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HYSTERSIS IN THE TRADE PATTERN

by

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Abstract

We study a world economy comprising two countries that may differ only in their prior experience in the research lab. Entrepreneurs in each country develop new technologies for varieties of a differentiated product whenever expected profits justify up-front research costs. Research productivity depends upon national stocks of knowledge capital, which accumulate in proportion to local research activity. The countries produce and trade their unique varieties of the differentiated good, as well as a homogeneous, "traditional" product. In this context, we ask whether a country can overcome a late start in research to develop a comparative advantage in the high-technology sector. We also examine the welfare properties of the equilibrium trajectory and of policies that might be used to reverse a country's fate.

Keywords: pattern of trade, innovation, R&D, technological progress

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I. Introduction

Writing on "The Role of Technology in the Theory of International Trade", Ron Jones (1970, p.85) asked: "What determines technical change?" Jones argued (p.87) that a sensible approach to answering this question would "entail setting up a distinction between the use of resources to produce [a] commodity and the use of resources to produce new technical knowledge." He noted further (p.87) that "expectations as to the future sales must affect the quantity of resources devoted to improving the technology." Finally, he challenged (p.89) trade theorists to ponder "how transmittable technical change is from one country to another." Even in idealized circumstances, he recognized (p.89), "technical progress in one country may not spill over to actually affect techniques used in other countries."

Twenty years later, we take up Jones' challenge, using exactly the approach that he proposed. Our analysis focuses on the issue that Jones raised concerning the implications for technical change and for patterns of trade of less than complete international spillovers of the public good that is technical knowledge.

In Grossman and Helpman (1991, ch.7) we have studied a world economy in which countries share in a common pool of general knowledge capital. A community of industrial researchers in each of two countries combines knowledge capital with two primary resources (human capital and unskilled labor) to generate blueprints for new, horizontally differentiated products. The countries manufacture these "high-technology" products and a homogeneous, traditional good using the same two primary inputs. Trade entails the exchange of the homogeneous good and some unique varieties of differentiated products manufactured in one country for the unique differentiated products of the other. Comparative advantage in the high-technology industry derives from endogenous activity in the research lab.

In this setting, we have established the validity of a dynamic version of the Heckscher-Ohlin theorem. The long-run trade pattern is determined entirely by relative factor endowments. A country that is relatively well endowed with human capital devotes relatively more resources to R&D (which we take to be intensive in its use of human capital), and comes to specialize relatively in producing the goods that require innovative technologies. The country that has an abundance of unskilled labor, on the other hand, specializes relatively in the production of (unskilled labor-intensive) traditional goods. Due to this pattern of specialization, the human capital abundant country enjoys a faster pace of technological progress and a higher rate of output growth than its international trade partner.

But the assumption of a common world pool of public knowledge capital seems at odds with aspects of reality. The concentration of research activities in places like the Silicon Valley and Route 128 near Boston suggests the possibility that technological spillovers may be geographically localized. This would be the case, for example, if highly trained personnel moving between research firms served as the principle conduit for the information exchange. But if knowledge capital stocks are location specific, then not only input prices but also prior research experience may affect a country's competitiveness in the research lab.

In this paper, we study a world economy with national stocks of knowledge capital. Entrepreneurs in each of two countries develop new technologies when expected future profits justify the up-front R&D outlays. Research productivity depends upon the stock of knowledge capital, which accumulates in proportion to local research activity. Our aim in all this is to illuminate the role of history in the determination of world trading patterns. Can a country overcome a late start in research to develop a comparative advantage in high-technology products, or will the latecomer be forever confined to exporting traditional products? With national stocks of knowledge capital and no exogenous comparative advantage, the answer to this question turns to be unequivocal.

II. A Model of Product Innovation

The world economy comprises two countries that may differ only in their prior experience in research. The countries are endowed with similar quantities of a single primary factor of production, which we call labor.[1] They use this labor to invent new varieties of differentiated products, to manufacture the previously developed differentiated brands, and to produce a homogeneous, "traditional" good. Both types of goods are traded on world markets, so that international trade has both intra-industry and inter-industry components.

Consumers worldwide share the same preferences. The representative household maximizes an intertemporal utility function of the form

$$(1) \qquad U(t) = \int_t^{\infty} e^{-\rho(\tau-t)} \log u(\tau)\, d\tau,$$

[1]In Grossman and Helpman (1991, ch.8) we conduct a more complete analysis that allows also for differences in country size. We shall note in the concluding section how some of our results depend upon the assumption of equally sized countries.

where $u(\tau)$ represents instantaneous utility at time τ and ρ is the subjective discount rate. Instantaneous utility is given by

(2) $$u = \left[\int_0^n x(\omega)^{\alpha} \, d\omega\right]^{\sigma/\alpha} y^{1-\sigma}, \quad 0 < \alpha,\sigma < 1,$$

where $x(\omega)$ denotes consumption of differentiated brand ω, y denotes consumption of the traditional good, and $n(t)$ represents the measure of differentiated products available at time t. These familiar preferences imply an elasticity of substitution between every pair of varieties equal to $\epsilon = 1/(1-\alpha)$, an elasticity of substitution between the differentiated products and the homogeneous good of one, and an intertemporal elasticity of substitution that is equal to one as well (see, for example, Helpman and Krugman, 1985). They yield static demands of the form

(3) $$x(\omega) = \sigma E p_X(\omega)^{-\epsilon}\left[\int_0^n p_X(\omega')^{1-\epsilon} d\omega'\right]^{-1}, \quad \omega \in [0,n],$$

(4) $$y = (1-\sigma)E/p_Y,$$

where $p_X(\omega)$ denotes the price of variety ω of the differentiated product, p_Y denotes the price of the homogeneous good, and E is aggregate spending. Dynamic optimization requires that spending evolve according to

(5) $$\dot{E}/E = r - \rho,$$

where r is the instantaneous interest determined on the integrated world capital market (see Grossman and Helpman, 1989).

The technology for manufacturing the traditional good is common knowledge to producers around the world. This good is supplied competitively by firms that derive one unit of output from each unit of labor input. Together, these considerations imply

(6) $$p_Y = \min (w^A, w^B),$$

(7) $$Y^i = 0 \quad \text{if } w^i > w^j, \qquad i = A,B;\ i \neq j,$$

where w^i is the wage rate in country i, $i = A,B$, and Y^i is the aggregate output of traditional goods there. By contrast, the technologies for the differentiated products are proprietary information. No firm can produce any such good until it has developed a design and perfected the necessary production techniques. The introduction of new products requires the allocation of resources to R&D, as we shall describe below. Once a firm has developed a blueprint, it can assemble the brand with one unit of labor per unit of output.

