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EXPLAINING JAPAN'S INNOVATION AND TRADE: A MODEL OF QUALITY COMPETITION AND DYNAMIC COMPARATIVE ADVANTAGE

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ABSTRACT

In this paper, I develop a model of dynamic comparative advantage based on endogenous innovation. Firms in each of two countries devote resources to R&D in order to improve the quality of high-technology products. Research successes generate profit opportunities in the world market. The model predicts that a country such as Japan, with abundance of skilled labor and scarcity of natural resources, will specialize relatively in industrial innovation and in the production of high-technology goods. Data are provided to support this prediction. I use the model to explore the effects of R&D subsidies, production subsidies and trade policies on the long-run rates of innovation in trade partner countries and on the long-run pattern of trade.

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I. Introduction

Japan's industrial structure and pattern of trade have changed dramatically in the last twenty five years. Table 1 tells the story. Besides the continuing decline of the resource-based sectors, there has been a marked decrease in the importance of unskilled labor-intensive industries and of some heavy (capital-intensive) industries. In their place, Japan has spawned a vigorous high-technology sector based largely on indigenous research and development efforts.

Several competing explanations have been offered for this remarkable transformation. Some ascribe it to the conscious design of the Japanese government, especially the Ministry of International Trade and Industry (MITI), which allegedly turned its vision into reality by means of a comprehensive and effective industrial policy (see, for example, Shinohara, 1982, Borrus, Millstein and Zysman, 1983, and Prestowitz, 1988). Proponents of this view point to MITI's Vision for the 1970's, issued by its Industrial Structure Council in 1970, which presciently forecast the movement of resources from the capital-intensive to the knowledge-intensive sectors and which outlined the government's intentions to use policy measures in support of this structural change. Other commentators deny that the government has had more than a marginal role to play in determining the ultimate allocation of resources in Japan, though some concede that MITI may have had an effect in accelerating inevitable trends (see, for example, Tresize, 1983, Patrick, 1986, and Saxonhouse, 1982, 1986a,b). Saxonhouse especially has espoused the view that Japan's industrial structure and trade pattern simply reflect its unique factor endowments. He has estimated a multi-country, multi-sector econometric model of resource-based trade, and finds Japan to be an outlier no more often than the "typical" country in his sample (see Saxonhouse, 1982, 1986b).

Those who see a central role for MITI and industrial policy in explaining Japan's success in the high-technology sectors have been critical of Saxonhouse's methods and of similar arguments that begin with national factor endowments. One frequently voiced criticism concerns the static nature of the Heckscher-Ohlin theory of trade, which admits no role for differences in technology across countries and thus no role for the creation of comparative advantage via research and development, learning-by-doing, etc. Competition in the high-technology sectors is fundamentally dynamic, with firms racing to bring out new or improved products, or to cut their production costs. For this reason, it is argued, Japan's performance cannot be understood with reference to static notions of comparative advantage, but reflects instead a Schumpeterian process in which government policy has been very important and factor endowments have played at most a supporting role. The following quote from Freeman (1987) is typical:

> "...These and other studies confirm that long-term shifts in world export shares between the leading manufacturing countries are not primarily explicable in terms of traditional price competition theory, but must be explained in other terms. The studies which have been discussed have provided evidence that 'technology' broadly defined has played a very important role." (p.96)

My working hypothesis in this paper is the same as Saxonhouse's: Japan's pattern of trade and its success in high-technology industries such as consumer electronics, semiconductors, and precision instruments reflect well the country's natural endowments, in particular its abundance of skilled labor and its shortages of arable land, oil, and other natural resources. I will not, however, test this hypothesis directly. Rather, I shall first present evidence that places Japan's factor endowment bundle in comparative perspective. Then I shall construct a theoretical model of trade in high-technology goods that is consistent with the observed stylized facts. In so doing, I fully accept the argument that it is necessary to consider R&D competition and potential technology gaps explicitly in order to understand performance in the high-technology sectors. Indeed I shall present evidence of a close relationship between Japan's cross-sectional trade performance and the sectoral intensity of R&D. Accordingly, the model that I shall construct emphasizes the dynamic nature of comparative advantage in the high-technology sector and is one in which the rate of innovation in each country is endogenously determined. The model shows how trade patterns can be linked to factor endowments through endogenously determined R&D, without reference to policy or to non-orthodox competitive theories. The model does allow us to examine, however, the effects of various industrial and trade policies on the long-run rate of innovation and the long-run industrial structure. I shall devote the last part of this paper to these issues.

The remainder of the paper is organized as follows. Cross-national evidence on relative factor endowments and on R&D spending and policies related thereto, as well as evidence on the evolving relationship between R&D intensity and Japan's pattern of trade, are presented in Section II. In Section III, I develop a two-country model of innovation and trade featuring quality competition and dynamic comparative advantage. I study the determinants of the steady-state pattern of trade in Section IV, and consider the effects of changes in factor endowments on rates of innovation and on international patterns of specialization in Section V. Section VI contains an analysis of the effects on the long-run rate of technological innovation of subsidies to R&D, subsidies to production of high-technology goods, and trade policies. Section VII concludes.

II. Japan's Human Capital, R&D, and Trade Pattern in International Perspective

Twenty five years ago Japan stood far behind the Western, industrialized countries in terms of its endowment of skilled labor and human capital.[1] Today that is no longer the case. In Table 2, I present several alternative measures of the relative endowment of human capital or skilled labor for Japan and for four of the largest industrialized countries. By the most commonly used measure of skilled labor endowment, namely the fraction of professional and technical workers in the economically active population, Japan still lags behind these others, though the gap has closed substantially since the early 1960's. As Leamer (1984) notes, however, this measure of human capital endowment can be quite misleading in international comparisons.[2] By looking at all the measures together, it seems that Japan has surpassed all countries but the United States in its relative endowment of human capital.

Table 3 documents the well known scarcity of agricultural land and natural resources in Japan. Japan is unique among the major industrial countries in having abundance of neither coal, nor oil and gas, nor land suitable for raising crops or feedstock. The United States, on the other

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[1] Bowen (1983) reports the following data for the percentage of skilled labor in the total labor force in 1963: United States, 12.3%; France, 9.9% U.K., 8.7%; West Germany, 8.4%; and Japan, 5.2%.

[2] Leamer (1984) notes that, by this measure, many developing countries are revealed to have greater relative abundance of skilled labor than the advanced countries. He concludes that "the resource data ... are a continuing source of concern."(p.108)

hand, enjoys substantial relative endowments of all three of these factors. The last column in the table shows Japan to be about average among industrial countries in its capital-to-labor ratio, although these figures are rather sensitive to the choice of procedure for conversion into a common currency.[3]

Turning to research and development, the rate of growth in this activity in Japan has been quite remarkable. In the twenty years from 1966 to 1986 real expenditures on R&D grew in Japan at an average annual rate of 8.3 percent.[4] The ratio of current R&D expenditures to GDP grew from 1.55 percent in 1965 to 2.07 percent in 1975 and to 2.61 percent in 1985 (OECD, 1987). As the first two columns in Table 4 indicate, the relative importance of R&D as an economic activity in Japan now rivals that for the United States and Germany, and exceeds that for France and the United Kingdom.

During this period, Japan has developed extensive capability in industrial innovation. This is clear from objective measures of R&D output, such as patent counts in foreign countries and citation counts for professional journals, or from so-called "technometric" studies that rate Japanese products especially highly in regard to their technical performance (see Freeman, 1982). Researchers in Japan seem especially adept at improving the quality of existing products rather than developing entirely new products (Okimoto and Saxonhouse, 1987). Indeed, much of Japanese technological effort seems geared to ensure the superior quality of Japanese goods (Freeman, 1982). These facts will guide our modeling of Japanese innovation in Section III

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[3] Heston and Summers (1989) use purchasing power parity exchange rates for five components of investment in developing their internationally comparable measures of the capital stock. This method seems preferable to the more standard one that uses market exchange rates.

[4] Calculated from figures on R&D expenditures and the R&D deflator in Kagaku Gijutso Chō (1989).

below.

The R&D sector in Japan is distinctive in several respects. First, Japan devotes most of its research effort to commercial objectives. Most other countries spend a much greater share than Japan on defense related research (see Okimoto, 1986). Second, as can be seen in Table 4, the percentage of R&D expenditures borne by the government is much smaller in Japan than elsewhere. Even if defense related R&D spending is excluded, the government share is 19 percent in Japan, compared to 26 percent in the United States, 34 percent in Germany, and 32 percent in France (Kagaku Gijutsu Chō, 1989). Third, R&D performed by private industry is almost entirely self financed in Japan, where the same is not true in the other industrialized countries (see Table 4). These features should be borne in mind when we come to consider the effects of R&D subsidies on the pattern of trade in Section VI below.

