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Elise Brezis

Paul Krugman

Daniel Tsiddon

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ABSTRACT

Much recent work has suggested that endogenous technological change tends to reinforce the position of the leading nations. Yet from time to time this leadership role shifts. We suggest a mechanism that explains this pattern of "leapfrogging" as a response to occasional major changes in technology. When such a change occurs, leading nations may have no incentive to adopt the new ideas; given their extensive experience with older technologies, the new ideas do not initially seem to be an improvement. Lagging nations, however, have less experience; the new techniques offer them an opportunity to use their lower wages, to break into the market. If the new techniques eventually prove to be more productive than the old, there is a reversal of leadership.

Elise Brezis
Department of Economics
Hebrew University of Jerusalem
Jerusalem 91905
Israel

Paul Krugman
Department of Economics
M.I.T.
Cambridge, MA 02139
and NBER

Daniel Tsiddon
Department of Economics
Hebrew University of Jerusalem
Jerusalem 91905
Israel

In recent years the "new growth theory", which emphasizes the role of nonconvexities and external economies in the growth process, has increasingly focussed on the interrelationship between trade and growth — and in particular on the possibility of economic divergence between nations. The mechanism emphasized by such authors as Lucas (1988), Young (1990), Romer (1990), and Grossman and Helpman (1991) is essentially an updated version of the traditional idea of uneven development. Suppose that some sectors generate more endogenous technological progress than others, say through learning-by-doing. Then a country that has for whatever reason acquired a comparative advantage in such technologically progressive sectors will tend to reinforce that advantage over time, and thus to establish a growing lead over less lucky rivals.

In spite of recent claims that the process of international growth is always and everywhere marked by convergence rather than divergence (see, for example, Barro 1991) it is easy to think of historical episodes in which a cumulative process of divergence does seem to have been at work; one need only think of England's growing industrial leadership in the early phases of the Industrial Revolution, or America's widening lead in the first half of the 20th century. Yet while individual countries have established long periods of economic and technological leadership, such periods of dominance are not forever. The early modern preeminence of the Dutch was ended by the rise of England; England's preeminence by the rise of America and Germany; and we may be seeing the US overtaken by Japan (See Table 1).

Such economic and technological "leapfrogging" could be essentially random: lagging countries may simply get lucky, leading countries get unlucky. Historians have often suggested, however, that a more systematic process is at work, in which the very success of the leading country at one stage of economic development prevents it from taking the lead in the next.

Why should success breed failure? One might appeal to sociological factors; or one might, like Olson (1982), suggest that a successful nation is bound to accumulate institutional rigidities that eventually cripple its economic performance. In this paper, we want to suggest a more narrowly economic explanation, based on a hypothesis about the nature of technological change.

We suggest that technological change is of two kinds. Most of the time technology proceeds incrementally, by gradual improvement of methods within a well-understood framework. This "normal" technical change is likely to proceed largely through learning by doing, and will tend to occur most rapidly in those countries with established advantages in technologically progressive sectors. At intervals, however, there are major breakthroughs that change the nature of technology fundamentally. Such major breakthroughs require that nations start fresh.

When a new technology becomes available, however, it may not initially seem much better than the old one — and to a nation that has established a commanding lead in the old technology, it may well seem worse. Thus 18th century Holland, with its established lead in shipping, banking and trading, was not attracted by the prospects for cotton spinning; it was the somewhat poorer English who moved into the new area and exploited its eventually far greater potential.

Such a failure to take advantage of new technologies may seem in retrospect like short-sightedness. In fact, however, it may have been a fully rational decision from the point of view of individual entrepreneurs. A country with an established lead will be a high wage nation[1]; new technologies or industries that are initially less productive than the old are therefore not profitable. It is only in a lagging nation, where the old technology is less well developed and hence wages are lower, that the new, relatively untried techniques seem attractive.