At a point in time, the number of firms with the ability to produce varieties of differentiated products is given by history. The firms engage in (static) price competition. Since firms that manufacture an identical product earn zero profits in a Bertrand competition, there will be no (costly) imitation undertaken in the equilibrium that we describe. Thus, no brand has more than a single producer. Each producer behaves as a monopolist in its own submarket. Facing the demands in (3), the (small) purveyor of a unique variety in country i maximizes profits by setting the price

(8) $$p_x^i = w^i/\alpha,$$

which is a fixed mark-up over the (local) unit production cost. With this price and the demands in (3), the n^i monopolists in country i attain an aggregate market share in the differentiated products industry equal to

(9) $$s_x^i = n^i(p_x^i)^{1-\epsilon}/\Sigma_j n^j(p_x^j)^{1-\epsilon} .$$

Each monopolist in country i captures instantaneous profits given by

(10) $$\pi^i = (1-\alpha)\sigma s_x^i E/n^i .$$

Entrepreneurs develop new blueprints using labor and the existing stock of (public) knowledge capital. The knowledge capital stock K^i in country i reflects the accumulated wisdom in applied science and engineering in the local research community. The greater is the level of understanding of basic scientific principles, the smaller is the quantity of labor needed to invent a new product. In particular, we assume that an entrepreneur located in country i can learn the technology for dn new products per unit time by allocating dn/K^i units of labor per unit time to research activities. Therefore, the measure of products known to some firm in country i expands according to

(11) $$\dot{n}^i = K^i L_n^i , \qquad i = A,B,$$

where L_n^i is the aggregate amount of labor devoted to R&D.

We follow Romer (1990) in assuming that knowledge capital accumulates as a byproduct of industrial research. This specification captures the notion that new research builds upon earlier ideas, and that researchers often make discoveries in the course of developing new products that have widespread applicability, but with benefits that are difficult to appropriate. We assume that each research product makes a similar contribution to the public stock of knowledge capital. But, whereas in our previous work (Grossman and Helpman, 1990; 1991, ch.7) we took these spillovers to be global in reach, here we make the opposite extreme assumption. That is, we confine the spillover benefits from research to the local community in which they are generated.[2] This makes the stocks of knowledge capital specific to each country, and the accumulation of knowledge capital proportional to the local research effort. More specifically, we take

(12) $$K^i = n^i,$$

since n^i reflects the cumulative amount of research activity that has been undertaken in country i. By making productivity in R&D depend upon the state of knowledge, and this a function of prior research experience in a particular location, we have introduced the potential for history and initial conditions to influence the equilibrium outcome.

We allow entrepreneurs to enter freely into R&D. Let v^i be the market value of a blueprint held by a producer in country i. Then an entrepreneur can attain v^i by bearing the product development cost, w^i/K^i. No R&D takes

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[2]Reality undoubtedly lies between these extremes. A more plausible specification might include, for example, lags in the diffusion of knowledge that are shorter within a country than between countries. See Grossman and Helpman (1990) for an analysis of this intermediate case.

place in country i when the research cost exceeds the benefit, whereas unbounded demand for labor results when the benefit exceeds the cost. Thus free entry implies, in the light of (12), that

$$(13) \qquad v^i \leq w^i/n^i, \qquad \text{with equality when } \dot{n}^i > 0 .$$

We equate the value of a blueprint with the present discounted value of the profits that accrue to its owners. That is,

$$(14) \qquad v^i(t) = = \int_t^{\infty} e^{-[R(\tau)-R(t)]} \pi^i(\tau)d\tau .$$

where $R(t) \equiv \int_0^t r(\tau)d\tau$ is the cumulative discount factor applicable at time t. Differentiating (14) with respect to t, and rearranging terms, we find

$$(15) \qquad \pi^i/v^i + \dot{v}^i/v^i = r.$$

This "no-arbitrage condition" equates the sum of the dividend rate and the rate of capital gain on blueprints (a perfectly safe asset in the present context) to the rate of return on a consumption loan.

We close the model by specifying the market clearing conditions for goods and factors, and by choosing a numeraire. In the market for traditional goods, the value of supply equals the value of demand, or

$$(16) \qquad p_Y(Y^A + Y^B) = (1-\sigma)E.$$

In the market for differentiated products, each country must produce aggregate output that matches in value the total amount of spending devoted to its varieties; i.e.,

$$(17) \qquad p_X^i X^i = \sigma s_X^i E ,$$

where $X^i = n^i x^i$ is the total quantity of differentiated products manufactured in country i. Finally, in the factor markets, we must have aggregate derived demand equal to the exogenous labor supply L in each country; i.e.,

$$(18) \qquad g^i + X^i + Y^i = L,$$

where $g^i \equiv \dot{n}^i/n^i$ is the rate of new product development in country i, and also the aggregate employment in R&D there.

As in all economies that lack a monetary sector, there is nothing here to determine the path of nominal prices. We are free to choose any normalization of prices that we wish, and our choice will have no bearing on the equilibrium allocation. Accordingly, we set

$$(19) \qquad E(t) = 1, \quad \text{for all } t.$$

This choice of numeraire turns out to be convenient, because when combined with (5) it implies equality between the nominal interest rate and the subjective discount rate at every moment in time. We record that

$$(20) \qquad r(t) = \rho, \quad \text{for all } t.$$

III. Steady States

In this section, we identify all steady-state equilibria that may emerge as long-run outcomes of the innovation process described in Section II. Then, in the following two sections, we analyze the equilibrium dynamics that lead to one or another of these steady states.

A steady-state equilibrium (or "balanced growth path") is characterized by a fixed intersectoral allocation of resources in each country. Using (6)-(9), (16)-(17), and (19), we may rewrite the labor market clearing conditions (18) as

$$(21) \qquad g^i + \alpha\sigma s_X^i/w^i + (1-\sigma)s_Y^i/w^i = L ,$$

where $s_Y^i = Y^i/(Y^A + Y^B)$ is the market share of country i in the traditional manufacturing sector. From this and the fact that the market shares are bounded by zero and one, we see that a constant intersectoral allocation of resources requires constant rates of innovation, constant wage rates, and constant market shares in each country.

Let us consider now the several possible long-run outcomes. First, R&D may be concentrated in a single country, while traditional goods emanate from both locations. Since the latter goods are competitively priced, both countries can supply them only if their wage rates are the same; i.e., $w^i = w$. Then, if country j innovates and country k does not, the former country captures in the long run all but a negligible share of the world market for differentiated products. With $s_X^j = 1$ and $g^k = s_X^k = 0$, (21) implies

(22) $$g^j + \alpha\sigma/w + s_Y^j(1-\sigma)/w = L,$$

(23) $$s_Y^k(1-\sigma)/w = L.$$

Also, we can differentiate the free-entry condition (13), which holds as an equality for country j, and substitute the result, together with the expressions for profits for firms operating in country j (10), for the nominal interest rate (20), and for spending (19), into the no-arbitrage condition (15), to derive

(24) $$(1-\alpha)\sigma/w = \rho + g^j,$$

Then (22)-(24), together with $s_Y^j + s_Y^k = 1$, determine the long-run wage rate common to the two countries, the long-run rate of product development, and the long-run market shares in the industry producing traditional goods. For the feasibility of this allocation, we require $s_Y^i \geq 0$, $i = j,k$. From the solution to the system, this implies

(25) $$L/(L+\rho) \leq (1-\sigma)/\sigma.$$

In other words, a steady-state equilibrium of the type just described can arise only if the budget share of the differentiated products is not too large.

A second type of steady-state equilibrium also has R&D concentrated in one location, but it has the production of traditional goods concentrated as well. Suppose that only country j innovates and only country k produces traditional goods. This requires $w^k \leq w^j$. The labor market clearing conditions that apply in the steady state now read

$$g^j + \alpha\sigma/w^j = L, \tag{26}$$

$$(1-\sigma)/w^k = L, \tag{27}$$

while the long-run no-arbitrage condition analogous to (24) takes the form

$$(1-\alpha)\sigma/w^j = \rho + g^j. \tag{28}$$

From these it is simple to calculate that $w^k \leq w^j$ if and only if

$$L/(L+\rho) \geq (1-\sigma)/\sigma. \tag{29}$$

Notice that (29) is just the opposite inequality from (25). The innovating country specializes its long-run manufacturing activities in the production of differentiated products when the share of these goods in total spending is relatively large.