Finally, Table 5 provides some crude evidence on the shifting source of Japanese comparative advantage.[5] In the table, I show the correlations between two alternative measures of the R&D intensity of different sectors and two measures of revealed comparative advantage. The first measure of R&D intensity is the ratio of R&D expenditures to industry sales. The second measure is the fraction of employees in the sector who are engaged in research. Revealed comparative advantage is gauged either by the share of exports in total domestic output or by the ratio of net exports (exports minus

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[5] Balassa and Noland (1989) provide related and corroborating evidence. They regress Japanese net exports by sector on measures of labor intensity, physical capital intensity, human capital intensity, and R&D intensity. They find a growing importance of R&D in "explaining" Japan's pattern of trade. However, their regressions are difficult to interpret, not only because payments to skilled labor appear both in the human capital and R&D variables (as the authors note), but also because R&D is an endogenous variable that is simultaneously determined with output and exports.

imports) to apparent domestic consumption (output plus imports minus exports). I have computed correlation coefficients for a cross-section of thirteen two-digit manufacturing industries, and for these industries plus agriculture and mining. Whichever series are taken, the data show a strong positive association between the sectors in which Japan now enjoys comparative advantage in world markets and the sectors in which R&D investments are undertaken intensively. Interestingly, this positive relationship did not exist in 1960.

III. A Model of Endogenous Innovation and International Trade

In the light of the previous discussion, it seems that a minimal model of Japanese innovation and trade ought to include the following: (i) two sectors, one comprising high-technology goods and one in which competitive advantage is determined by more static considerations; (ii) two factors, human capital in locally abundant supply and natural resources in scarce supply; (iii) competitiveness in the high-technology sector that is determined as much by the quality of the goods as by their price; and (iv) industrial R&D efforts aimed at raising product quality. I present a model with these features in the current section, and study its properties in the sections that follow.[6]

The high-technology sector comprises a continuum of industries indexed by $\omega\in[0,1]$. The product of each industry potentially can be improved an unlimited number of times. Each improvement raises the quality of the state-of-the-art product (i.e., the best existing variety) by a fixed percentage, to

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[6] The basis for the model presented here was first developed in Grossman and Helpman (1989a). It draws several building blocks from earlier work by Segerstrom et al.(1988) and Aghion and Howitt (1989).

a level $\lambda>1$ times as great as before. Quality improvements occur stochastically when firms devote resources to industrial research. I shall defer until later specification of the R&D technology.

Consumers worldwide maximize an additively separable intertemporal utility function of the form

$$(1) \qquad U = \int_0^\infty e^{-\rho t} \log u(t)dt,$$

where ρ is the common subjective discount rate and

$$(2) \qquad \log u(t) = s_x \int_0^1 \log [\Sigma_m q_m(\omega)d_{mt}(\omega)]d\omega + (1-s_x)\log d_{yt}$$

represents instantaneous utility at time t. In (2), $q_m(\omega)=\lambda^m$ is the measure of the quality of high-tech product ω after m improvements, with $q_0=1$ by choice of units, $d_{mt}(\omega)$ denotes consumption of quality m of product type ω at time t, and d_{yt} denotes consumption of a homogeneous good.

The representative consumer maximizes utility by choosing an optimal time pattern for spending and by allocating spending optimally at each point in time. Given prices $p_{mt}(\omega)$ for the high-technology goods and p_{yt} for the homogenous good, and given expenditure $E(t) = \int_0^1[\Sigma_m p_{mt}(\omega)d_{mt}(\omega)]d\omega + p_{yt}d_{yt}$, the consumer maximizes (2) by allocating a share s_x of spending to high-tech goods and spreading this evenly across the product types. For each ω, the consumer should choose the single variety that offers the lowest quality-adjusted price $p_{mt}(\omega)/q_m(\omega)$. We shall find that in equilibrium it is always the highest available quality that provides the lowest quality-adjusted price. Substituting the optimal, static allocation of spending into (2), and the result into (1), we obtain the indirect utility function

$$(3)\qquad U = \int_0^\infty e^{-\rho t}\{\log E(t) - s_x \int_0^1 \log[p_t(\omega)/q_t(\omega)]d\omega - (1-s_x)\log p_{yt}\}dt \ ,$$

where $q_t(\omega)$ denotes the quality of the state-of-the-art variety of product ω at time t, and $p_t(\omega)$ its price.

Consumers can borrow or lend freely on an international capital market with instantaneous (and riskless) rate of interest r.[7] They take this interest rate as given, though its value will be determined in the general equilibrium. The optimal time profile for nominal spending maximizes (3) subject to an intertemporal budget constraint limiting the present value of expenditures to the present value of income plus the value of initial asset holdings. The solution to this problem yields the following differential equation for spending:

$$(4)\qquad \dot{E}/E = r - \rho \ .$$

The consumer-investor also must solve a portfolio allocation problem. He may choose among shares in a variety of domestic or foreign profit-making firms and among interest-bearing bonds. Claims on particular firms bear risk, as we shall see. However, the risk attached to each equity is idiosyncratic, so the investor can earn a sure rate of return by holding a diversified portfolio of shares. It follows that, in equilibrium, all assets must earn

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[7] The allocation of resources in the steady-state equilibrium does not depend upon whether capital is internationally mobile or not. For expositional convenience I present the model under the assumption that capital is mobile.

the same expected rate of return.

Consider the value of equity shares in a firm that earns a profit stream $\pi(\tau)$ for $\tau \geq t$. Below we will find that profits accrue only to firms that are able to manufacture a state-of-the-art product. The stream of profits of such a producer continues until the time that another firm succeeds in bettering its product. Then the value of shares in the displaced leader falls to zero. Recognizing this risk of total capital loss, we can calculate the expected return to any equity as follows. If $v(t)$ is the value of a firm at time t, $(\pi/v)dt$ is the dividend rate in a time interval of length dt and $(\dot{v}/v)dt$ is the rate of capital gain. With probability fdt the shareholders will suffer a capital loss of v at the end of the interval. Summing these components of the expected return and equating the result to the sure rate of return on bonds, we have

$$\pi/v + \dot{v}/v - f = r \ . \tag{5}$$

This equation implicitly determines the value of any firm as a function of its profit rate, the interest rate, the rate of capital gain, and the relevant value for f. In what follows, I shall link f to the activities that competitors undertake in order to supplant the industry leaders.

We turn now to the production side of the economy. The homogenous good can be produced in either country A or country B by a constant-returns-to-scale technology that does not change over time. The market structure in this sector is that of perfect competition. Let $c^Y(w^i,z^i)$ be the cost of producing this good in country i, i=A,B, where w^i is the wage of skilled labor in country i and z^i is the local factor payment to a non-traded resource (e.g., land). If production of this good takes place in both countries, then we must have

$$p^Y = c^Y(w^i, z^i), \quad i = A, B. \tag{6}$$

I assume that all high-technology goods can be manufactured according to a common, constant-returns-to-scale production function, regardless of their type ω or quality q. Let $c^X(w^i, z^i)$ denote the cost of producing a unit of any one of these goods in country i. Of course, high-technology goods cannot be produced by any firm unless its research laboratory has succeeded in developing the requisite prototype.

Producers in the same industry ω compete as Bertrand (price-setting) oligopolists. Competition in the high-technology sector takes place, therefore, in both price and quality dimensions. Consider a firm that has succeeded in its efforts to improve upon the state-of-the-art variety of some product ω, and so is able to produce a good that is better than that of any of its rivals. Suppose, as will be the case in the equilibrium below, that the product is exactly one quality increment better than that offered by the nearest rival. Then the industry leader maximizes profits by setting a price that is λ times the cost of production of that nearest competitor. By so doing, the leader captures the entire market for product ω. Higher prices would allow the competitor to profitably undercut, while lower prices are not optimal given the unit elastic demand for product group ω. With the optimal pricing strategy, an industry leader located in country i facing a nearest competitor in country j makes sales $x^{ij}(\omega) = s_x E/\lambda c^X(w^j, z^j)$ and earns profits

$$\pi^{ij}(\omega) = s_x E\left[1 - \frac{c^X(w^i,z^i)}{\lambda c^X(w^j,z^j)} \right] \tag{7}$$

Two things are apparent from (7). First, profits do not depend upon ω or the quality level that has been achieved in that industry. Second, all firms earn higher profits when their nearest competitor resides in a high cost country. This latter fact implies that all researchers, no matter what their national origin, prefer to improve upon products that are at the moment being produced in a high cost country. If one country indeed were to exhibit a higher cost of production for high-tech products, then over time it would lose competitiveness in all such products. This is because all research efforts worldwide would be targeted at improving that country's products, and each success abroad would mean the loss of a product that would never be recaptured. Such a situation cannot be consistent with a steady state in which high-tech products are manufactured in both countries. As a condition of steady-state equilibrium with incomplete specialization, we have

$$c^X(w^i,z^i) = c^X(w^j,z^j) \ . \tag{8}$$

Equation (8) implies $\pi^{ij}(\omega) = (1-\delta)s_x E$ for all i,j and ω, where $\delta \equiv 1/\lambda$.

