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Endogenous Innovation in a North-North Model of the Product Cycle

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ENDOGENOUS INNOVATION IN A NORTH-NORTH MODEL OF THE PRODUCT CYCLE

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Abstract

This paper examines the effect of endogenous innovation in a North-North model of the product cycle. Innovation is a dynamic process that requires labor to be employed in research and development for innovation to occur. Technology is transferred both within and across countries. The results show that in this generalized product-cycle model, the amount of innovation and technology transfer affects the economic incentives to innovate and the relative wages in both countries. As a result, changes in the amount of innovation in one country can have significant redistributive effects worldwide, both across and within countries.

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INTRODUCTION

Product-cycle models, as discussed by Vernon (1966), examine how product innovation and the subsequent transfer of the production technology determine the pattern of trade between two countries. These models have historically focused on North-South trade, where an industrialized country (the North) produces only products that have been recently innovated (new goods) and the less-developed country (the South) produces only products for which the production technology is internationally available (old goods). Recent extensions of this literature have focused on quality cycles and the relationship between product cycles and economic growth.

There are several features that make this paper different from other product-cycle models. Most significantly, innovation occurs in both countries, and technology is transferred across and within countries. There are both skilled and unskilled labor in each country, and the productivity of skilled workers can differ across the two countries.¹

These features generalize the product-cycle framework to one where product-cycle effects occur both within and across countries (the so-called North-North approach). The North-South

1. This assumption is consistent with the stylized facts. For example, firms in industrialized countries do produce a significant percentage of old goods. According to the Organisation for Economic Co-operation and Development (1986), in the seven major industrialized countries, between 42.7 and 64.5 percent of manufacturing workers are employed in low R&D-intensive industries.

approach is simply a special case of the model (see Butler, 1989a). As a result, in addition to examining the standard effects of product innovation on the terms of trade (although these effects are somewhat different in this more generalized framework), I can examine several other issues ignored in previous product-cycle models. First, because there is both innovation and technology transfer in each country, the amount of innovation in one country affects the relative wage between skilled and unskilled labor in the other country. Second, the two types of labor allow me to examine how the relative allocation of skilled and unskilled labor affects innovation and relative wages both domestically and in the other country. Third, the amount of innovation in one country directly affects the incentives to innovate in another.

In order to focus on the issues discussed above, this paper abstracts from several other interesting issues that have been examined in other related research. In this paper, both technology transfer and obsolescence are assumed to be given by exogenous processes. For an examination of the former in a North-South model, see Dollar (1986, 1987), and Segerstrom, Anant, and Dinopoulos (1990). For a discussion of the latter, see Stokey (1988, 1990). In addition, the interest rate is not formally modeled, and so the method of financing initial R&D is not well-specified. For more formal modeling of these effects in a North-South context, see Grossman and Helpman (1991c), and Segerstrom, Anant and Dinopoulos (1990). In addition, all innovation takes the form of new products. See Grossman and

Helpman (1991a, 1991b), and others for examination of quality-based product cycles.

The paper is organized in the following manner. The next section describes the static household sector and derives demand functions for goods. The firm's problem is then described and solved and the old good sector characterized. Finally, conclusions and extensions are discussed.

THE HOUSEHOLD SECTOR

The utility function for individuals is a restricted CES utility function that is the same for all individuals in both countries.² As a result, this function is treated as an aggregate utility function, but prices are considered parameters as if the utility function were maximized for each individual and then aggregated. Individuals consume all goods that are produced. Goods are produced in three sectors: the innovating sectors of each country, and the non-innovating old good sector (these goods are produced in both countries). Within each innovating sector, monopolistically competitive firms decide how much variety to create, and how much of each variety to produce. The amount of variety in the old good sector is the same in both countries. Perfect competition in both the input and output

2. This utility function, borrowed from Dixit and Stiglitz (1977), also has the property that all goods of the same price are valued the same. Although this is not a realistic assumption, it is one of the few utility functions that allows for latent demand for goods that have yet to be innovated. In addition, this utility function is standard in the literature and provides results that can be compared with those found by Krugman (1979) and others.