A third type of steady-state equilibrium involves equal rates of innovation in the two countries, and the production of traditional goods in both locations. With $g^j = g^k = g$, and $w^j = w^k = w$ (as required by the condition of competitive pricing in the traditional manufacturing sector), the steady-state labor market clearing conditions become

$$g + \alpha\sigma s_X^i/w + (1-\sigma)s_Y^i/w = L, \qquad i = j,k, \tag{30}$$

while the no-arbitrage conditions that apply to the value of firms in either location read

$$(31)\qquad (1-\alpha)\sigma s_x^i/w = \rho + g, \qquad\qquad i = j,k.$$

From (31) we see that $s_x^j = s_x^k = 1/2$. Then (30) implies $s_Y^j = s_Y^k = 1/2$. In this case, long-run resource allocations are the same in both countries.

This exhausts the possibilities for feasible, steady-state outcomes. It is not possible, for example, for the countries to develop new products at different rates in the long run, because then the no-arbitrage condition for the slower innovating country would require its wage to approach zero along with its market share in the differentiated products industry. But a zero wage would imply a zero price of traditional goods, and thus infinite demand for these products. Also, both countries cannot innovate at the same rate with only one of them producing traditional goods, because then the two labor markets could not both clear.[3]

We see that, for any set of parameter values, there exist exactly <u>three</u> different steady-state equilibria. In two of these, the R&D activity is concentrated in a single country, while the remaining country specializes (almost entirely) in the production of traditional goods.[4] In the third

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[3]If both countries innovate at the same rate, both employ equal quantities of labor in R&D. Also, the no-arbitrage conditions require $s^j/w^j = s^k/w^k$, when $g^j = g^k$. But then both counries employ similar quantities of labor in manufacturing differentiated products. Since the countries are of equal size, the labor markets cannot both clear if one uses labor in the production of traditional goods and the other does not.

[4]It also manufactures a negligible quantity of the unique varieties that its firms knew to produce to begin with.

equilibrium, the countries allocate their resources similarly in the long run, and achieve equal rates of innovation. It can be shown, however, that this "interior" allocation is globally unstable (see Grossman and Helpman, 1991, ch.8). That is, unless the countries happen to begin with the same prior experience in research and thus equal stocks of knowledge capital, the world economy can never reach the equilibrium in which both countries innovate. Moreover, if this equilibrium ever is attained, any slight perturbation that causes the countries to innovate at different rates for even a brief moment puts the world economy on a path that diverges from the initial steady state. In the light of this instability, we shall focus our attention henceforth on the equilibria that have geographic concentration of research activity.

The question that faces us now is: which country innovates? In principle, either country could play the role of the innovator, since the countries have similar endowments and similar natural abilities. But one of them may inherit a head start in the technology race, for reasons of historical accident, or otherwise. Can the other country overcome its initial deficiency in knowledge capital? Will there be multiple equilibria supported by self-fulfilling expectations? Or does history seal a country's fate? We answer these questions in the sections that follow.

IV. Equal Wage Trajectories

We begin with the case in which $L/(L+\rho) \leq (1-\sigma)/\sigma$, so that the two long-run equilibria of interest involve production of traditional goods in both countries. We will show that, if the world economy is large enough, then there exists an equilibrium trajectory characterized by cross-country wage equality at every moment in time, and R&D activity that is always concentrated in a single country. Along this trajectory, only the country that inherits the larger stock of knowledge capital can play the role of the innovator.

Let us conjecture the existence of an equal-wage trajectory, and begin to investigate its properties. The issues having to do with existence will become clear as we proceed. We let $\bar{n}^i$, i = A,B, denote the initial numbers of differentiated products and the initial stocks of knowledge capital in the two countries. For concreteness, we take $\bar{n}^A > \bar{n}^B$. It follows immediately that if $w^A = w^B$ all along the equilibrium path, then only country A can engage in research. For, if wage rates are equalized, so too are per-brand profits (see (9) and (10)). Then (14) implies $v^A = v^B$; i.e., blueprints have the same value in either location. But if R&D offers the same reward everywhere, the capital market will finance the efforts of entrepreneurs only in the location where research costs are lowest. Initially, country A is the lower cost innovator, because researchers there are more productive and factor prices are everywhere the same. But then country A widens the technology gap over time, and so the concentration of R&D activity is self-perpetuating.

Along an equal-wage trajectory, the wage rate is guided by the no-arbitrage condition that applies to blueprints held by firms in country A. Using (15), (8), (19), (20), and $v^A = w/n^A$ (which follows from (13) and the fact that $g^A > 0$), we have

$$\dot{w}/w = g^A + \rho - (1-\alpha)\sigma s^A/w. \tag{32}$$

Next we sum the labor market clearing conditions (21) that apply for i = A and i = B, to derive

$$(33) \qquad g^A = 2L - [1 - (1-\alpha)\sigma]/w.$$

Finally, we combine (32) and (33) to obtain

$$(34) \qquad \dot{w} = w(\rho + 2L) - [1 - (1-\alpha)\sigma] - (1-\alpha)\sigma s_x^A.$$

In Figure 1, the line segment DE shows combinations of the wage rate and the market share of country A in the differentiated products industry that imply no change in the wage rate, per (34). This line has been drawn only for values of $s_x^A \geq 1/2$, because with $w^A = w^B$, (9) implies that $s_x^A = n^A/(n^A+n^B)$, and we have seen that country A innovates only if $n^A > n^B$. The arrows in the figure show the direction of movement of the variables at all points. The market share of country A always is rising for $1/2 \leq s_x^A < 1$ (provided that g^A in (33) is positive), because this country expands through time its share in the total number of differentiated products, and the terms of trade do not change.[5] The wage rate rises above DE, and falls below it. We see that a unique trajectory leads to the steady-state equilibrium at E.

The figure also shows the constraints on the wage and the market share that must be satisfied for there to exist a momentary equilibrium with equal wages. Feasibility requires non-negative allocations of resources to all activities. For non-negative employment in the R&D sector of country A, we need the right-hand side of (33) to be non-negative. This restricts us to the

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[5]Differentiating (9) with respect to time, and noting $p_x^A = p_x^B$, $g^B = 0$, and (33), we find $\dot{s}^A = s^A(1-s^A)\{2L - [1 - (1-\alpha)\sigma]/w\}$, which is positive for $0 < s^A < 1$ and $g^A > 0$.