I allow free entry into the R&D activity. Any entrepreneur can open a research lab and attempt to improve upon the best available variety in some industry ω.[8] If successful, the entrepreneur will become an industry leader

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[8] I do not allow for imitation here. In an equilibrium with factor price equalization, such as that which arises below in a regime of free trade, costly imitation would never be undertaken. This is because, even if successful, an imitator stands to earn no profits in the resulting Bertrand equilibrium. We study imitation in a model of North-South trade in Grossman

and so earn profits until the next improvement comes along. As we discussed in Grossman and Helpman (1989a), this specification captures a public good aspect of technology, inasmuch as newcomers can learn from observing the state-of-the-art product even if they are unable to produce it.

The technology for industrial research is as follows. A firm that targets some product ω for improvement and undertakes R&D at intensity ι for a time interval of length dt will succeed in its efforts to develop the next generation product with probability ιdt. Thus, research entails uncertainty, and successes follow a Poisson process as in Lee and Wilde (1980). The flow cost of undertaking research at intensity ι is $c^{\iota}(w^i,z^i)\iota$ in country i.

Let v^i be the value of a firm in country i that holds the technological lead in some industry ω. Entrepreneurs in country i can attain stock market value v^i with probability ιdt by undertaking research at intensity ι for a time interval of length dt. The cost of such research is $c^{\iota}(w^i,z^i)\iota dt$. Maximization of stock market value requires infinite research effort whenever $v^i > c^{\iota}(w^i,z^i)$, and zero effort whenever $v^i < c^{\iota}(w^i,z^i)$. Accordingly, in an equilibrium with active R&D sectors in both countries, we must have

$$v^i = c^{\iota}(w^i,z^i) , \qquad \text{for } i=A,B . \tag{9}$$

In a steady-state equilibrium industry leaders undertake no research. This is because the <u>incremental</u> profits that a leader stands to gain from a research success are strictly less than the profits that non-leaders can obtain by innovating. A leader who further improves a high-tech product would

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and Helpman (1989b).

find itself two steps ahead of its nearest rival on the quality ladder. It would then be able to charge a price equal to $\lambda^2 c^x(\cdot)$. With this price, the firm would earn extra profits equal to δ times its original profits. But $\delta < 1$, so the non-leaders always have greater incentive to undertake R&D than do the leaders.[9] This justifies our supposition that leaders always are exactly one quality increment ahead of their nearest competitors.

In a steady state, all nominal variables grow at a common rate. This implies, for instance, that $\dot{v}^i/v^i = \dot{E}/E$ for i=A,B. I choose E=1 as numeraire. This implies $\dot{E}=0$. Then $\dot{v}^i=0$ in a steady state. Let ι^i, i=A,B, denote the aggregate intensity of global research effort targeted at a typical product currently being manufactured in country i. Using (4), (9), the no-arbitrage condition (5), and the fact that $\dot{v}^i=0$ in a steady state, we have

$$(10) \qquad \frac{(1-\delta)s_x}{c^\iota(w^i,z^i)} = \rho + \iota^i \,, \qquad \text{for } i = A,B.$$

In writing (10), I have made use of the fact that the probability of catastrophic loss for an industry leader, fdt in (5), is just the aggregate probability of a research breakthrough by a would-be successor, $\iota^i dt$.

Next we have the factor-market clearing conditions. In country i, employment of skilled labor in R&D is $(\iota^{ii}n^i + \iota^{ji}n^j)c^\iota_w(w^i,z^i)$, where ι^{ji} is the aggregate intensity of research targeted at each good manufactured in country j by firms located in country i, n^i is the number of high-tech goods produced in country i, and thus $\iota^{ii}n^i + \iota^{ji}n^j$ is the aggregate level of

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[9] In Grossman and Helpman (1989b) we provide industry leaders with a cost advantage in developing the next generation product. Then we may find active research departments in both leading and following firms in equilibrium.

research activity undertaken in country i. Similarly, the input of natural resources to R&D is $(\iota^{ii}n^i + \iota^{ji}n^j)c_z^{\iota}(w^i,z^i)$. Aggregate output of high-tech goods is $n^i\delta s_x/c^X(w^i,z^i)$ in country i. Each unit of output is produced with $c_w^X(w^i,z^i)$ units of skilled labor and $c_z^X(w^i,z^i)$ units of the natural resource. Finally, country i produces Y^i units of the homogeneous good, each with $c_w^Y(w^i,z^i)$ units of skilled labor and $c_z^Y(w^i,z^i)$ units of the resource. Equating factor supplies to factor demands in each country, we have

$$(11) \qquad (\iota^{ii}n^i + \iota^{ji}n^j)c_w^{\iota}(w^i,z^i) + \frac{n^i\delta s_x c_w^X(w^i,z^i)}{c^X(w^i,z^i)} + Y^i c_w^Y(w^i,z^i) = H^i, \quad i=A,B,$$

$$(12) \qquad (\iota^{ii}n^i + \iota^{ji}n^j)c_z^{\iota}(w^i,z^i) + \frac{n^i\delta s_x c_z^X(w^i,z^i)}{c^X(w^i,z^i)} + Y^i c_z^Y(w^i,z^i) = R^i, \quad i=A,B,$$

where H^i is the (fixed) stock of skilled labor in country i, and R^i is the (fixed) stock of resources there.

The world market for the homogeneous good must clear as well.[10] Aggregate spending on this good is $1-s_x$. (Recall that $E = 1$.) The value of world output is $p^Y(Y^A+Y^B)$. Therefore, in equilibrium,

$$(13) \qquad 1-s_x = p^Y(Y^A+Y^B) \ .$$

Finally, we have a steady-state condition that ensures that the number of high-tech goods produced in each country remains constant over time. At every

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[10] We have already ensured that the market for each high-technology good clears by writing the quantity of output as $\delta s_x/c^X(w^i,z^i)$, which we know to be the demand for that product.

instant country A researchers will successfully improve upon a fraction ι^{BA} of the n^B high-tech products that country B manufactured the moment before. Similarly, country B acquires leadership position in $\iota^{AB}n^A$ goods formerly produced in country A. In a steady state, these flows balance, or

$$\iota^{BA}n^B = \iota^{AB}n^A \ . \tag{14}$$

Using (14), we may rewrite the factor-market clearing conditions as follows:

$$\iota^i n^i c_w^{\iota}(w^i,z^i) + \frac{n^i \delta s_x c_w^X(w^i,z^i)}{c^X(w^i,z^i)} + Y^i c_w^Y(w^i,z^i) = H^i, \quad i=A,B \ , \tag{15}$$

$$\iota^i n^i c_z^{\iota}(w^i,z^i) + \frac{n^i \delta s_x c_z^X(w^i,z^i)}{c^X(w^i,z^i)} + Y^i c_z^Y(w^i,z^i) = R^i, \quad i=A,B \ . \tag{16}$$

Equations (6), (8), (10), (13), (15) and (16) constitute ten independent relationships that determine the steady-state values of n^A, p^Y and ι^i, w^i, z^i, Y^i, for i=A,B, where we recall that $n^B=1-n^A$. These equations apply provided that the solution yields non-negative values for all outputs, factor prices and R&D intensities. If no such solution exists, then a steady-state equilibrium with incomplete specialization is impossible.

Before proceeding, it is worthwhile to review the qualitative nature of the equilibrium that we have described. At every moment in time, each country enjoys technological leadership in some subset of high-technology goods. Industry leaders export their state-of-the-art products, and also sell them at home. Thus, intra-industry trade takes place. Competitiveness in particular high-tech products evolves dynamically over time as firms in each country race to bring out the next generation products. When a research effort succeeds, a new firm takes over the market for the targeted good. The intensity of R&D and the number of high-technology goods produced in each country are determined in the general equilibrium. So is the pattern of inter-industry trade, to which we now turn.

IV. The Pattern of Specialization and Trade

Our first task will be to analyze the long-run pattern of specialization and trade. I focus on steady-state equilibria characterized by incomplete specialization in both countries. With incomplete specialization, equations (6) and (8) imply factor price equalization; i.e., $w^A=w^B$ and $z^A=z^B$. Then (10) implies that the intensities with which goods manufactured in each country are targeted for improvement are equal; i.e., $\iota^A=\iota^B$. In this case, free commodity trade is sufficient to reproduce the long-run equilibrium that would obtain in a hypothetical "integrated world economy" -- one in which no international borders exist to limit factor movements.

The pattern of global specialization in a free-trade equilibrium with factor price equalization can be described with the aid of Figure 1. In the figure I have drawn a rectangle with dimensions that represent global factor endowments, H^A+H^B and R^A+R^B. Let the line segment 0^AM in the figure represent the vector of resources that would be deployed in R&D in a hypothetical long-run equilibrium of an integrated world economy. Similarly, let MN represent those that would be used in manufacturing high-technology goods, and $N0^B$ those that would be used in producing homogeneous goods, in such an equilibrium. Notice that the relative slopes of these segments imply that R&D is the most human capital-intensive activity and that production of the homogeneous good is the most resource-intensive activity. I shall maintain this ranking throughout.