This relationship between high wages in leading countries and the failure to switch to sectors with higher productivity was mentioned by Maddison (1982, p.33). On the turning point between the Netherlands and the UK, he notes that: "there seems little doubt that a contributory factor to Dutch decline in the 18th century was that the currency was overvalued"; similarly, in describing the switch from the UK to the US, he underlines that: "At the time it was overtaken by the USA, there were strong signs that the UK was growing at less than its potential because its

[1]The Netherlands remained a distinctly richer and higher-wage nation than England as late as the time of The Wealth of the Nations, in which Adam Smith remarked in passing that "The province of Holland, on the other hand, in proportion to the extent of its history and the number of its people, is a richer country than England... The wages of labor are said to be higher in Holland than in England".

currency was over-valued".[2]

In this paper we develop a simple formalization of these ideas, using a minimalist two-country model of trade and growth. The paper is in five parts. In the first part we set out the basic assumptions of the model. In the second we describe the conditions of equilibrium at a point in time. In the third part we describe the model's dynamics during a period of "routine" technological progress, where productivity rises only because of learning within the bounds of a well-established technology, and show how such learning tends to "lock in" the role of the leading nation. In the fourth part we show how introducing a new technology, for which experience with the old is not very helpful, can lead to endogenous "leapfrogging", in which the leader is passed by the erstwhile follower. A final section suggests some conclusions and possible extensions.

1. The Basic Model

We consider a world of two countries, Britain and America. There are two kinds of goods: a technically stagnant good, food, and a set of technically progressive manufactured goods. Labor is the only factor of production, and we assume that the two countries have equal labor forces L.

In the food sector we suppose that there are constant returns

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[2] For our purpose, an overvaluation of the exchange rate is equivalent to over valued real wages.

to scale, with the productivity of labor the same in both countries. Without loss of generality we set the productivity of labor in food production equal to 1. Thus the output of food in Britain and America respectively are

$$Q_F = L_F \tag{1}$$

$$Q_F^* = L_F^* \tag{2}$$

where L_F, L_F^* are the employment in food production in the two countries.

Manufactures consists of a series of increasingly sophisticated generations of goods, which for simplicity we assume to be perfect substitutes. Production within each generation of the sequence is subject to external learning effects, which are specific to each country. That is, let $Q_i(t)$ be Britain's rate of output of the manufactured good of generation i at time t; then for the current output we have

$$Q_i(T) = A_i(K_i(T))L_i \tag{3}$$

where

$$K_i(T) = \int_{-\infty}^{T} Q_i(t)\,dt \tag{4}$$

Similarly, for the US we have

$$Q_i^*(T) = A_i(K_i^*(T)) \tag{5}$$

where

$$K_i^*(T) = \int_{-\infty}^{T} Q_i^*(t)\,dt \qquad (6)$$

We assume $A'>0$, $A''<0$. That is, there are positive learning effects; but learning is subject to diminishing returns as each technological generation matures. The significance of this assumption will become apparent shortly.

We choose units so as to make quantities of successive generations of manufactured goods comparable. Given this choice of units, each successive technological generation is <u>better</u> than the previous one — that is, $A_{i+1}(Z)>A_i(Z)$ for any given Z. The new technology is only better, however, given equal experience. A nation with extensive experience in an old technology may be more productive using that technology than it would be in the early stages of a new one.

Demand we assume to be identically Cobb-Douglas in the two countries.

$$U = D_M^{\mu} D_F^{1-\mu} \qquad (7)$$

where D_M is consumption of the manufactures aggregate, D_F consumption of food. We assume, for reasons that will be clear in a moment, that the share μ of manufactures exceeds 0.5.

2. Short-run Equilibrium

Except for occasional moments when one of the countries in our model is just in the process of passing the other, one of the two countries will have higher productivity in manufactures, while they have the same productivity in food. We will consider an initial situation in which Britain is the high-productivity nation, that is, where $A_1>A_1^*$; but with a few changes the same equations apply when the countries' roles are reversed.

