-1}) + M(H_{t_1,b},\ K_{t_1-1})} - \frac{M(H^N_{t_1,a},\ K_{t_1})}{M(H^N_{t_1,a},\ K_{t_1}) + N(K_{t_1})}\right] \tag{10}$$

Recall that, as stated in condition 1, if productivity growth in the laggard country is higher, capital will flow from the leader country to the laggard, whereas if productivity growth is faster in the leader country, capital will flow from the laggard to the leader. In order to analyse the effect of the new technology on capital flows, let us assume for simplicity that, before t_1, capital flows are zero. Since the increase in productivity in b raises the marginal product of capital in b for any given stock of capital, it induces relocation of capital from a to b.[10] Furthermore, since adoption of N implies a faster technological change (C2(iv)), this flow of capital continues to exist in periods following t_1. The adoption of technology N by country b shifts, therefore, capital from country a to country b and the net capital inflow into country b now becomes positive (see Case a in Figure 1). Thus, upon adoption of a new technology by the laggard, the leader necessarily becomes the

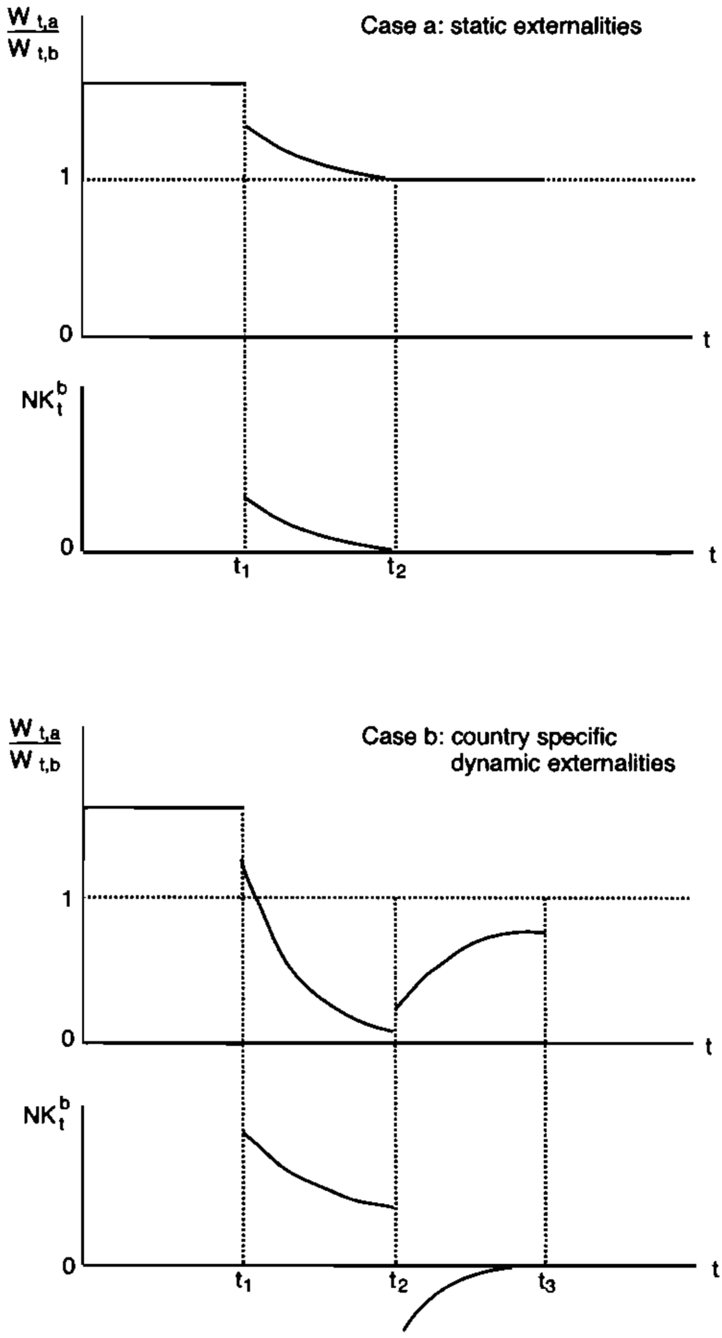

Figure 1 Dynamics after adoption of a new technology

financer of country b's growth. Capital flows are indeed affected by the decision to adopt in country b.