Let a point such as E represent the factor endowments of the two trading countries; that is, the vector 0^AE (not drawn) is the endowment bundle of country A and the vector $E0^B$ is that of country B. Since point E lies above the diagonal, country A is relatively well endowed with skilled labor.[11] We use now the facts that factor prices are equalized, that the trade equilibrium reproduces the aggregate outputs of the integrated equilibrium, and that factor markets must clear separately in each country. Consider the following allocation of resources. Country A devotes inputs 0^AM^A to R&D, M^AN^A to the production of high-technology goods (where N^A lies along the line segment joining 0^A and N), and N^AE to the production of the homogeneous good. Country B devotes 0^BM^B to R&D, M^BN^B to the manufacture of high-technology goods, and N^BE to production of the homogeneous good, where 0^BM^B is parallel to 0^AM^A, M^BN^B is parallel to M^AN^A and N^BE is parallel to N^AE. I shall argue that this allocation satisfies all of the conditions for a long-run equilibrium.

The fact that corresponding input vectors are parallel implies that techniques of production are the same in the two countries, as must be the case with factor prices equalized. Notice too that the techniques are the same as those for the integrated equilibrium. This, together with the fact that the aggregate inputs to the three activities are the same as in the

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[11] Point E must lie in the interior of the parallelogram 0^AN0^BP, or else a steady-state equilibrium with incomplete specialization does not exist. This corresponds to a familiar proposition from static theories of trade, namely that factor price equalization requires that the countries' relative factor endowments not be "too" different.

integrated equilibrium implies that aggregate outputs are equal to those of the integrated equilibrium. All activities earn zero excess profits in the integrated equilibrium. This must be so in the proposed free-trade equilibrium as well, since factor prices are the same. Also, the no-arbitrage condition (10) must be satisfied for both countries in the proposed free-trade equilibrium, since it is so for the integrated equilibrium and we have already seen that factor price equalization implies $\iota^A=\iota^B$.

It remains to be shown only that product markets clear in the proposed equilibrium, and that the R&D undertaken in each country and so the extent of each country's competitiveness in high-technology goods are consistent with the designated quantities of production of these goods in each country. The fact that factor prices are the same in the proposed free-trade equilibrium as in the integrated equilibrium means that commodity prices are the same, and so is aggregate income. But then, since preferences in (1) and (2) are homothetic, aggregate demands must be the same. We have seen that aggregate supplies are the same, so commodity markets must clear under the proposed allocation. Finally, it can be seen from (15) and (16) that, with factor price equalization and $\iota^A=\iota^B$, the ratios of the use of either factor in R&D to the use of that same factor in the production of high-technology goods must be identical for the two countries. This requirement indeed is satisfied in the proposed allocation, as can be verified by noting the similarity of triangles $0^AM^AN^A$ and $0^BM^BN^B$.

As is evident from the figure, in a free-trade equilibrium, the skilled labor-rich country specializes relatively in both R&D and in production of high-technology goods. The resource-rich country specializes relatively in the production of the homogeneous good. We have then a prediction about the pattern of world specialization that is reminiscent of that from static theories of factor-endowment based trade, but one that has been derived from a dynamic model in which innovation is endogenous and competitiveness must be created in the industrial research laboratory. Our model predicts, for example, that Japan - with its abundance of skilled labor and its paucity of natural resources - ought to be found specializing in high-technology sectors, not because of any superiority in the Japanese system or due to the influences of industrial policy (other than perhaps policies aimed at the accumulation of human capital), but because the forces of long-run equilibrium in world factor and commodity markets dictate this pattern of production.

What then is the pattern of trade in the long-run equilibrium? Since I have assumed that financial assets can be traded internationally, there is no guarantee that commodity trade will balance in the long run. A country might, for example, finance a steady-state deficit on trade account by a surplus on service account. It might even happen, then, that in the steady state one country imports both the homogeneous product and (on net) high-technology goods. If this does not occur, then only one pattern of trade is possible.[12] With homothetic preferences, the composition of aggregate demands are the same in the two countries. But we have seen that the composition of outputs differ systematically. Thus, if one country imports the homogeneous good and exports (on net) the high-tech goods, it must be the skilled labor-rich country.

I summarize the findings in

<u>Proposition 1</u>: In a long-run, free-trade equilibrium with incomplete

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[12] In the absence of international capital mobility, the trade account must always balance. Then the trade pattern must be as described below.

specialization, the skilled labor-abundant country specializes relatively in R&D and the production of high-technology goods. It imports the resource-intensive good and exports (on net) high-technology products, unless its long-run trade account is highly imbalanced.

V. Factor Accumulation

The remainder of this paper is devoted to analyzing the long-run comparative static effects of endowment and policy changes. To simplify the calculations and exposition, I shall specialize the production technology somewhat further. I assume henceforth that R&D requires only skilled labor as an input, with unit input coefficient a, and that the manufacture of high-technology goods and homogeneous goods use skilled labor and natural resources in fixed proportions. I denote the unit input coefficients in the latter two activities by a_{ij}, $i=H,R$ and $j=X,Y$.

With these assumptions, the steady-state equilibrium can be expressed in a simple reduced form that will facilitate a diagrammatic analysis. First use (16) applied for $i=A,B$ to solve for Y^A and Y^B. Substitute these solutions into (15). Then sum the equations for the two countries and recall that $p^X=\lambda c^X$ to derive

$$(17) \qquad ag + \frac{n^A s_X D}{p^X a_{RY}} = H^A+H^B - \frac{a_{HY}}{a_{RY}}(R^A+R^B) ,$$

where $D \equiv a_{HX}a_{RY}-a_{RX}a_{HY} > 0$ and $g \equiv \iota^A n^A + \iota^B(1-n^A)$ is the aggregate rate of innovation for the world as a whole. I plot this curve as HH in panel a of Figure 2. The curve represents combinations of g and p^X that are consistent with equilibrium in the two markets for skilled labor. Its slope can be understood as follows. An increase in g increases employment of skilled labor in R&D. Then p^X must rise to alleviate demand for high-technology goods and so release skilled labor from the manufacturing sectors.

Next, solve for p^Y in terms of p^X and ι^A using (6) and (10). Then compute Y^A+Y^B from (16). Substitute these expressions into (13), noting that $\iota^A = \iota^B$ implies $g = \iota^A$, and rearrange to find

$$\left(R^A + R^B - \frac{s_x a_{RX}}{p^X}\right)\left[a_{RY}\delta p^X - \frac{D(1-\delta)s_x}{a(\rho+g)}\right] = a_{RY}a_{RX}(1-s_x) \quad . \tag{18}$$

This equation, shown as YY in the figure, expresses equilibrium in the world market for the homogeneous good. When g rises, w must fall to maintain the no-arbitrage condition. Then p^Y rises, which chokes off demand for the homogeneous good and creates a situation of excess supply.. The price of high-technology goods must fall, which reduces supply of the homogenous good and, because py falls with p^X, raises demand.

The long-run equilibrium values of p^X and g can be found at the intersection of these two curves (at point E). Panel b of the figure can now be used to decompose g into component parts that reflect the number of high-technology goods manufactured in each country and the intensity of research effort targeted at each country's products. The curve AA in the figure represents combinations of ι^A and n^A that enable the market for skilled labor in country A to clear. The equation for this curve is found using (15) and (16), and is given by

$$(19) \qquad a\iota^A n^A + \frac{n^A s_X D}{p^X a_{RY}} = H^A - \frac{a_{HY}}{a_{RY}} R^A ,$$

The curve is drawn for the particular value of p^X that satisfies (17) and (18). It slopes upward, because an increase in ι^A raises employment of skilled labor in R&D in country A (employment equals $a\iota^A n^A$), and so n^A must fall to reduce demand for skilled labor in both R&D and the production of high-technology goods. The curve BB expresses the analogous relationship for the skilled labor market in country B. The equation for the curve is

$$(20) \qquad a\iota^A(1-n^A) + \frac{(1-n^A)s_X D}{p^X a_{RY}} = H^B - \frac{a_{HY}}{a_{RY}} R^B ,$$

where I have used the fact that $\iota^A = \iota^B$ in writing the first term of (20). The curve slopes downward, because employment of skilled labor in R&D and the production of high-tech good in country B are proportional to $n^B = 1-n^A$. The intersection of AA and BB at F gives us the equibrium values of n^A and ι^A.

We use the figure to explore the consequences of a build up of human capital, such as has occurred in Japan over the last twenty five years. An increase in H^A shifts the HH curve to the left. The new equilibrium at E' has a faster agregate rate of innovation in the world economy and a lower relative price of high-technology goods (measured in units of expenditure). Turning to panel B, the BB curve shifts down due to the fall in p^X, while the AA curve also shifts down for this reason, but shifts up due to the direct effect of the increase in skilled labor supply there. The net movement must be upward, since we know that ι^A (=g) must rise.