At any given point in time this model is simply a conventional two-good Ricardian model. In general such models have three kinds of equilibrium: one in which both countries produce food and therefore receive equal wages; one in which both countries are specialized, and relative wages are determined by demand; and one in which both countries produce manufactures, with relative wages determined by relative productivity in manufactures. Our assumptions that $\mu>0.5$, and that the two countries have the same labor force, rule out the first kind of equilibrium and ensure that one country will always be specialized in manufactures.[3] To determine whether the other country also produces manufactures, we first ask what the relative wage rate would be if both countries

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[3] Suppose that both countries produced food. Then the wage rate in both countries would necesarily equal 1, and whichever country had the higher productivity in manufacturing would therefore produce all manufactured goods. But total world expenditure on manufactured goods would be $2\mu L$, implying (since w=1) that $L_M=2\mu L$. But with $\mu>0.5$, this implies $L_M>L$ -- which is impossible. Thus only one country produces food, with the other completely specialized in manufactures.

were specialized. In that case $L_M = L = L_F^*$. Let E be world expenditure. Of this world expenditure, a share μ falls on manufactured goods, a share $(1-\mu)$ on food. Thus we must have

$$wL = \mu E \tag{8}$$

$$w^*L = (1-\mu)E \tag{9}$$

implying

$$\frac{w}{w^*} = \frac{\mu}{1-\mu} \tag{10}$$

Is this situation, which we will refer to as "full specialization", an equilibrium? Only if this relative wage rate does not exceed A_i/A_i^*. If this criterion is not met, America must also produce some manufactures, and the relative wage rate will be

$$\frac{w}{w^*} = \frac{A_i}{A_i^*} \tag{11}$$

In such an equilibrium, which we will refer to as "partial specialization", we can immediately determine the allocation of American labor between food and manufactures. Let food (and hence American labor) be the numeraire. Then world income is

$$Y = \left(\frac{w}{w^*} + 1\right)L \tag{12}$$

and world spending on food, which equals American employment in food production, is simply

$$L_F^* = (1-\mu)\, L\left(\frac{A_i}{A_i^*} + 1\right) \tag{13}$$

As we will see, the model will in general predict alternation between full and partial specialization. Thus we note for future reference several features of the two kinds of equilibria. First consider full specialization. In this case, as noted, the relative wage is $\mu/(1-\mu)$. The price of manufactures in terms of food is

$$P_M/P_F = \frac{\mu}{(1-\mu)A_i} \tag{14}$$

And the real wage rates of the two countries are

$$\omega = A_i^{\mu}\left(\frac{\mu}{1-\mu}\right)^{1-\mu} \tag{15}$$

$$\omega^* = \left(\frac{(1-\mu)A_i}{\mu}\right)^{\mu} \tag{16}$$

In the case of partial specialization, the relative wage is A_i/A_i^*. The price of manufactures in terms of food is

$$P_M/P_F = \frac{1}{A_i^*} \tag{17}$$

and the real wage rates of the two countries are

$$\omega = A_i\,(A_i^*)^{-(1-\mu)} \tag{18}$$

$$\omega^* = (A_1^*)^\mu \quad (19)$$

We will assume that initially Britain has a productivity advantage in manufacturing that exceeds $\mu/(1-\mu)$. Thus the initial equilibrium is one of full specialization, in which Britain is specialized in manufactures, America in food.

3. Dynamics within a technological generation

Given the assumed initial pattern of specialization, Britain will steadily widen its productivity advantage over the US. This will simply ratify, indeed lock in, that pattern of specialization. Since the entire British labor force L is devoted to manufactures production, we have

$$\frac{\dot{A}_1}{A_1} = A_1' L \quad (20)$$

Thus British productivity will rise over time, while American productivity will remain constant. Given the assumed shape of A(.), however, the rate of British productivity growth will decline over time.

Throughout this period, relative wages will be governed by (10); thus they will remain unchanged in spite of Britain's growing productivity advantage in manufactures. The growing productivity will instead be reflected in a corresponding decline in the relative price of manufactures.