region above the horizontal line FF'. Provided that L is sufficiently large, point F lies below point D, and this constraint does not bind.[6] For $s_Y^B \geq 0$ and $s_Y^A \geq 0$, we must have

$$(35) \qquad 0 \leq wL - a\sigma(1-s_x^A) \leq 1-\sigma,$$

in the light of the expression for s_Y^B that derives from (21) and $g^B = 0$. This confines us to the region bounded by the lines labelled $s_Y^A = 0$ and $s_Y^B = 0$. The former line lies everywhere above point E, when $L/(L+\rho) \leq (1-\sigma)/\sigma$. The latter line lies everywhere below the horizontal line through F, and thus never binds when $g^A \geq 0$. We conclude that an equal-wage trajectory with positive innovation exists, whenever

$$(1-\sigma)/\sigma \geq L/(L+\rho) \geq 1 - (1-a)\sigma.$$

We have established conditions under which a productivity lead in R&D will be self-sustaining for country A. Of course, the same conditions apply to country B, if that country happens to inherit the larger knowledge base. Moreover, neither country can overcome an initial productivity disadvantage along a trajectory that maintains wage equality. Thus, the equal-wage trajectories exhibit a strong form of hysteresis. Events in history that may have provided one country with a head start in the accumulation of knowledge

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[6] More precisely, this requires $L/(L+\rho) \geq 1 - (1-a)\sigma$. If this condition is not satified, then part of the trajectory HE may pass below FF', in which case there will be no innovation if the countries begin with nearly equal numbers of differentiated products. If the entire trajectory HE lies below FF', as will occur if $2L/(2L+\rho) > 1 - (1-a)\sigma$, then the world economy experiences no innovation, regardless of the initial product shares.

will have long-lasting effects.[7]

Along the equilibrium trajectory HE, the economies follow very different paths of economic development. In country A, the rate of innovation rises through time. The rising wage increases costs in all activities, but the accumulating stock of knowledge capital makes the cost of research rise less quickly than other costs. Therefore, resources move from the manufacturing sectors into R&D. Country B, on the other hand, experiences no technological progress, and sees its labor force drift from the differentiated products industry to the traditional manufacturing sector. As a result, its pattern of trade becomes more and more skewed over time.

One should be careful, however, in attaching normative significance to these findings. Along the equilibrium trajectory, residents of the two countries earn similar labor incomes, because their wage rates are the same. They face similar investment opportunities, because world capital markets are integrated. And they enjoy similar consumption opportunities, thanks to international trade. It follows that households with similar levels of initial wealth fare identically along any equal-wage trajectory.

IV. Unequal-Wage Trajectories

We turn now to the case in which $L/(L+\rho) > (1-\sigma)/\sigma$. For such parameter values, the intersection of the $s_Y^A = 0$ line in Figure 1 with the vertical axis at $s_X^A = 1$ lies below the point E. Thus, the equal-wage trajectory must pass into the region where the constraint $s_Y^A \geq 0$ becomes binding. As country A comes to dominate the world market for differentiated products, the

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[7]Markusen (1991) obtains a similar result in a two-period model. Related findings are reported by Krugman (1987), Feenstra (1990), and Young (1991).

fulfillment of the demands for labor by the manufacturers of these goods and by research firms leaves less and less to spare for the traditional manufacturing sector. Eventually, the traditional sector releases all of its resources, and still the combined labor demand of the remaining two activities continues to grow. At that moment, the wage rates in the two regions begin to diverge.

The eventual, or perhaps immediate, divergence in wage rates does not alter the main conclusions from the previous section. In particular, it continues to be the case that, in the international technology race, a country that begins ahead, stays ahead. No country can ever overcome an initial deficit in knowledge capital. In the long run, the country that trails initially loses all of its production base in the differentiated products industry.

To establish these claims, let us suppose that the opposite were true. Then there must come a time when the lagging country (call it country B), trails by only a small amount in the technology race. Since we assume that country B overtakes country A, the rate of knowledge accumulation in the former country must be higher than that in the latter. Suppose that $w^B < w^A$ at that moment when $n^B = n^A - e$, for e small and positive. Since $g^B > g^A$, country B employs more workers in R&D at that moment than country A. With $w^B < w^A$ and the number of brands produced by each country almost equal, country B also employs as much or more labor in the production of differentiated varieties.[8] Finally, if $w^A < w^B$, country B devotes labor to

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[8]The differentiated products industry employs $a\sigma s^i/w^i$ units of labor in country i. With $w^B \leq w^A$ and $n^B \approx n^A$, equation (9) implies $s^B/w^B \geq s^A/w^A$.

traditional manufacturing, while country A does not. Therefore, at the moment when $n^B = n^A - e$, if $w^B < w^A$, country B allocates more labor to every use. This contradicts the assumption that the countries are of equal size.

The remaining possibility is that $w^B \geq w^A$ when $n^B = n^A - e$. Then entrepreneurs in country B, with lower productivity in the research lab and no factor cost advantage, must face higher costs of product development than their counterparts in country A. The entrepreneurs in country B can attract financing under these circumstances only if their prospective reward from developing a new product exceeds that which is available to entrepreneurs in country A; i.e., only if $v^B > v^A$. But firms in country B can have greater value than those in country A only if per-brand profits are higher in the former country than in the latter over some finite interval of time. During this time, which presumably would come after country B had taken the technological lead, the wage rate in country B would need to be lower than that in country A. But then country B would experience the greater derived demand for labor by manufacturers of differentiated products, and only country B would use labor for producing traditional goods. Again, this contradicts our assumption that the countries have equal labor supplies under the hypothesis that country B introduces new products more quickly. It follows that the wage in country B cannot be greater than, equal to, or less than that in country A at the moment when $n^B = n^A - e$. We reject the hypothesis that country B can eliminate its knowledge deficit.

When $L/(L+\rho) > (1-\sigma)/\sigma$, the country that conducts R&D does not also produce traditional goods in the steady-state equilibrium. Let us investigate the equilibrium dynamics in a regime in which country A alone innovates and country B alone produces traditional goods, in order to see whether the steady state can be reached along a trajectory that everywhere maintains this pattern of international specialization.

Using the expression (10) for per-brand profits in country A, the free entry condition (13) that applies in that country, and the expressions for spending (19) and the interest rate (20), we can re-express the no-arbitrage condition (15) that applies to the value of brands produced in country A as

$$\dot{w}^A/w^A = g^A + \rho - (1-\alpha)\sigma s_X^A/w^A. \tag{36}$$

Then we can substitute for g^A using the labor market clearing condition (21), with $s_Y^A = 0$. This yields the following differential equation for the wage rate in country A:

$$\dot{w}^A = w^A(L + \rho) - \sigma s_X^A. \tag{37}$$

We use (37) in Figure 2 to plot the combinations of the wage rate and the market share of the innovating country that imply a constant value for w^A. Above the line labelled $\dot{w}^A = 0$ the wage in country A rises, while below the line it falls.[9]

Next we determine the evolution of the market shares in the differentiated products industry. Differentiating (9) and noting $g^B = 0$ and $\epsilon = 1/(1-\alpha)$, we obtain

$$\dot{s}_X^A = s_X^A(1-s_X^A)\left[\, g^A - \frac{\alpha}{1-\alpha}\,(\dot{w}^A/w^A - \dot{w}^B/w^B)\,\right].$$

[9]Figure 2 has been drawn for a particular set of parameter values. These are: $L = 2$, $\rho = 0.3$, $\sigma = 0.8$, and $\alpha = 0.8$.