At F', both ι^A and n^A are larger than at F. Thus, accumulation of human capital causes the R&D sector in country A to expand (its size is proportional to $\iota^A n^A$), and the range of high-technology goods produced there to grow. This finding accords well with intuition, and also with the evidence concerning the transformation of the Japanese economy that was discussed above.

We can also derive the consequences of this build up of human capital for the structure of production in the trade-partner country. There, ι^B rises, but $n^B=1-n^A$ falls. It is possible to show, however, that the former response is proportionately larger, so that innovation abroad, which is the product of these two, must accelerate.[13] The foreign country conducts more R&D, but the range of high-technology goods that it produces in the long-run equilibrium contracts. I summarize in

<u>Proposition 2</u>: An increase in the supply of skilled labor in one country expands the number of high-technology goods produced there and accelerates steady-state innovation in both countries.

For completeness, let us consider also the implications of growth in the stock of natural resources, R^A. This analysis makes use of the two panels of Figure 3. In panel <u>a</u>, both the HH and YY curves shift downward when R^A expands. The aggregate rate of innovation in the world economy must decline, but p^X may rise or fall. If it rises (case not drawn), then BB shifts up, while AA shifts up for this reason but down in response to the resource

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[13] This and other claims not explicitly proved in the text can be established by differentiating the complete system of equilibrium conditions. These calculations have been collected in an appendix that is available from the author.

expansion. The net movement is downward, so both n^A and ι^A decline. If, on the other hand, p^X falls in the adjustment to the new long-run equilbrium, then we have the case depicted in Figure 3. Both the AA and the BB curves shift downward, but the former shifts by more (for given n^A). This is because the decline in p^X causes both curves to shift down by the same amount, but AA shifts down by an additional amount due to the rise in R^A. It follows that, in this case as well, both ι^A and n^A decline in response to an increase in R^A.

Clearly, the rate of innovation falls in country A. It can also be established that that the rate of innovation declines in country B, as ι^A falls by proportionately more than n^A rises. We have then

Proposition 3: An expansion in the stock of natural resources in one country reduces the number of high-technology goods produced there and slows steady-state innovation in both countries.

Taken together the two propositions imply that the long-run rate of innovation in the world economy responds positively to accumulation of the factor used intensively in R&D, and negatively to accumulation of the remaining factor. When one trade partner accumulates human capital faster than the other, its comparative advantage in high-technology goods expands. Thus, our model can account for at least part of Japan's recent success in the high-technology industries without any reference to industrial policy. Nonetheless, the model provides a useful tool for exploring the long-run consequences for innovation and trade patterns of a variety of policy measures. I turn to these matters in the section that follows.

VI. Industrial and Trade Policies

I study first the effects of a subsidy to R&D in country A. I assume that the payments are financed by lump-sum taxes that keep the government's budget intertemporally balanced. Let σ be the share of private R&D costs that the government finances. With this policy in place, the no-arbitrage condition (10) relevant for firms in country A must be modified to

$$\frac{(1-\delta)s_x}{(1-\sigma)aw^A} = \rho + \iota^A . \tag{21}$$

The other equilibrium conditions remain as before. Notice that (6) and (8) continue to imply factor price equalization in an equilibrium with incomplete specialization, but (10) and (21) now imply $\iota^A > \iota^B$. That is, in long-run equilibrium, researchers target high-technology goods manufactured in country A for improvement to a greater extent than they do those manufactured in country B. This means, of course, that the stream of monopoly profits that accrues to an industry leader in country A lasts on average for a shorter period of time. The lower private cost of research in country A is matched in equilibrium by a lower expected return to success, and so the rate of return on equities in country A firms remains "normal".

When we solve for the new reduced form using (21), we find two modifications of the system. First, since $\iota^B = (1-\sigma)(\rho+\iota^A)-\rho$, the first term in (20) becomes $a(1-n^A)[(1-\sigma)(\rho+\iota^A)-\rho]$. Second, since (10) and (21) imply $aw^A = (1-\delta)s_x[1+\sigma n^A/(1-\sigma)]/a(\rho+g)$, the term in square brackets in (18) becomes

$$a_{RY}\delta p^X - \frac{D(1-\delta)s_x}{a(\rho+\iota^A)}\left(1 + \frac{\sigma}{1-\sigma} n^A\right) .$$

Accordingly, the introduction of a subsidy to R&D shifts the YY curve upward, and leads to a rise in both g and p^X. The rise in p^X causes both the AA and the BB curves to shift upward, by equal amounts, and the BB curve shifts up by an additional amount due to the direct effect of σ in (20).

What then are the effects of the subsidy? The aggregate rate of technological progress increases, as does the rate of innovation in the subsidizing country. The latter claim can be seen from equation (19). We have seen that n^A falls and p^X rises, so the second term on the left-hand side must shrink. Then the first term must grow, and so $\iota^A n^A$ rises. It is also possible to show that the rate of innovation in the trade partner country (without any subsidy) declines. But the fact that n^A falls means that, in the long-run, the country that subsidizes R&D will enjoy comparative advantage in a <u>smaller</u> range of high-technology products than before. This counterintuitive result can be understood as follows. Although country A undertakes more R&D with the subsidy than without, and country B less, researchers worldwide devote more attention to improving the products of country A than those of country B. On net, country A loses products in this process. Put differently, country A uses more of its skilled labor in the research lab when R&D is subsidized, and so less is available for manufacturing high-technology goods. At the same time, skilled labor in the trade partner country is released by the R&D sector, and so becomes available for production.[14]

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[14] It is possible to show, moreover, that these effects hold not only for the introduction of an R&D subsidy from an initial situation with $\sigma=0$, but also for any increase in σ from an arbitrary initial value. Such an increase causes YY to shift up for given n^A, but the decline in n^A has an offsetting influence. Suppose that the latter dominated. Then p^X would fall, which would require a fall in w^B hence a rise in ι^B. But then (20) could not be satisfied, because all terms on the left-hand side would have increased. It

This finding is particularly interesting in the light of the evidence reported in Section II. As we noted there, the Japanese government finances a much smaller fraction of private R&D than is typical for the advanced, industrial countries. My analysis suggests that this policy asymmetry contributes to an <u>expansion</u> in the size of the Japanese high-technology sector (or, at least, that part of it engaged in production). I record

<u>Proposition 4</u>: An R&D subsidy raises the rate of innovation in the policy active country, lowers the rate of innovation in the trade partner country, and raises the global rate of technological progress. The number of high-technology goods produced in the policy active country declines.

Next I shall consider subsidies to production. It is sometimes alleged that Japan implicitly subsidizes the production of high-technology goods via the government's procurement practices. Other governments seemingly do likewise, especially where products with defense applications are concerned.

Let β be the ad valorem rate of subsidy to manufacturers of high-technology products in country A, again financed by lump-sum taxation. The introduction of such a subsidy modifies the equilibrium relationships in two ways. First, manufacturing costs in country A must exceed those in country B. Otherwise, researchers will prefer to target country B products for improvement, since the un-subsidized producers would be less formidable rivals when a research success is achieved. In place of (8), we have now

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follows that any increase in σ causes g and p^X to rise. The other implications follow then by the same arguments as in the text.

(21) $$w^A a_{HX} + z^A a_{RX} = (1+\beta)(w^B a_{HX} + z^B a_{RX}) \; .$$

Second, the subsidy raises the profit rate for producers of high-tech products in country A, so that (10) becomes

(22) $$\frac{(1+\beta)(1-\delta)s_x}{a w^A} = \rho + \iota^A \; .$$

With these changes in the equilibrium system, there are again two modifications of the reduced form. In (20), the first term becomes $a(1-n^A)[(\rho+\iota^A)\gamma - \rho]$, where

$$\gamma = \left[1 + \beta - \frac{\beta a a_{RY} \delta p^X (\rho+\iota^A)}{D(1-\delta)s_x} \right]^{-1} \; .$$

and p^X represents now the price paid by consumers for high-technology goods. Also, in (18), the term in the square brackets is replaced by

$$\left[a_{RY}\delta p^X - \frac{D(1-\delta)s_x}{a(\rho+g)}\right] \left(1 + \frac{1-\gamma}{\gamma} n^A\right) \; .$$

After some inspection, it becomes clear that the reduced form system with a production subsidy in place mirrors that for an R&D subsidy, but with $1-\sigma$ replaced by γ. Since γ is an increasing function of β, it follows that the long-run effects of a subsidy to production of high-technology goods are just the <u>opposite</u> of those of a subsidy to research. Namely, we have

Proposition 5: A production subsidy for high-technology goods reduces the rate of innovation in the policy active country, increases the rate of innovation in the trade partner country, and slows the global rate of technological progress. The number of high-technology goods manufactured in the policy active country grows.