A second question in this context is whether capital flows affect the decision to adopt. This question, however, should be treated with care. In this model, capital flows stand for two linked although different concepts: on the one hand, they represent the flow of information from one country to another, and on the other hand, they represent the flow of investment goods. To the extent that one can disentangle intangible knowledge (flows of information) from its tangible manifestations (flows of investment) the question becomes two sub-questions. We take these two sub-questions separately. Since the effect of investment goods exists only in the case of learning-by-doing externalities, this section analyses only the role of capital as a channel of information.

When world capital stock no longer stands for the knowledge base condition, C2(ii) is not sufficient to guarantee adoption of the new technology N by entrepreneurs in country b. Lack of perfect mobility reduces knowledge by assumption, and may, of course, alter the decision to adopt. Adoption by b can (i) be postponed, (ii) coincide with adoption by a, or (iii) never materialize, depending on the exact specification of the functional forms. This, however, is not the only effect capital flows have on the decision to adopt; the effect of the tangible component of the flow of capital on this decision is no less important. This effect applies, however, only to the case of country-specific externalities. We therefore return to this issue in the next section.

3.2 Country-specific dynamic externalities and 'leapfrogging'

This subsection considers the effects of country-specific learning-by-doing on the patterns of growth, capital flows and economic leadership. Since we focus here on the country-specific effect of learning-by-doing the information accumulated with experience is assumed neither marketable nor transferable. We show that when learning-by-doing is quantitatively significant, the backward country, having adopted the new technology first, may overtake the leading economy. We call this phenomenon 'leapfrogging'. We also show that the flows of capital facilitate this change in leadership. In fact, in the absence of tangible flows of capital, leapfrogging may be delayed or never take place. Note that, in order to avoid repetition, we discuss here the effect of capital as a physical asset only. As in the previous subsection, we proceed in three steps: we first define technology, then discuss output dynamics and finally discuss the role of the tangible flow of capital.

Technology

Assume that country-specific experience in production affects the new technology invented at time t_1. The production function for N now becomes:

$$Y_{t,i} = [N(H_{t,i}, K_t)]^{1-\alpha} K_{t,i}^{\alpha} L_{t,i}^{1-\alpha} \tag{11}$$

To discuss the adoption of this new technology one needs to modify (C2) to account for the effects of country-specific learning-by-doing. If C3 holds at time t_1, country b adopts the new technology while country a does not.

Condition 3 (C3)

(i) $M(H_{t,a}, K_t) > N(0, K_t)$ for $t = t_1, t_1 + 1$

(ii) $N(0, K_{t_1}) > M(H_{t_1,b}, K_{t_1})$

(iii) $$\frac{N(H_{t+1,b},\ K_{t+1})}{N(H_{t,b},\ K_t)} > \frac{M^N(H_{t+1,a},\ K_{t+1})}{M^N(H_{t,a},\ K_t)}\ \forall t \geq t_1$$

(iv) $$\frac{N(H_{t+1,b},\ K_{t+1})}{N(H_{t,b},\ K_t)} > \frac{M(H_{t+1,b},\ K_{t+1})}{M(H_{t,b},\ K_t)}\ \forall t \geq t_1$$

Since this assumption is similar to C2, we do not discuss its specifics.

Output dynamics

The evolution of the world economy from time t_1 onwards is very similar to the previous case. There is, however, one qualitative difference: as time goes by, country b learns to be more and more efficient. While this process has only a quantitative effect on b's evolution while it lags behind a, it becomes crucial when country b becomes the leader. The fact that country b becomes more efficient than country a is evident given C3(iii). Unlike the previous case, however, this does not guarantee that, at this moment (or at any other moment), entrepreneurs in country a will find it profitable to switch to the more promising technology. The reason for this is simple. Since output grows with learning, and learning is country-specific, the fact that b's output is larger than a's output does not imply that a can now replicate b's success. In fact, b's output can exceed a's output and condition C3(i) may never be reversed, in which case country a will never switch to the new technology and will remain the laggard forever. If C3(i) is reversed, country a will switch to the new technology, but will continue to lag behind country b. Only if the marginal effect of experience dissipates will country a catch up with the current leader, country b. In general, the new economic order, as implied by the timing of adoption, will persist at least until a new invention takes place. Leapfrogging is not temporary.