market for old goods, combined with the same production technology in both countries ensures that the price of all old goods are the same.³ The innovating sector, however, is characterized by monopolistic competition and therefore those prices are derived via optimization below. The utility function has the following functional form:

$$(1) \quad U = \left[\int_{a=0}^N C(a)^\theta da \right]^{1/\theta}; \quad U > 0, \quad U_c > 0,$$

where

$N = N_{1n} + N_{2n} + N_0$ is the amount of variety available in the new goods sectors of Country's One and Two and the old good sector, respectively,

$\theta =$ the weight put on quantity relative to variety, and

$C(a) =$ the quantity consumed of the a th type of good.

To derive the world demand functions for goods, utility is maximized subject to world income.⁴ From the first order conditions, the relative demand between new and old goods can be determined; this is given by:

$$(2) \quad C_a/C_o = (p_a/p_o)^{-\epsilon}; \quad \forall a \in \Omega_{1n} + \Omega_{2n}, \quad \forall o \in \Omega_o,$$

3. For simplicity, transportation costs are assumed to be zero.

4. World income is defined as the sum of all workers income. This type of maximization is possible because the demand functions are linear with respect to income. World demand functions are used because the demand a firm faces for any given product comes from all individuals.

where

ϵ = the (constant) elasticity of substitution between any two varieties,

Ω_{1n} = the feasible set of different types of goods that can be produced in Country One,

Ω_{2n} = the feasible set of different types of goods that can be produced in Country Two,

Ω_o = the feasible set of different types of goods that can be produced in the old good sector.

Normalizing prices and wages on the price of old goods, p_o , setting units such that the price of old goods equals one and solving results in the following demand functions:

$$(3) \quad C_o = Y/Z, \quad \forall o \in \Omega_o,$$

$$(4) \quad C_{1a} = P_{1a}^{-\epsilon} Y/Z, \quad \forall a \in \Omega_{1n},$$

$$(5) \quad C_{2a} = P_{2a}^{-\epsilon} Y/Z, \quad \forall a \in \Omega_{2n},$$

where

$$Z = \int_{a=0}^N (P_a)^{1-\epsilon} da; \quad a \in \Omega = \Omega_{1n} + \Omega_{2n} + \Omega_o,$$

P_{ja} = price of good a in country j , $j=1,2$, and

y = world income.

THE FIRM'S PROBLEM

All firms have identical innovation and production technology, although for simplicity they innovate different products. Innovation is a dynamic linear function of the number of R&D workers, and a firm produces each innovation until the production technology is transferred to the old good sector.

Production is characterized by constant returns to scale, and although the number of firms is indeterminant, firms are assumed to be small enough relative to the market that they do not perceive they can effect other firms decisions, and therefore take other prices as parametric.

Skilled workers are more productive when employed in the innovating sector, and are assumed to receive a higher wage in that sector. The labor market is perfectly competitive, and wages are flexible. The reservation wage is assumed to be sufficiently below the wage in the old good sector to ensure all workers are employed. Unskilled workers can only work in the old good sector.

Because the innovation and production functions are linear with respect to the decision variables, the problem is solved for a representative firm and then aggregated. The problem is solved recursively: The choice of the price for any given good is a static problem and solved first; the choice of R&D workers is dynamic and contingent on the solution to the static problem and thus solved second. All results are solved for Country One; the results for Country Two can be found by changing the relevant country-specific variables.

The Firm's Static Problem

The demand for any good 'a', $a \in N_{1n}$, is given by equation 4. The production function is given by:

$$(6) \quad Q_{1a} = \alpha_1 L_{1a}^P, \quad \forall a \in N_{1n},$$

where

α_1 = the productivity parameter associated with skilled workers in Country One, and

L_{1a}^P = the number of skilled workers employed in production of good a in the new good sector of Country One.