Intuitively, the subsidy has offsetting effects on the incentives for innovation. On the one hand, the higher prices received by producers of high-technology goods raises the profitability of quality improvements. On the other hand, the increased wage of skilled workers caused by the expansion of demand for these individuals in the manufacturing sector raises the cost of R&D. Evidently, the latter effect dominates.

We are interested, finally, in the long-run effects of trade policy. Recognizing that trade policies combine elements of a production subsidy and a consumption tax, it proves useful to consider first the effects of a consumption tax alone. This policy raises the price paid by consumers in country A for high-technology products. Let t be the rate of ad valorem taxation and let p^X represent now the price received by producers. Then consumers in country A pay $p^X(1+t)$. Sales of each high-technology good are given now by $s_x[1-tE^A/(1+t)]/p^X$, where E^i is steady-state expenditure in country i, and $E^A+E^B = 1$ as before. This change affects (10), (15) and (16). In the reduced form we find all occurrences of s_x replaced by $s_x[1-tE^A/(1+t)]$, with the exception of the term $(1-s_x)$ on the right-hand side of (18).

The effects of a small tax on consumption of high-technology goods from an initial position of laissez faire are shown in Figure 5. In panel a, the HH and YY curves both shift leftward. However, for given g, the former curve shifts by more.[15] Thus, the tax causes the rate of innovation to rise and the relative price of high-technology goods to fall. Both the tax and the adjustment of p^X shift the AA and BB curves in panel b by equal (vertical) distances. It follows that a small tax on consumption of high-technology products increases the rate of innovation in both countries, while leaving the number of high-tech goods produced by each unchanged.

Turning to trade policy, I consider a small tariff on imports of all high-technology goods coupled with a small export subsidy for these goods at an equal ad valorem rate. This corresponds to a subsidy to production of high-technology products and an equal rate tax on consumption. The production subsidy expands the number of high-technology goods produced in the policy active country, whereas the consumption tax has no effect on n^A. Accordingly, an import tariff cum export subsidy causes n^A to rise. The two policies have, as we have seen, offsetting effects on the rate of innovation. It turns out that, where domestic innovation is concerned, the effect of the production subsidy wins out: an import tariff cum export subsidy on high-technology products reduces the size of the local R&D sector. For the world as a whole, the effect of the consumption tax varies directly with the level of local consumption of high-technology goods, whereas the effect of the production subsidy varies with the scale of local production. By direct calculation we can prove that trade intervention increases the rate of global technological progress if and only if the policy active country is a net importer of high-technology goods. The following proposition summarizes these findings.

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[15] The HH curve shifts to the left by $E^A p^X dt$. This fall in p^X leaves $s_x[1-tE^A/(1+t)]/p^X$ unchanged. It therefore causes the left-hand side of (18) to decline. It follows that the leftward shift of YY is smaller.

Proposition 6: A small tariff on imports of high-technology goods coupled with a small subsidy to exports of these goods at equal ad valorem rate expands the number of high-technology goods manufactured and exported by the policy active country. The rate of technological progress falls in the policy active country. It rises for the world as a whole if and only if this country imports high-technology products on net.

VII. Conclusions

I have presented a two-country model of endogenous innovation and international trade. Two manufacturing sectors operate in each country. One sector produces a homogeneous good under competitive conditions, with natural resources (including land) as principal input. The other sector supplies a variety of high-technology products. The high-technology industries are distinguished by their intensive use of skilled labor as an input to production and by the dynamic nature of competition. In each high-technology industry, firms worldwide compete to bring out the next generation product, which is always one of higher quality. Success in the research lab brings temporary market leadership and a stream of oligopoly profits. Far-sighted entrepreneurs invest in R&D until the expected return just equals the laboratory costs. In the steady-state equilibrium, an endogenously determined rate of innovation is realized in each country, and the pattern of intersectoral trade (though not the pattern of trade in any particular high-technology product) is stable through time.

The model predicts that the country with the greater relative endowment of skilled labor compared to natural resources will develop over time a comparative advantage in the high-technology sector. That comparative advantage is "created", in the sense that technologies are generated by the devotion of resources to R&D. Intuitively, the country with a greater relative endowment of skilled labor will enjoy an incipient cost advantage in R&D, and so in the long run will specialize to a relatively extent in generating industrial innovations.

The model presented here may provide some insight into the recent Japanese success in the high-technology industries. The growth in that sector of the Japanese economy corresponds closely to the country's build up of human capital. Twenty five years ago, Japan stood far behind the United States and Western Europe in the education and skills level of its labor force. Today, the per capita endowment of human capital is at least equal to that of every country except perhaps the United States. The abundance of skilled labor in Japan, together with the well known scarcity of natural resources, suggest a pattern of specialization and trade much like that predicted here. Moreover, the data support the model's predictions. Japan's build up of human capital has generated remarkable growth in indigenous R&D activity. And Japan's cross-sectoral pattern of revealed comparative advantage now correlates very highly with the R&D intensities of those sectors.

I have used the theoretical model to explore the consequences of various policy measures for the long-run rates of innovation and the long-run industrial structures of the two trading partners. Most interesting, perhaps, are the findings for R&D subsidies. This policy induces greater research effort in the country that undertakes the subsidy, but ultimately leads to a contraction of its high-technology sector. In effect, the research labs compete with the manufacturing sector for skilled labor, so that expansion of the former implies a contraction of the latter. It is interesting to note that the Japanese government finances a smaller share of industrial research than is typical for industrialized countries. While the consequences of this policy stance may be adverse for the rate of innovation in Japan, the results here suggest that the lack of subsidies may in fact contribute to Japan's competitive strength in producing and exporting high-technology goods.

I find that the long-run effects of production subsidies are qualitatively the opposite from those of R&D subsidies. Subsidies for output of high-technology goods induce an expansion of this sector at the intensive and extensive margins. A country that introduces such a subsidy will see its competitiveness in high-technology products grow, but its long-run rate of indigenous innovation decline.

Finally, I have studied the long-run consequences of trade policies. A country may protect its high-technology sector via a tariff on imports of foreign high-tech goods and a subsidy to exports of local high-tech products. This policy combination leads to an expansion of competitiveness in the high-technology sector, but to a decline in the rate of indigenous innovation. The rate of technological progress for the world as a whole rises if the policy active country is the one with comparative disadvantage in the high-technology sector (i.e., if it imports these goods on net), but falls if the policy active country is the one with comparative advantage in this sector.

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Table 1

Structural Transformation of Japan's Tradeables Sector

	Share of Sector's Output in Total Tradeables Output[a]		Share of Sector's Exports in Total Exports		Ratio of Net Exports to Apparent Domestic Consumption[b]	
	1960	1987	1960	1987	1960	1987
GAINERS						
Electrical Machinery	5.9	14.1	5.7	24.5	.060	.241
Motor Vehicles	6.1	12.0	10.1	25.1	.120	.320
Ordinary Machinery	6.5	9.9	4.5	13.9	-.003	.186
Precision Instruments	0.9	1.5	2.0	3.2	.115	.248
LOSERS						
Agriculture and Forestry	13.4	5.4	3.3	0.1	-.137	-.131
Mining Products	1.7	0.8	0.1	0.1	-.500	-.692
Foods and Beverages	15.9	10.5	3.3	0.6	-.015	-.062
Textiles	8.6	2.7	20.3	2.0	.207	-.004
Primary Metals	14.4	10.3	8.4	5.9	-.012	.007

Sources: Japan, Statistics Bureau, Management and Coordination Agency, *Kagaku Gijutsu Kenkyu Chosa Hokoku*, 1988 (Report on the Survey of Research and Development); Japan, Economics Planning Agency, *Kokumin Keizai Keisan Nenpo* (Annual Report on National Accounts), 1987.

[a] Tradeables Sector defined to include all manufacturing sectors plus agriculture and forestry products and mining products.

[b] Apparent Domestic Consumption = Output + Imports - Exports.

Table 2

International Comparisons of Human Capital

	Share of Professional and Technical Workers in Economically Active Population		Average Years of Formal Education as of 1984	Percentage of Cohort Enrolled in Higher Education in 1985		Degrees Awarded in Physical Science and Engineering in 1985[a]	
	Percent	Year	Years	Percent	Cohort	Bachelor's	Graduate
Japan	10.6	1985	11.2	32.1	18-21	14.31[b]	2.14
United States	14.8	1985	12.5	41.7	18-24	17.39[c, d]	4.39[c, d]
West Germany	13.9	1984	9.5	23.9	19-22	5.80	1.41[e]
France	14.1	1982	10.8	26.9	18-22	8.03[f, g]	3.04[f, g]
United Kingdom	15.9	1981	10.9	18.7	18-20	15.44[g]	3.52[g]

Sources: International Labour Organization, *Yearbook of Labour Statistics*, 1986, 1987; Angus Maddison, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, Vol.25, No.2, 1987; Japan, Kagaku Gijutsu Cho, *Kagaku Gijutsu Yoran* (Indicators of Science and Technology), 1987, 1989.