These dynamics are captured in the second case shown in Figure 1(b). Note that the figure is drawn under the assumption that country a does switch to modern technology at time t_2 but complete convergence never takes place.

The effect of capital flows

Subsection 3.1 (*capital flows*) demonstrated the role of the intangible component of capital in the dynamics of adopting a new technology. This subsection answers the following question: does the flows of the physical component of capital affect the transmission of leadership as well? The answer is, again, yes. In order to focus on the role of the flow of physical capital let us assume again that the dynamic path of the two economies is such that, before the new invention is introduced, there are no actual flows of capital.[11]

The adoption decision by the young in country *b* depends both on change in output today and on the change in output in the next period.[12] We have shown earlier (equation (10)) that capital flows change as a result of the adoption. Since, thanks to the adoption, the rate of return on capital increases in country *b*, capital is being exported from *a*. This capital inflow not only increases output today but, due to the effect of learning-by-doing, it increases output in the next period as well. Suppose now that a new invention, *N*, materializes, but that there are no international flows of capital.[13] The absence of actual flows of capital decreases production in this period relative to production in the case of perfectly mobile capital, and therefore has a negative effect on the accumulation of knowledge in this period. This reduces the capacity to produce in the next period relative to the capacity that would have prevailed with capital inflow. In the absence of capital inflows, C3(iv) may not be satisfied although it would have been satisfied if capital flows did exist. If the second period effect is strong enough this will postpone adoption.

Although the phenomenon itself is general, it can best be illustrated using threshold externalities in learning-by-doing.[14] Suppose technology *N* exhibits threshold externalities in the local component of learning-by-doing. Suppose, further, that in the absence of capital flows the economy does not produce enough (due to capital shortage) and does not accumulate enough knowledge, so that the next period's production is no better than this period's production. Since in technology *M* (the old technology) this threshold either does not exist or was crossed long ago, production in *M* does contribute to the accumulation of information and the process of innovation in *M* continues. Quite possibly, the discounted sum of output with *M* will be higher than that of output with *N*. If, however, capital flows are allowed, country *b* imports capital and may cross the threshold to make the adoption of technology *N* desirable. In this case capital flows are essential to the timing of adoption.

In fact, it is not only the timing of adoption and thus of leapfrogging that is affected. Using the interaction between the global information embodied in capital and the country-specific learning-by-doing, one can come up with examples where the absence of international capital flows will produce a friction strong enough for country *a* to adopt technology *N* together with *b*. In this case, the restriction on capital flows will prevent leapfrogging.

Restricting capital flows may postpone adoption in *b*; but the world is changing with the accumulation of more capital, and the next period, condition C3(i) may no longer hold. In this case, both countries may adopt together.

Not only does learning-by-doing enable leapfrogging, it increases the importance of international capital mobility. Capital mobility not only smooths the transmission of leadership, but in some cases leapfrogging would never occur without the financial push to the laggard.

4. CONCLUSIONS

History has shown numerous cases in which countries lost their position of economic leadership while at the same time exporting capital. This work claims that such leapfrogging can result from the fact that entrepreneurs in rich countries do not have the economic incentives to adopt important technological inventions at the time of their inauguration. Moreover, capital flows are important in the transmission of economic leadership, and may generate leapfrogging that would not have occurred without free capital mobility.

Our model shows that these features can be obtained in a simple two-country endogenous growth model where technological progress is external to the firm. We analyse the case where innovations generate country-specific as well as worldwide externalities. Important inventions, however, depend mostly on basic knowledge and can therefore always be adopted by other countries. When inventions have strong learning-by-doing country-specific externalities, the country that adopts the new technology first obtains leadership. A richer country that had no incentive to adopt the new technology first might lose its supremacy forever.