The problem facing the firm is to maximize the following profit function subject to equations 4 and 6:

$$(7) \quad \Pi = P_{1a}Q_{1a} - W_1L_{1a}^P - W_1L_{1a}^R,$$

where L_{1a}^R is the number of R&D workers used to innovate good 'a'. Substituting in and solving yields the following solutions for the price and number of production workers used to produce a single good:

$$(8) \quad P_{1a} = W_1/\alpha_1\theta,$$

$$(9) \quad L_{1a}^P = P^{-\epsilon}Y/\alpha_1Z.$$

These equations hold for any product $a \in N_{1n}$, and because none of the variables on the right-hand side change as 'a' changes, the price of any good produced by this firm will be the same; a constant markup over the wage. In fact, because these firms are identical, the price charged by all firms in the innovating sector of Country One is the same.

The Firm's Dynamic Problem

The firm solves for the optimal time path of R&D workers by maximizing total discounted profits, given the price and output level determined in the previous section. The amount of

R&D labor the firm hires determines the variety of goods it produces. Technology transfer is a costless process in this model, and is proportional to the amount of variety available in the new good sector. The rate of change of variety in the innovating sector of Country One is given by:

$$(10) \quad dN_{1j}/dt = i_1 L_{1j}^R - k_1 N_{1j}; \quad 0 < i_1 < 1, \quad 0 < k_1 < 1,$$

where i_1 is the productivity parameter associated with R&D workers and k_1 is the exogenous rate of technology transfer in Country One.

The demand for production workers for a single firm is determined by the production function for a single good times the number of different types of goods the firm can produce, N_{1j} ($0 < N_{1j} < N_{1n}$). As a calculus of variations problem, firm j maximizes the following:

$$(11) \quad \int_0^\infty e^{-rt} [P_1 \alpha_1 L_{1j}^P - W_1 (L_{1j}^P + L_{1j}^R)] dt,$$

subject to equations 8, 9, and 10, and the initial condition, given by

$$N(0) = 0,$$

where r is the discount rate, which is assumed to be the same for both countries.

Substituting the constraints of equation 11 and solving for Euler's necessary condition for an optimum yields:

$$(12a) \quad \partial V / \partial N_{1j} = e^{-rt} \beta;$$

$$(12b) \quad \frac{\partial}{\partial t} \left[\frac{\partial V}{\partial (dN_{1j}/dt)} \right] = e^{-rt} r \gamma,$$

where

$$\beta = (W_1/\theta - W_1)(W_1/\alpha_1 \theta)^{-\epsilon} Y/\alpha_1 Z - W_1 k_1 / i_1, \text{ and}$$

$$\gamma = W_1 / i_1.$$

Setting them equal to equations 12a and 12b yields the following condition:

$$(13) \quad \beta = r\gamma.$$

Euler's equation requires that, in equilibrium, the discounted cost of R&D today ($r\gamma$) is exactly offset by the discounted benefit of production tomorrow (β).

To determine the steady-state employment levels of production and R&D workers, we set dN_{1j}/dt to zero and solve for N_{1j} .⁵ Because all firms are identical, applying the aggregate labor constraint for skilled workers provides the following steady-state allocations of production and R&D workers and variety in the innovating sector:

$$(14) \quad L_1^P = (r + k_1)\theta L_{1n}/(k_1 + \theta r),$$

$$(15) \quad L_1^R = (1 - \theta)k_1 L_{1n}/(k_1 + \theta r),$$

$$(16) \quad N_{1n} = i_1(1 - \theta)L_{1n}/(k_1 + \theta r),$$

where L_{1n} is the total number of skilled workers in Country One.

Because it is assumed that the firm is small relative to the market and therefore does not perceive that its behavior affects the variety of goods produced in the other sector, only domestic variables, the discount rate and the utility parameter affect the level of innovation and the allocation of production and R&D workers.