The labor market constraint for country B implies $\dot{w}^B = -a\sigma\dot{s}_x^A/L$ when $g^B = 0$, while the labor market constraint for country A implies $g^A = L - a\sigma s_x^A/w^A$. Substituting these relationships and (37) into the expression for $\dot{s}_x^A$, we find

$$(38) \qquad \dot{s}_x^A = \frac{s_x^A(1-s_x^A)[1-\sigma+a\sigma(1-s_x^A)]}{(1-a)(1-\sigma) + [1-a(1-s_x^A)]a\sigma(1-s_x^A)} [a\sigma s_x^A/w^A + (1-2a)L/a - \rho].$$

When $(1-a)L > a\rho$, as is required for an equilibrium with sustained innovation, the term in brackets on the far right-hand side of (38) is positive at all points above the $\dot{w}^A = 0$ locus. Then the market share of country A is rising in this region, for all $s_x^A < 1$. We have indicated this fact by the arrows in Figure 2. With these dynamics, only one trajectory (labelled DE) leads to the steady-state equilibrium at point E.

The trajectory DE represents an equilibrium path, provided that it implies no contradiction of the assumptions upon which its construction was based. For example, the assumption that country B performs all manufacturing of traditional products requires the wage in that country not to exceed the wage in country A (see (7)). From the labor market clearing condition for country B (21) and the hypothesis that $g^B = 0$, we calculate

$$(39) \qquad w^B = [(1-\sigma) + a\sigma(1-s_x^A)]/L.$$

The line labelled w^B in the figure shows the relationship between the wage in country B and the market share of country A in the differentiated products industry. The equilibrium path must not cross below this line, as will be the case if the initial market share exceeds $\tilde{s}_x^A$.

The construction of DE relied also on the assumption that country B performs no research. To justify this assumption, we must check that R&D always is unprofitable in country B. The profitability of research hinges on a comparison of research rewards, v^B, and research costs, w^B/n^B. No research takes place when $v^B < w^B/n^B$, or when $V^B < w^B$, where $V^B \equiv n^B v^B$ is the aggregate value of firms operating in country B. To locate V^B in the figure, we first calculate how this value changes through time, as dictated by the no-arbitrage condition. Making the usual substitutions of (10), (19) and (20) in (15), we find that when $g^B = 0$,

$$\dot{V}^B = \rho V^B - (1-\alpha)\sigma(1-s_x^A). \tag{40}$$

Thus, V^B must approach zero in the long run, or else it will rise without bound. The latter possibility is excluded by the valuation equation (14), since per-brand profits are bounded from above. For V^B to approach zero, its initial value must fall below the $\dot{V}^B = 0$ schedule (derived from (40)) in Figure 2. Then, the value of firms in country B follows a trajectory such as the one labelled V^B in Figure 2. The parameter values that were used in drawing the figure locate this trajectory below the w^B line for all $s_x^A \leq \tilde{s}_x^A$. In this case and others like it, the assumption that country B performs no research is well justified.

We conclude that, for the parameter values used in the figure, if country A inherits a fraction of the world's differentiated products that affords it an initial market share in this industry in excess of $\tilde{s}_x^A$, then the trajectory labelled DE in Figure 2 represents an equilibrium growth path. Along this path, the wage in country A always exceeds that in country B, and country A captures an ever growing fraction of world sales in the differentiated products industry. The long-run pattern of trade in this case entails (net) exports of differentiated products by country A and exports of traditional goods by country B.

What happens if the initial market share of country A in the differentiated products industry happens to fall short of the critical level $\tilde{s}_x^A$? In this case, country B will not be able to satisfy all of world demand for traditional goods and also produce its unique varieties of differentiated products. During an initial phase of the dynamic equilibrium, the wage rates in the two regions must be equal, and country A must contribute some of world supply of traditional goods. Only later, when the market share of country B in the differentiated products sector becomes sufficiently small, does the divergence in wage rates take effect, and with it the cessation of traditional manufacturing in the innovating country.

One last possibility can arise for parameter values different than those that underlie Figure 2. In Figure 3 we have drawn a case where the path of aggregate firm values passes above the line w^B, for a range of market shares in excess of $\tilde{s}_x^A$. In this case, the trajectory DE will not be feasible during an initial phase of the dynamic equilibrium (when the market share of country A is less than $\hat{s}_x^A$), because the implied wage rates and brand values make R&D a profitable activity in country B. Instead, the equilibrium has an initial period with active research in both countries, but with more rapid innovation taking place in country A than in country B. During this period, the lower factor costs that prevail in country B, and the higher profit rates that result from this cost advantage, offset the country's productivity disadvantage in the research lab. But the disadvantage grows over time, as country A accumulates knowledge capital more quickly, and eventually R&D becomes unprofitable in country B. This occurs when the economy reaches point C in the figure, whereupon R&D ceases in country B and the economy proceeds along the path leading to the steady state at E.

We can summarize our findings as follows. When $L/(L+\rho) > (1-\sigma)/\sigma$, then the long-run equilibrium necessarily involves the concentration of R&D activity in the country that inherits the larger stock of knowledge capital, and the concentration of traditional manufacturing in the other country. Depending upon parameter values and the initial difference in knowledge capital, the entire transition to the steady state may be characterized by this same pattern of specialization, or else there may be an initial phase with traditional manufacturing in the country that does none of this activity eventually, or with active R&D in the country that fails to innovate in the long run. In any case, the country that begins ahead in the technology race enjoys faster growth in real output all along the equilibrium trajectory, and a discounted value of (lifetime) labor income that exceeds that of its trade partner.

V. Subsidies to R&D

We have seen that initial conditions fully determine long-run outcomes when technological spillovers are confined to the country in which they are generated. In all cases, a country that begins ahead in the research race realizes faster output growth at every moment in time and exports technology-intensive goods in the long run. We ask now whether the government of an initially lagging country can use policy intervention to change its ultimate fate, and whether such policies that "tip" the equilibrium can be justified on grounds of social welfare.

For the purpose of illustrating this potential use of policy, we introduce an R&D subsidy in the country that begins with the smaller stock of knowledge capital. Under this policy, the government (of country A, say) pays a fraction z of all research expenses. Despite the policy intervention in the market, wage rates may nonetheless be the same in both countries all along the equilibrium trajectory. We will concentrate our formal analysis on this case. With wage rates equalized at all points in time, the value of brands produced in the different countries must also be equal. Thus, R&D activity will be concentrated in the country that has the lower <u>private</u> cost of research. This will be the lagging country A, whenever $(1-z)/n^A < 1/n^B$, or when $s_x^A = n^A/(n^A+n^B) > (1-z)/(2-z)$. For values of z approaching one, this inequality must be satisfied.

When, in an equal-wage regime, entrepreneurs in country A conduct research with the support of their government, free entry implies

$$v = (1-z)w/n^A. \tag{41}$$

Then $\dot{v}/v = \dot{w}/w - g^A$, and the no-arbitrage condition becomes

$$\frac{\dot{w}}{w} = g^A + \rho - \frac{(1-\alpha)\sigma s_x^A}{(1-z)w}. \tag{32'}$$

The labor market clearing conditions are the same as before, so (33) continues to give the rate of product development as a function of the wage rate. Substitution of this expression into (32') gives the differential equation for the wage rate that applies in a subsidy regime, namely

$$(34') \qquad \dot{w} = w(\rho + 2L) - [1 - (1-a)\sigma] - (1-a)\sigma s_x^A/(1-z).$$

Using (34'), we can find the combinations of the wage rate and the market share which imply a stationary wage. These values are depicted by the line segment CE' in Figure 4. The line has been drawn only for market shares in excess of $s_x^A = (1-z)/(2-z)$, because the assumption that entrepreneurs in country A conduct research requires s_x^A to be at least this large. Above the line the wage rises when a subsidy is in effect, while below the line it falls.