[a] Expressed as fraction of economically active population × 10,000.

[b] 1986.

[c] 1983.

[d] Uses 1985 figure for economically active population.

[e] Includes doctoral degrees only.

[f] Includes degrees in agricultural sciences.

[g] Uses 1984 figure for economically active population.

Table 3

International Comparison of Resource and Physical Capital Endowments

	Ratio of Arable plus Pasture Land to Economically Active Population (1985)[a]	Ratio of Coal Output to Economically Active Population (1985)[b]	Ratio of Oil and Gas Output to Economically Active Population (1985)[b]	Ratio of Physical Capital Stock to Economically Active Population (1986)[c]
Japan	0.09	1.61	0.45	62.51
United States	3.68	39.60	76.93	55.56
West Germany	0.43[d]	29.78	6.52	68.70
France	1.32	4.24[d]	3.37[d]	66.35[d]
United Kingdom	0.69	23.08[d]	62.48[d]	n.a.

Sources: International Labour Organization, Yearbook of Labour Statistics, 1986, 1987; Food and Agriculture Organization, Production Yearbook, 1986; International Energy Agency, Energy Balances of OECD Countries, 1986; Alan Heston and Robert Summers, "An Evolving International and Intertemporal Data System Covering Real Outputs and Prices," Paper presented at NBER Mini-conference on Economic Growth, 1989.

[a] Expressed as hectares per economically active individual.

[b] Expressed as tons of oil equivalent per economically active individual × 10.

[c] Expressed as thousands of 1980 U.S. dollars per economically active individual.

[d] Uses 1984 figure for economically active population.

Table 4

International Comparison of R & D Activity and Policy

	R & D Expenditures as Percentage of GDP (1985)	Researchers as Percentage of Economically Active Population (1985)	Percentage of Total R & D Funded by Government (1986)	Percentage of R & D Conducted by Industry Funded by Government
Japan	2.61	0.64	19.6	1.79 (1986)
United States	2.83	0.66	48.3	35.53 (1987)
West Germany	2.66	0.52	37.5	15.28 (1987)
France	2.37	0.45[a]	46.1	22.42 (1983)
United Kingdom	2.32	0.33[a]	42.2	23.19 (1985)

Sources: OECD, "Total Factor Productivity,"*OECD Economic Outlook*, No. 42, 1987; Japan, Kagaku Gijutsu Cho, *Kagaku Gijutsu Yoran* (Indicators of Science and Technology), 1989.

[a] Uses 1984 figure for economically active population.

Table 5

Correlation Between Measures of R&D Intensity and Measures of Japan's Revealed Comparative Advantage

Correlation Between:	13 Manufacturing Sectors[a]			15 Tradeables Sectors[b]		
	1960	1970	1987	1960	1970	1987
Series (1) and (3)	.238	.643	.794	.343	.687	.823
Series (1) and (4)	.117	.580	.750	.265	.427	.612
Series (2) and (3)	-.324	.228	.586	.010	.328	.639
Series (2) and (4)	-.489	.087	.504	.274	.308	.457

Series:

(1) Intramural Expenditure on R&D as Percentage of Sales

(2) Number of Researchers per 10,000 Employees

(3) Exports as Percentage of Output

(4) Ratio of Net Exports to Apparent Domestic Consumption

Sources: See Table 1.

[a] The manufacturing sectors are: Foods and Beverages; Textiles; Pulp and Paper; Chemicals; Primary Metals; Fabricated Metals; Ordinary Machinery; Electrical Machinery; Motor Vehicles; Precision Instruments; and Other Manufactures.

[b] Includes 13 manufacturing sectors plus Agricultural, Forestry and Fishery Products and Mining Products.

Figure 1

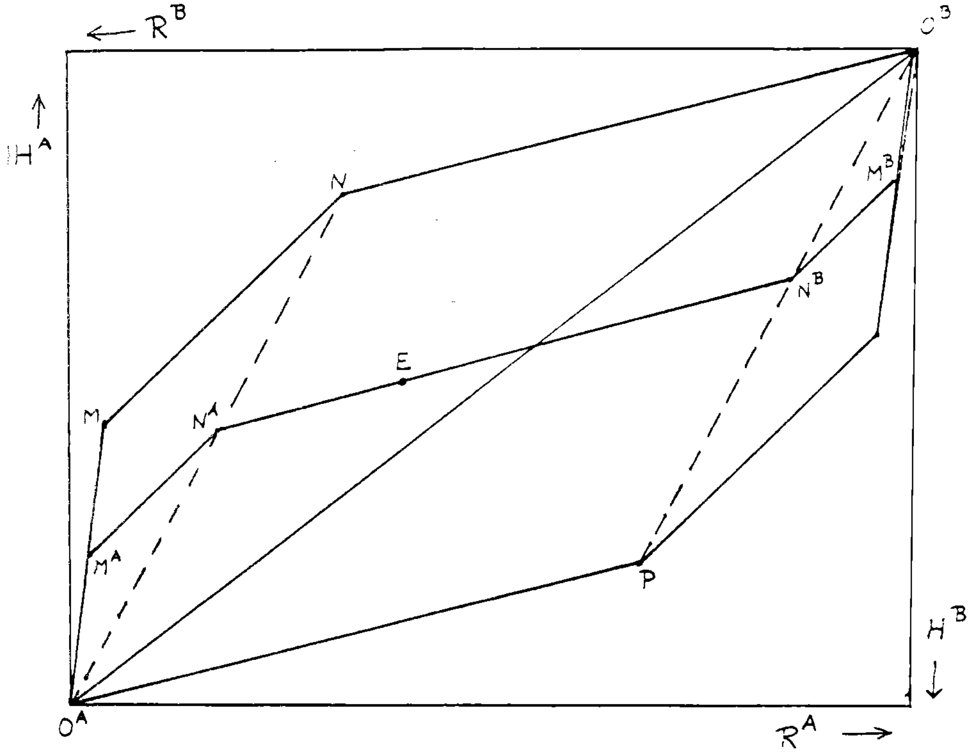
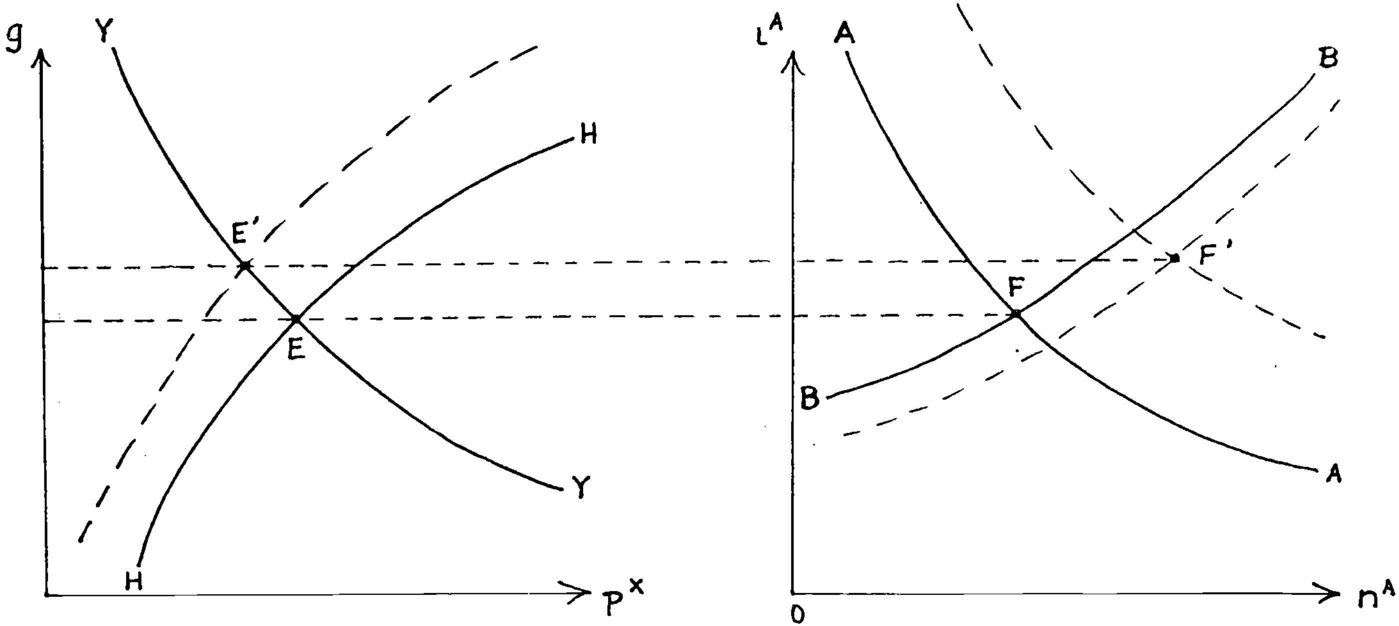