5. Since the rate of change of variety is asymptotically stable and converges for all values of the parameters, we can go directly to the steady-state solution.

THE OLD GOOD SECTOR

The old good sector produces only goods for which technology is internationally available. This technology comes from the two innovating sectors. Thus, technology is transferred not only from one country to another, but between sectors within a country. Eventually, old goods become obsolete and are no longer produced. Goods become obsolete at a rate proportional to level of variety in the old good sector, which is a function of the amount of innovation in the new good sectors. The assumption of obsolescence is not formally modeled here, but simply is imposed on the model. Formulating obsolescence in these terms is motivated by appealing to the idea that some old goods eventually are displaced by goods whose product attributes dominate those of the existing old goods. It is not necessary that all old goods become obsolete; rather only that some proportion of old goods are continually replaced.

The variety of goods in the old good sector is determined by a dynamic process described by the following differential equation:

$$(17) \quad dN_o/dt = k_1 N_{1n} + k_2 N_{2n} - g N_o, \quad 0 < g < 1,$$

where g is the obsolescence rate, which is the same for both countries because the stock of old goods is the same.

To solve directly for the steady-state solution, the rate of change of N_o is set to zero and then solved for N_o , substituting in the steady-state values of N_{1n} and N_{2n} :⁶

6. This equation can be solved directly due to the stability properties of the function.

$$(18) \quad N_o = (1 - \theta)[i_1 k_1 L_{1n}/(k_1 + \theta r) + i_2 k_2 L_{2n}/(k_2 + \theta r)]/g.$$

Production in this sector occurs in a perfectly competitive input and output market in the sense that free entry and constant average costs (due to constant returns to scale in production) ensure zero profits. Each worker is assumed to produce one unit, and because the cost of producing old goods is the same for all goods, every old good has the same price.

RESULTS AND COMPARATIVE STATICS

Using the result that the price of all goods within a sector are the same, equation 2 can be rewritten as:

$$(19) \quad C_1/C_o = (p_1/p_o)^{-\epsilon} = (P_1)^{-\epsilon}.$$

where C_1 is the demand for any new good in Country One. Thus, the relative quantities demanded between any two goods, or group of goods with the same price, is a function of only the relative price and the weight given to variety versus quantity.

From the supply constraints and the steady-state solutions derived above, the domestic relative wage and relative price equations are given by:

$$(20) \quad p_1/p_o = (N_{1n}L_o/\alpha_1 L_1^p N_o)^{1-\theta} \\ = \left(\frac{g i_1 L_o}{(r+k_1)\theta \alpha_1 \{ [i_1 L_{1n} k_1 / (k_1 + \theta r)] + [i_2 L_{2n} k_2 / (k_2 + \theta r)] \}} \right)^{1-\theta}.$$

$$(21) \quad w_1/w_o = (N_{1n}L_o/L_1^p N_o)^{1-\theta} (\alpha_1 \theta)^\theta \\ = \left(\frac{g i_1 L_o}{(r+k_1) \{ [i_1 L_{1n} k_1 / (k_1 + \theta r)] + [i_2 L_{2n} k_2 / (k_2 + \theta r)] \}} \right)^{1-\theta} (\alpha_1 \theta)^\theta.$$

One of the unique features of this model is the way in which foreign variables affect domestic relative wages and prices. Standard product-cycle models, as well as the more

recent models of innovation and growth, do not capture the way in which foreign innovation can influence the domestic incentives to innovate and the distribution of income between skilled and unskilled workers in both countries.

The difference between the relative wage and relative price equations are due to the differential effects the productivity and utility parameters have on these variables. The comparative statics for equation 20 and 21 are otherwise the same.