During the 18th century, Holland, the leader country, lent to Britain and at the same time lost its supremacy. Similarly, the UK lent to the US and Pax Britannica was over. Our model allows us to analyse the effects of capital on these dynamics; capital flows play a major role in the adoption of new technologies. When a new technology first appears, the leading country lends capital to the laggard, helping the latter to surpass the former. It seems that this fact is not alien to well-known episodes of more recent take-offs. While some countries (Japan) financed their own take-off with a higher saving rate, others (South Korea, Indonesia, etc) mastered the utilization of technology-intensive capital inflows.

Capital mobility lies at the heart of the adoption of a new technology, and obstacles to capital flows might postpone the adoption and prevent an otherwise natural change in leadership. The impression might be obtained that since the leader loses both its leadership and future output (due to capital outflows and foregone experience), it is in the public interest to ban the free flow of capital. Not so, for two reasons. One is that leadership carries no weight in the utility of individuals in our standard formulations. It may very well be the case that some time in the future the current leader, while being a follower, will enjoy a higher level of consumption than would prevail if capital flows are banned and the leader stays the leader. Not only is leadership not a relevant measure of welfare but production is also not a reasonable welfare criterion. While output is lower on impact, income is not. It is the fact that the yield on capital is higher abroad that generates capital outflows. The falling behind leader still enjoys a higher income with capital (out)flows than without. The second reason is that one should view the change in leadership as a natural cycle. Postponing the current takeover may result in a delay in recapturing the lead when the next technology materializes. Therefore such strong policy recommendations need further analysis and depend crucially on the welfare function chosen.

NOTES

1 See Aghion and Howitt (1992), Grossman and Helpman (1991), Romer (1989). Some empirical support for the relevance of externalities in the process of growth can be found in Bartelsman *et al.* (1991).

2 Historically, a good example is the technical changes in the cotton industry which were not characterized by one invention but by a continuum of small innovations induced by learning. These improvements were country-specific; all the improvements and adjustments were done in Britain. From Kay's fly shuttle (1733) to the spinning frame of Wyatt and Paul (1738), then Hargreave's Jenny (1765), Arkwright's water frame (1769) to Crompton's mule (1779). Of course, some innovations are not country-specific: for instance, technological progress can be embodied in tradable capital. For our purposes it suffices that *some* country-specificity exists.

3 Taking the general function $M(\ )$ to the power of $1 - \alpha$ is, of course, non-essential. It is done solely to simplify the algebraic exposition.

4 Since there are many firms in each country, each firm makes its own decisions while ignoring the effect on the aggregate.

5 Note however, that in this model, making the wrong decision for the long run is not the result of the OLG structure. Rather, it results from individuals not internalizing the external effects of the new technology and it continues to hold in infinite horizon models as long as one does not discuss the central planner optimization (Brezis *et al.*, 1993).

6 The same general discussion holds when the old are the investors. The specifics of the argument are, however, different. To avoid unnecessary repetition we discuss only the case of young entrepreneurs.

7 If this condition does not hold at time t_1 it may do so later on. We ignore this case as it provides no further insight. In addition, this condition may not hold. An example is when the new invention is radically better than the maturing technology. In this case both countries adopt the new technology at once. Since in this case both countries immediately become indistinguishable, the resulting quick convergence and the no-trade equilibrium need no further discussion.

8 Note that it is not true that country a, the leader, is not upset with country b's decision to adopt the new technology. We return to this point when discussing policy implications.

9 The figures are drawn for the continuous time analogue.

10 The effect of adoption of the new technology on the capital flows is shown in (11). While the left-hand fraction inside the square brackets of (11) is not altered (as it includes only productivity before the invention is adopted), the fraction on the right must decrease. This decreases the numerator and necessarily decreases the denominator by less (or increases it). Thus, the adoption of technology N by country b increases the expression inside the square brackets.

11 The technology in both economies changes at the same rate.

12 To be precise, they care about wages today and the rate of return on capital in the next period, which in the case of Hicks neutral technological progress (as in our model) is equivalent to caring about output in both periods.

13 Of course, a restricted flow of capital will have the same qualitative result.

14 These threshold externalities were first used in Azariadis and Drazen (1990).

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