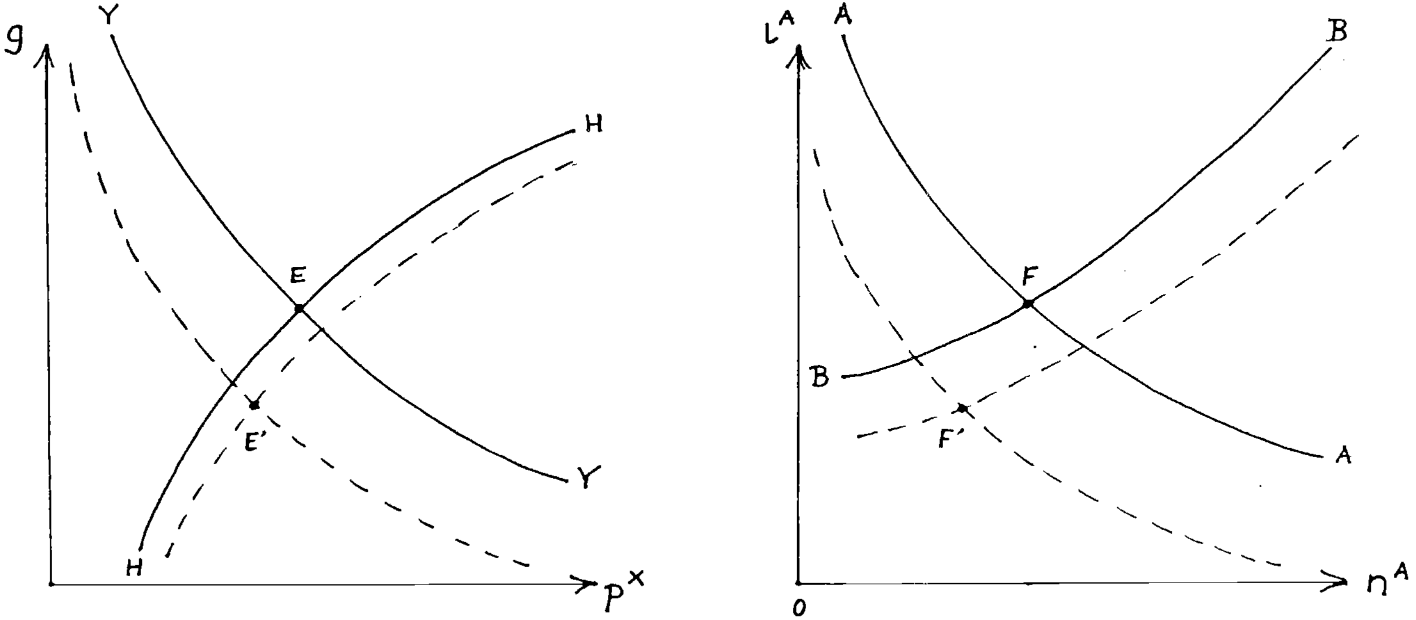
Figure 2



a

b

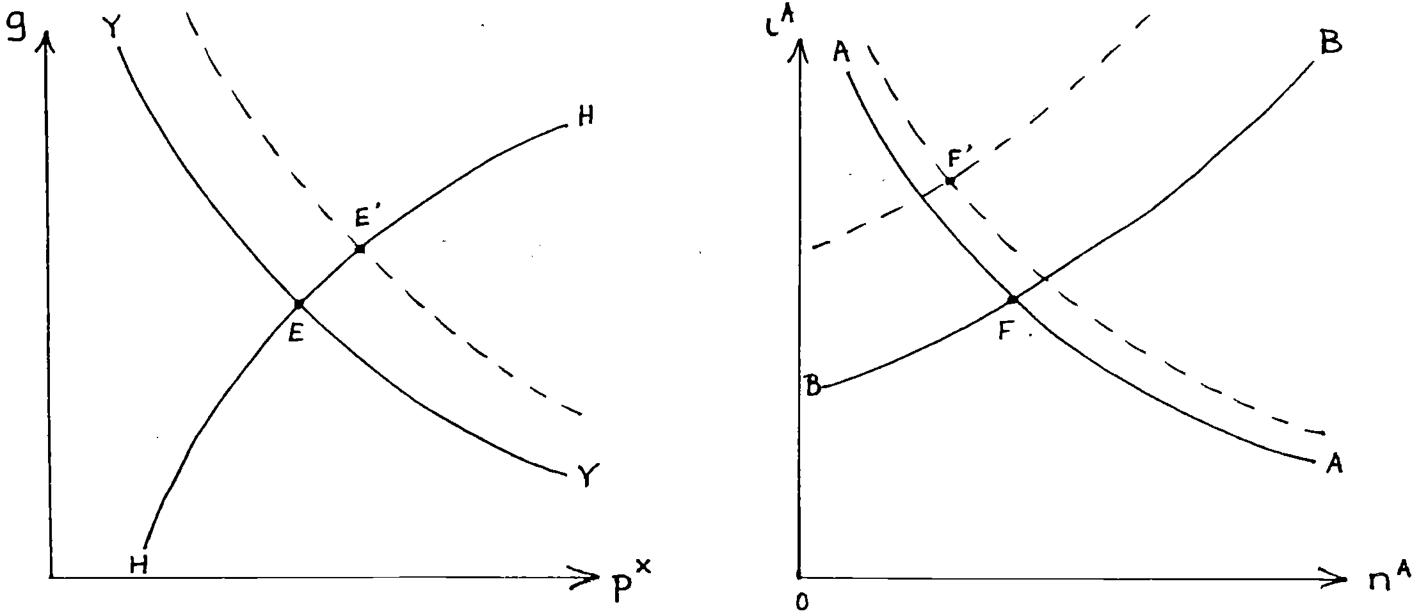
Figure 3



a

b

Figure 4



a

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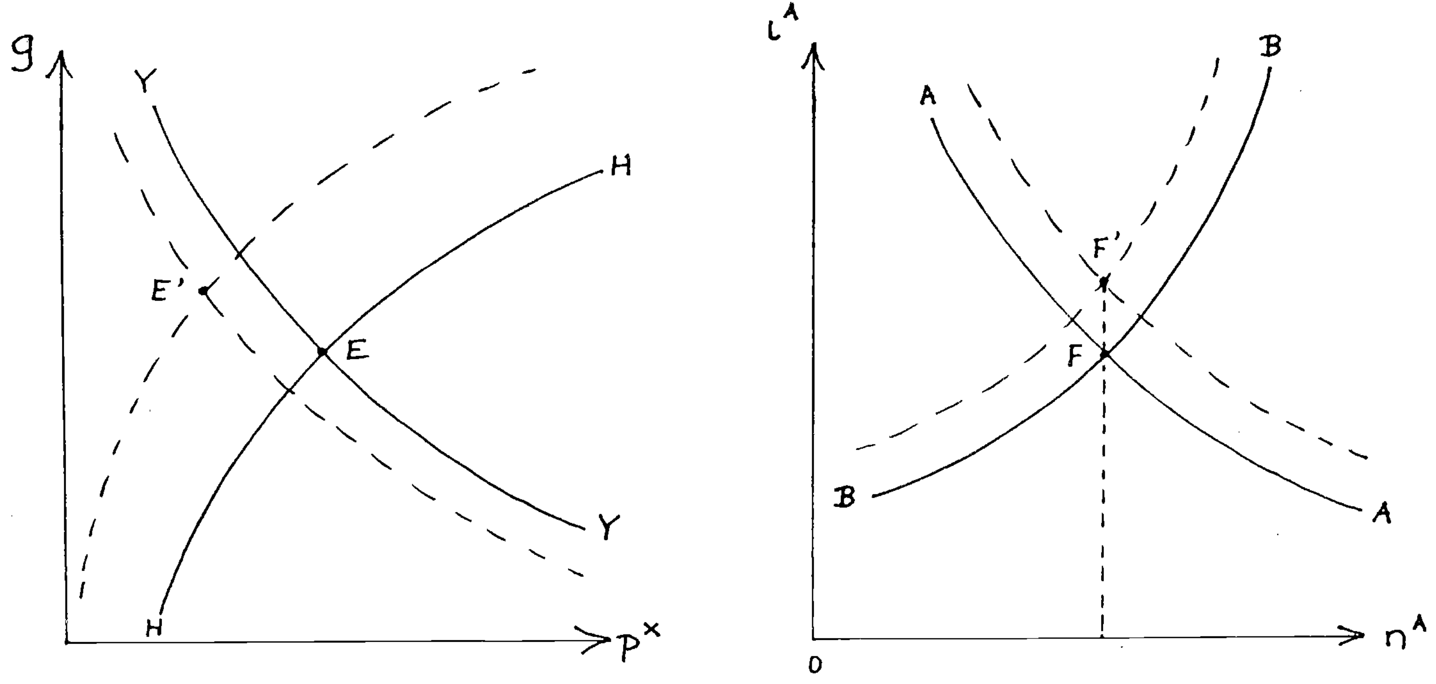
Figure 5



a

b