The terms of trade and the international relative wage are determined from the relative demand equations for new goods produced in the two countries, the aggregate production constraints, and the steady state solutions given above:

$$(22) \quad P_1/P_2 = [i_1\alpha_2(r+k_2)/i_2\alpha_1(r+k_1)]^{1-\theta}.$$

$$(23) \quad W_1/W_2 = [i_1(r+k_2)/i_2(r+k_1)]^{1-\theta}(\alpha_1/\alpha_2)^\theta.$$

The comparative statics results are shown in table 1.⁷ The effect of changes in the parameters on world income is also examined, with income being defined in terms of physical units of goods. Note that an increase in income does not necessarily increase utility.

Proposition One: An increase in the productivity of R&D workers in Country One increases the domestic relative wage and

7. The derivatives are given in the appendix. If the sign of the derivatives is the same for wages and prices, only one is shown, and the effects on the terms of trade and the domestic relative wage are discussed.

the terms of trade. Income is redistributed to the innovating sector in Country One from the other two sectors, while world income remains constant.

Proof: See equations A.11 through A.17 in the Appendix.

An increase in the productivity of R&D workers has a symmetric effect on the demand for both R&D and production workers, increasing the amount of innovation while leaving the allocation of skilled workers unchanged. The subsequent increase in variety generates additional demand for new goods in that sector, which, at full employment, puts upward pressure on wages and therefore prices. The increase in variety in Country One increases the variety available in the old good sector, which increases demand for the less-expensive old goods. In Country One, the effect of increased innovation in the new good sector dominates the demand effects in the old good sector, and the domestic relative wage and terms of trade increase.⁸ In Country Two, however, there is no offsetting increase in innovation, and the domestic relative wage falls in that country.

Proposition Two: An increase in the productivity of R&D workers in Country One can eliminate the incentive to innovate in Country Two.

Proof: See equation A.13 in the Appendix.

8. Firm's profits remain zero, however, because wages also rise.

If the increase in R&D productivity is large enough in Country One, the relatively higher prices that induce firms to innovate in Country Two evaporates and the wage between skilled and unskilled workers equalizes in that country. If innovation ceases in Country Two, all of its unskilled workers would be employed in the old good sector. In this case, world variety unambiguously declines, but the effect on output and therefore world income depends on whether the increase in output produced by workers formerly employed in the R&D sector is greater than the loss of output due to skilled workers being employed in the less productive old good sector.⁹

Proposition Three: An exogenous increase in skilled labor in Country One redistributes income from the skilled to the unskilled sector, while leaving the terms of trade unchanged. Thus, an increase in the number of skilled workers can reduce or eliminate the incentive to innovate in either or both countries.

Proof: See equations A.21 through A.27 in the Appendix.

An increase in skilled labor increases innovation, while simultaneously lowering the wage because labor is now relatively more abundant. The demand effect in the old good sector dominates the innovation effect in the new good sector of Country One, so domestic relative prices fall in that country.

 9. For simplicity, as long as the domestic relative wage is not negative, skilled workers are assumed to remain employed in that sector. This can be justified by appealing to the idea that skilled workers receive more than pecuniary rewards from their jobs.

Country Two only experiences the increased demand in the old good sector, so the domestic relative wage falls there as well. If the increases in skilled workers is sufficiently large, the incentives and rents associated with innovation can be eliminated in either or both countries.

If the increase in skilled workers results from a costless improvement in unskilled workers (that is, an increase in the proportion of workers that are skilled), then the reduction in the domestic relative wage will be greater because of the fall in output in the unskilled sector. World variety increases, but world output falls.¹⁰

Proposition Four: An increase in the rate of technology transfer in Country One reduces the amount of innovation and output in that country and therefore the terms of trade declines.

Proof: See equations A.31 through A.37 in the Appendix.

The effect of a change in the rate of technology transfer in the steady state can be looked at as a change in a country's patent length K_j , where:¹¹

10. Whether or not the effect of an increase in skilled labor in one country is greater on the domestic relative wage of that country or the foreign country depends on the relative size of the country-specific parameters, i.e., the rate of technology transfer and the productivity of R&D workers in the two countries.