If this were the only form of technological change, this would be the full story. To get "leapfrogging", we must add a second kind of change.

4. Leapfrogging

We now suppose that a new technology, which we designate as technology 2, is introduced. As assumed above, the new technology is better than the old in the sense that given the same amount of experience it yields higher productivity. We assume, however, that for the British, who have extensive experience in the old technology but none in the new, the new technology is initially inferior. That is, at T_2, the date at which the new technology is introduced,

$$A_2(0) < A_1(K_1(T_2)) \tag{21}$$

The result is that individual producers in Britain have no incentive to adopt the new technology.

American producers are in a different situation, because they pay lower wages and lack experience in the old technology. The new technology will be profitable to introduce in America provided that

$$\frac{A_2(0)}{A_1(K(T_2))} > \frac{1-\mu}{\mu} \tag{22}$$

We assume this to be the case. The assumptions about the new and old technology are illustrated in Figure 1.

The introduction of the new technology has an immediate impact on the pattern of specialization, shifting it from full specialization to partial. Britain's relative wage rate (w/w^*) falls from $\mu/1-\mu$ to A_1/A_2^*, and America begins to produce manufactured goods.

What we now assume is that the A( ) function for the new technology is sufficiently steep in its early stages, and the slope of the function for the established technology sufficiently flat (at its current, well developed stage), that American productivity now begins to rise more rapidly than British productivity does.

During this rise in American relative productivity, the equation for American employment in food is

$$L_F^* = (1-\mu)\, L\left(\frac{A_1}{A_2^*} + 1\right) \qquad (23)$$

Since A_2^* will be rising relative to A_1, American food employment will steadily fall. As long as A_1/A_2^* remains greater than 1, however, the pattern will remain one in which Britain remains specialized in manufactures.

During this transition, real wages in America will steadily rise, because rising productivity in manufacturing will lead not only to higher output but to improving terms of trade:

$$\omega^* = \left(\frac{(1-\mu)\,A_2^*}{\mu}\right)^{\mu} \qquad (24)$$

Meanwhile, however, rising relative American productivity will worsen Britain's terms of trade, possibly leading to a declining real wage:

$$\omega = A_1 (A_2^*)^{-(1-\mu)} \tag{25}$$

At some point (T_2) America may overtake British productivity in manufactures. At that point there must be an abrupt reversal of the trade pattern: America now specializes completely in manufactures, while Britain produces some food as well as manufactures.

Why has America now surpassed Britain in productivity? Because America has adopted and gained experience in the ultimately superior technology, while Britain has not. Eventually if the new technology surpasses the old by enough, that is:

$$\frac{A_2^*(\bar{T}_2)}{A_1(\bar{T}_2)} > \frac{\mu}{1-\mu}$$

we get full specialization again and we have reversed the initial position. After this reversal the British produce only food, while the Americans produce manufactures. At this point, of course, we now have the conditions for a future reversal of fortune, in which lagging Britain once again overtakes America.

A useful way to think about this potential cycle is in terms of relative wages, as illustrated in Figure 2. In periods of full specialization the leading country has a wage rate $\mu/1-\mu$ times that of the lagging nation; when there is a major change in technology that wage advantage is suddenly reduced, then gradually erodes further and is eventually reversed; and the stage is set for the next major technological shock to initiate a new round of leapfrogging.

5. Conclusion

David Landes, echoing many other observers, has noted that "Prosperity and success are their own worst enemies" (Landes (1966), p. 563). The usual explanation of the dynamic of of "shirtsleeves to shirtsleeves in three generations" rests on non-economic and/or socio-economic factors. This paper suggests, however, that there may also be a simple economic explanation. In times of normal, incremental technological change, increasing returns to scale tend to accentuate economic leadership. However, at times of a new invention or a major technological breakthrough, economic leadership, since it also implies high wages, can deter the adoption of new ideas in the most advanced countries. A new technology may well seem initially inferior to older methods to those who have extensive experience with those older methods; yet that initially inferior technology may well more potential for improvements and adaptation. When technological progress takes this form, economic leadership will tend to be the source of its own downfall.