If the subsidy is permanent, the world economy converges to a steady state at point E' along the trajectory labelled FE'. The subsidy allows country A to replace country B as the increasingly dominant producer of differentiated products. Point E' lies above point E^B, the steady-state equilibrium that would obtain in the absence of the subsidy. This means that the subsidy raises the long-run wage rate. Then, from (33), we see that it increases the long-run rate of innovation as well.

The subsidy need not be permanent, however, for it to induce a long-run equilibrium with country A dominant in the world market for differentiated products. All that is required for this outcome is that the subsidy remain in effect until country A has overcome its knowledge deficit. Let us suppose, for example, that the government in country A announces a temporary subsidy for R&D that will expire on date T. Before time T, equation (33') guides the movement in the wage rate. But once the subsidy has been removed, equation (33) must apply. We know, moreover, that there can be no jump in the value of blueprints at time T. Otherwise, investors would stand to make infinite capital gains or losses. It follows from this that the wage must fall discretely at time T, so that the private cost of innovation equals the value of a blueprint both before and after the policy change.

We can use Figure 4 once more to describe the equilibrium trajectory that obtains with a temporary subsidy. In the figure, we have reproduced from Figure 1 the saddle path that leads to the steady-state equilibrium at point E^A. Recall that the economy follows this path when, in the absence of government policy, country A has an initial advantage in research productivity. With the subsidy in place, the world economy travels at first along the trajectory labelled MM' (where M gives the initial product share of country A). By time T, the point labelled M' is reached. Then, the government removes the subsidy, and the wage falls by z percent, to the level indicated by point N. Thereafter, the economy follows the saddle path trajectory to the long-run equilibrium at point E^A. How can we be sure that the wage drop at time T will leave the economy on the saddle path trajectory? Clearly, the initial wage at point M must be chosen "correctly", so as to ensure this outcome.

Evidently, temporary government policies can turn a stagnant economy into a growing one, and reverse entirely a country's long-run pattern of trade. This finding reflects again the hysteretic properties of the equilibrium dynamics. Temporary shocks can have permanent effects when "initial conditions" matter.

Would a government that is motivated by concerns for social welfare choose to implement such policies? In the situation described by Figure 4, the answer is "probably not". The equalization of wage rates both with and without the subsidy means that the policy has no effect on the terms of trade. The subsidy's effects on national welfare stem from the induced effects on the equilibrium rate of innovation and the efficiency with which any research is carried out, and from the budgetary implications of the policy.

The subsidy causes research activity to relocate from a place where knowledge capital is relatively abundant to one where it is initially scarce. This raises the resource cost of achieving any given rate of innovation, with adverse consequences for welfare in both countries. The subsidy has an ambiguous effect on the world rate of innovation. The direct effect of the inducement works to promote product development, but the indirect effect associated with the rise in the resource cost of this activity works in the opposite direction. If the aggregate rate of innovation falls, then residents of country A certainly lose from the policy, because the free market equilibrium has a pace of technological progress that is already suboptimally slow.[10] Even if the rate of innovation rises, the residents of country A may not gain from this, because the benefits of faster product development are shared globally under a free-trade regime, whereas the fiscal costs of the subsidy are borne entirely at home.

An important message emerges from this discussion. In a world economy with international trade in goods and assets, the growth rate of domestic output provides a poor measure of national welfare. A country that specializes its production activities in sectors that offer little prospect for technological progress may nonetheless benefit as much as others from the

[10]Due to the positive externalities that are generated by industrial research and the non-competitive pricing of the differentiated products, the market allocates fewer resources to R&D than is socially optimal.

advances that are made in the more progressive sectors of the world economy. Here, commodity trade offers the residents of the non-innovating country the opportunity to consume the complete range of innovative products, while asset trade provides these households with the opportunity to reap high rates of return on their savings.

But even in this context, there do exist circumstances under which a subsidy to R&D in the technologically lagging country might be justified on grounds of national welfare. Consider, for example, the scenario of Section IV, where parameter values are such that the steady-state equilibrium cannot support equal wage rates in the two countries. We recall that, in this case, the long-run wage rate is higher in the country that captures the R&D activity. Thus, a tipping policy such as the one described above may effect an increase in labor income relative to the level that would obtain in the absence of policy. Then, national welfare may be increased by the intervention as well. This argument for policy is similar to the one offered by Frank Graham (1923), which recently has been formalized in Ethier (1982). Ethier showed, in the context of a static, two-sector model of trade with increasing returns to scale in one sector, that a country might benefit from policies that ensure local production of the increasing returns good.[11]

VI. Concluding Remarks

The stark findings of this paper -- that initial conditions fully determine long-run trading patterns, and that a deficit in the technology race

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[11]We note that a lagging country might also benefit from R&D subsidies in situations where opportunities for foreign portfolio investment are limited. Then the subsidy could be used to promote the local accumulation of knowledge, which would then raise the rate of return on domestic savings.

can never be overcome -- are partially the result of the parsimonious way in which we have posed our question. In particular, we have studied the endogenous creation of comparative advantage in two entirely symmetric economies. The only way in which these countries have been allowed to differ is in their initial stocks of knowledge capital. In such a setting, if knowledge capital were globally accessible, then the cross-country pattern of specialization and trade would be completely indeterminate. We have sought, without success, to find an equilibrium path along which the initially lagging country "picks itself up by its bootstraps". Unlike in some other contexts, optimistic expectations are not enough to support the overturning of adverse initial conditions.

But this does not mean that history alone will rule in high-technology trade when countries differ in their underlying structures. For example, in Grossman and Helpman (1991, ch.8) we have argued that a large country may overcome an initial deficit in knowledge capital, even if technological spillovers are national in scope. The large country may be able to meet all of world demand for the traditional good, and still have enough resources left to undertake more research than its trade partner. If so, then this country can begin with a low wage that compensates for its productivity disadvantage in the research lab. Then knowledge capital will accumulate there more quickly than abroad, until the large country overtakes the smaller one in the high-technology race. A similar result would undoubtedly apply when, in a multi-factor world economy, a country that is well endowed with a factor that is used intensively in research, happened to begin with a deficiency in knowledge capital. Such a country would have a natural tendency to specialize in R&D, and its initial productivity disadvantage could be offset by a factor cost advantage. In general, both initial conditions and country attributes will matter in the determination of long-run trade patterns.

We close by repeating our caution about the normative interpretation of our results. Not only have we shown that, in some circumstances, a country that begins behind in the technology race will never be able to catch up, but also that, in many of these cases, the failure to do so has no adverse implications for the well being of the populace. The integration of world product and capital markets makes it possible for the residents of one country to avail themselves of the benefits of technological strides taken abroad. By having access to imports of innovative products, these residents can enjoy the same set of consumption opportunities as residents of the country where the inventions occur. And by having the ability to trade in international asset markets, they can enjoy the same set of investment opportunities as well. While the welfare analysis does suggest cases where a country might want to promote its local entrepreneurs in their global technological competitions, it hardly provides a blanket endorsement of such policies.