Of course this need not happen. A number of conditions must hold if introduction of a new technology is to lead to a leapfrogging process:

(i) The difference in wage costs between the leading nation and potential challengers must be large.

(ii) The new technology must, when viewed by experienced producers, appear initially unproductive compared with the old.

(iii) Experience in the old technology must not be too useful in the new technology.

(iv) The new technology must ultimately offer the possibility of substantial productivity improvement over the old.

When these conditions hold, however, there will a systematic process in which success breeds failure and vice versa.

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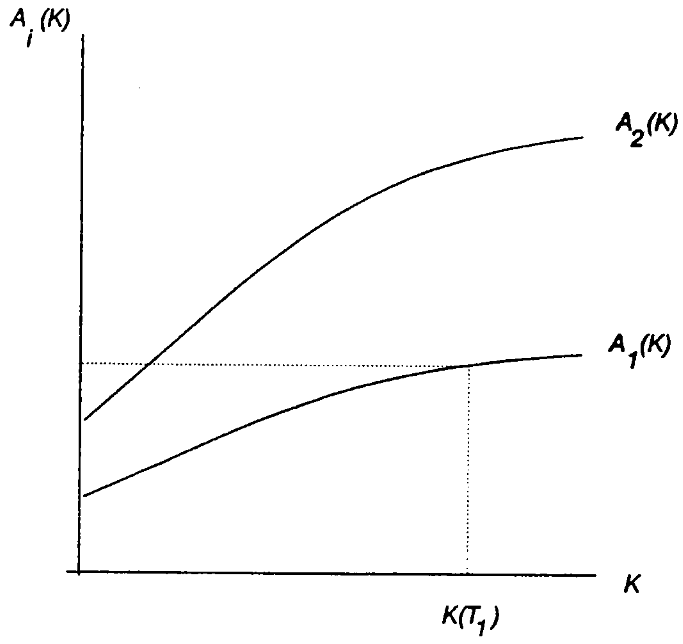

Figure 1

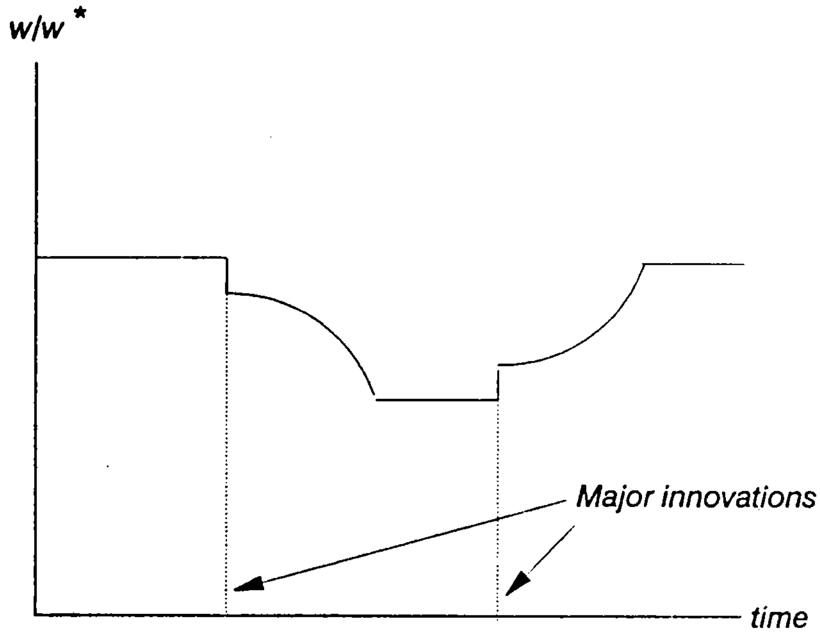

Figure 2