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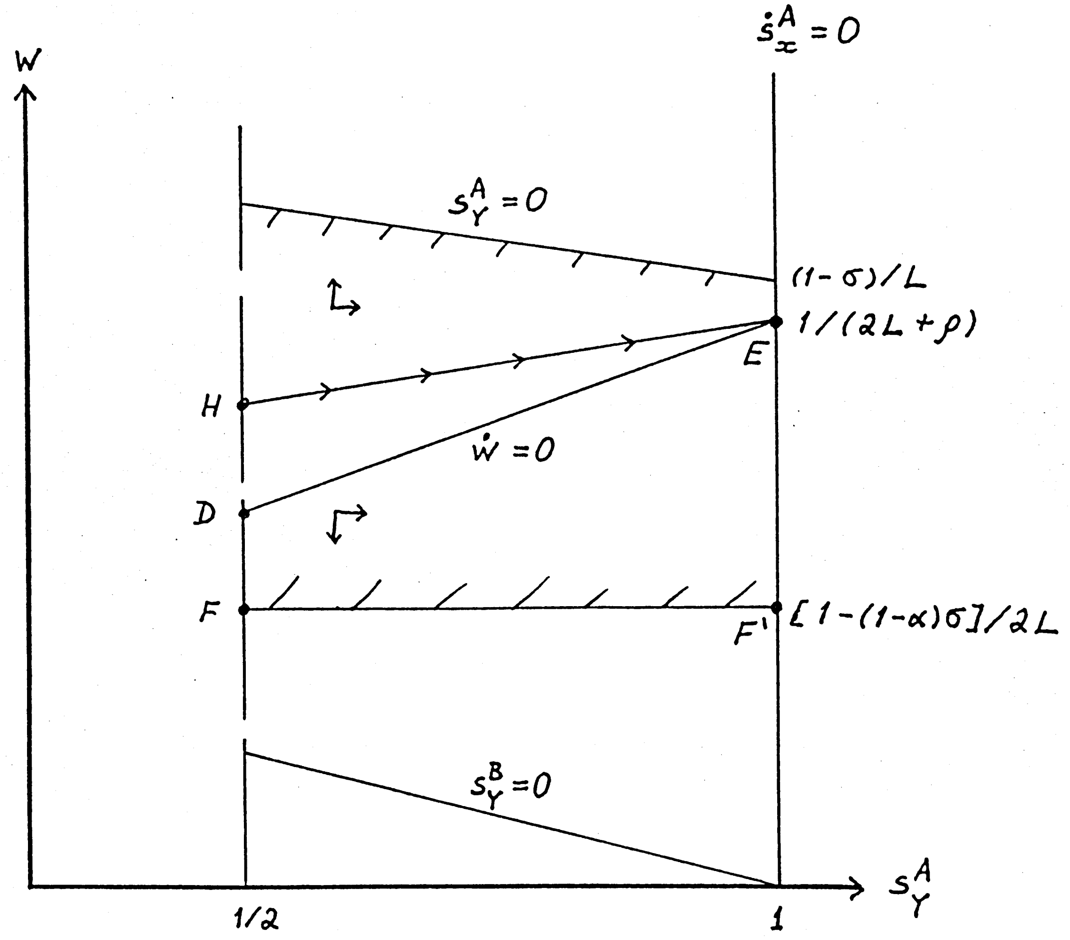
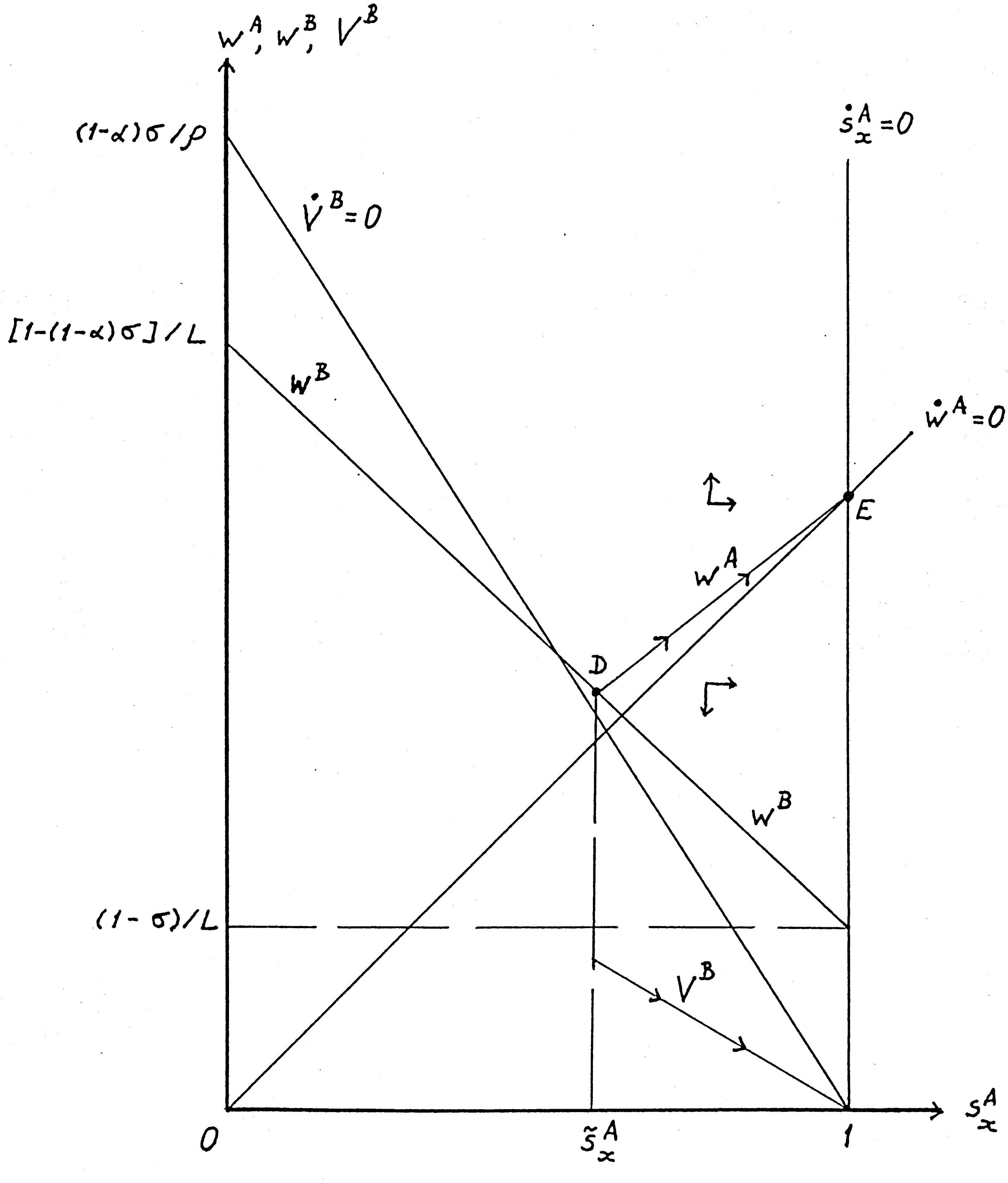

$\dot{s}_x^A = 0$
W
$s_Y^A = 0$
$(1-\sigma)/L$
$1/(2L+\rho)$
E
H
$\dot{W} = 0$
D
F
F'
$[1-(1-\alpha)\sigma]/2L$
$s_Y^B = 0$
s_Y^A
1/2
1

Figure 1



$L = 2, \ \rho = 0.3, \ \sigma = 0.8, \ \alpha = 0.8$

Figure 2

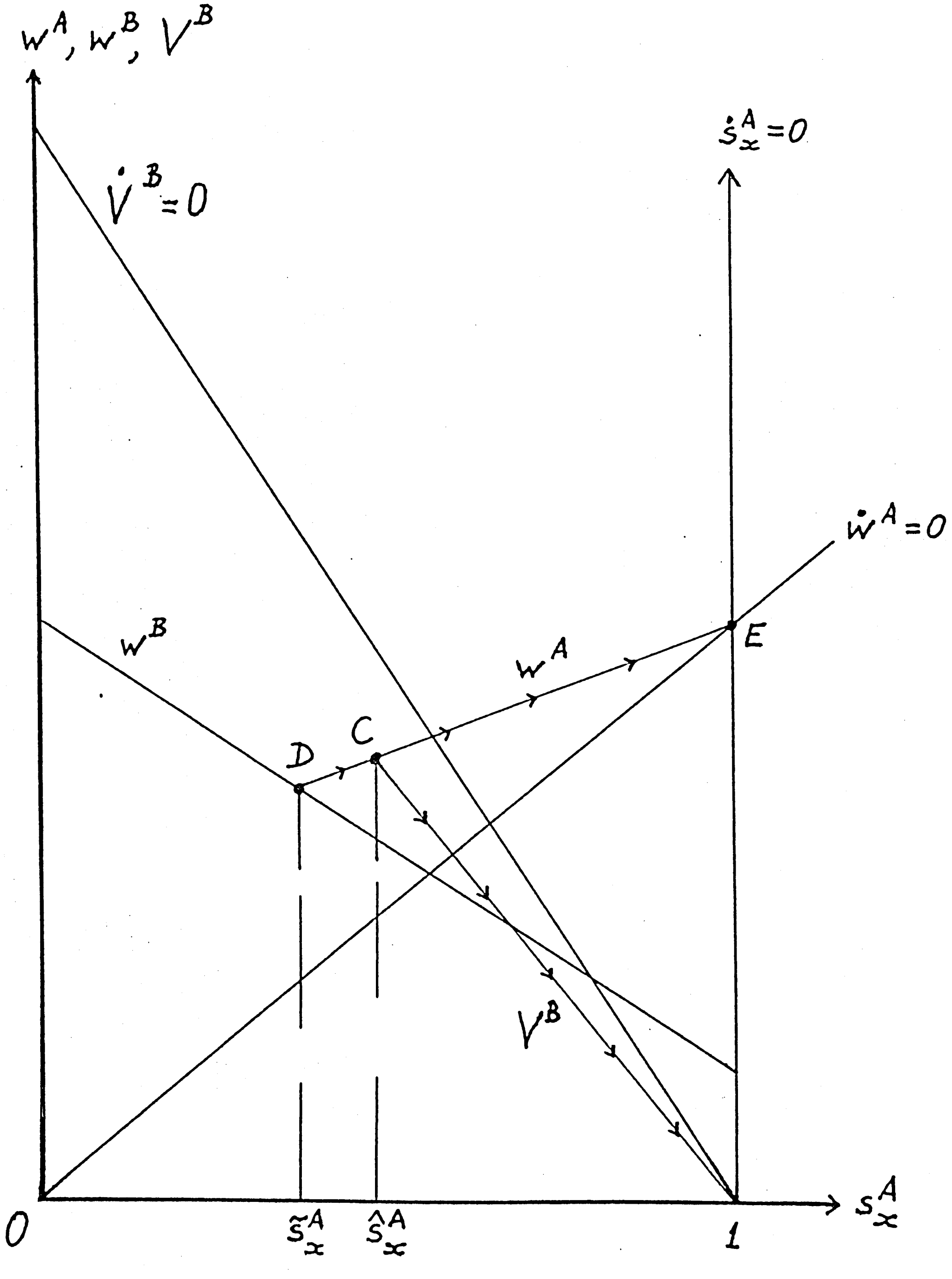

w^A, w^B, V^B
$\dot{V}^B = 0$
$\dot{s}_x^A = 0$
$\dot{w}^A = 0$
w^B
w^A
E
C
D
V^B
0
$\tilde{s}_x^A$
$\hat{s}_x^A$
1
s_x^A

Figure 3

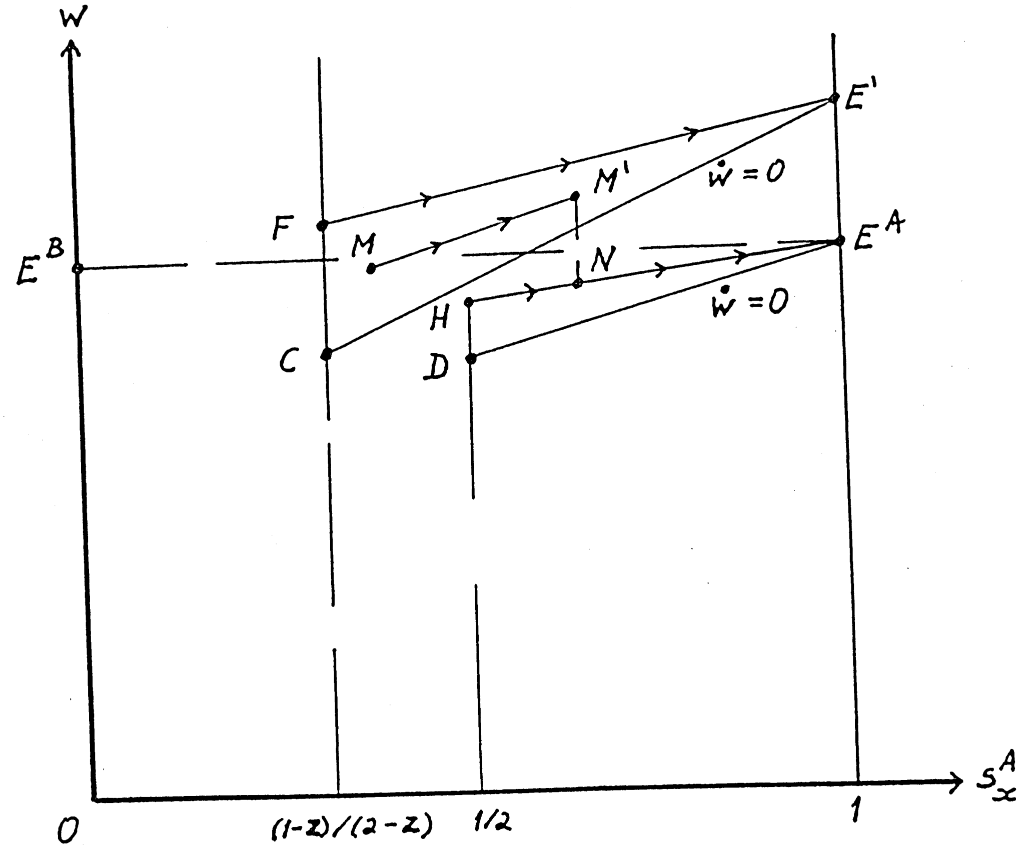


Figure 4