11. See, for example, Segerstrom, Anant and Dinopoulos (1990). Note that the signs of the derivatives shown in Table 1 are reversed for patent lengths.

$$K_j = 1/k_j, \quad j=1,2.$$

A decrease in the patent length in Country One reduces the length of time a firm can produce each new good and therefore the income earned on every innovation. As a result, the demand for production workers falls, because each good is produced for fewer periods. A shorter patent length also decreases variety in the innovating sector, causing a decline in the demand for goods in Country One, and therefore in each firm's total revenue. To maintain its revenue, each firm (and therefore all firms) demands more R&D workers. Given full employment, however, this increase in R&D workers comes at the expense of production workers. As a result of the (implicit) trade-off for the sector as a whole, fewer additional R&D workers are hired than firms desire, and the variety available in Country One declines, reducing demand in that sector. This shift in demand causes a reduction in the terms of trade. In addition, world income falls (but not necessarily utility) due to the reallocation in the skilled sector in Country One.

The fall in the terms of trade that results from faster technology transfer is found in most North-South models of the product cycle, including this one. In Krugman (1979), the effect is direct since both innovation and technology transfer are exogenous processes. In Dollar (1986), in a model with endogenous technology transfer, this effect occurs through an improvement in the marginal productivity of Southern workers. Jensen and Thursby (1987) find the effect on the terms of trade

ambiguous, because the effect depends on the redistribution of workers between the traded and non-traded good sector.

Proposition Five: An increase in the rate of technology transfer reduces the incentive to innovate in both countries (although not necessarily by the same amount).

Proof: See equation A.33 in the Appendix.

A shorter patent length increases demand for old goods by increasing variety in that sector. As a result, the domestic relative wage falls in both countries. Thus, a decline in the patent length redistributes income from skilled to unskilled workers in both countries. This possible reallocation of income is used by both developing and industrialized countries to justify their respective opposition and support for increased intellectual property rights internationally.

If a country's patent length becomes too short (relative to the other country's patent length and other parameters), firms in that country will no longer have an economic incentive to innovate. While this result differs from that found by Jensen and Thursby (1986), Grossman and Helpman (1991c), and Segerstrom, Anant and Dinopoulos (1990) in a North-South context, who find that innovation increases as a result of faster technology transfer, as is pointed out by the latter this result is consistent with the partial equilibrium literature in industrial organization, which generally find that a decrease in

the patent length decreases the reward on and therefore the amount of innovation.

Proposition Six: An increase in the productivity parameter has the standard effect in a trade model here: the terms of trade decline, relative wages increase while relative prices fall.

Proof: See equations A.41 through A.48 in the Appendix.

CONCLUSION

This paper examines the effect of endogenous innovation on relative prices, wages, output and variety in a product-cycle model that allows for incomplete specialization. Endogenous innovation in a generalized product-cycle model raises many interesting issues that could not be examined in other models. Most other papers that examine trade between innovating countries ignore how technology transfer between and within these countries can alter the effects of innovation on trade and on relative prices and wages. This omission is significant, because, as this model shows, changes in the parameters that determine the amount of innovation in one country can alter the incentive to innovate in both countries. In addition, the existence of a skilled and unskilled sector in each country suggests how innovation and technology transfer, both foreign and domestic, can effect the distribution of income between workers within a country.

Many interesting policy questions can be examined within this model. For example, the addition of an unskilled sector puts a twist on the standard result that the optimal level of patent protection differs between the North and South (see, for example, Chin and Grossman, 1990). Here, while a decrease in a country's patent length narrows the income disparity between skilled and unskilled workers, it also reduces the amount of innovation in that country; as a result, the terms of trade decline.

This model has interesting empirical implications as well. Most traditional studies of the determinants of wages have focused on the effects of domestic variables. The results derived here show that foreign variables, such as the supply of skilled labor and the amount of innovation in a competing country may also affect the wage differential between skilled and unskilled workers. Preliminary evidence has found some support of this hypothesis (Butler, 1989a).

There are many ways to extend this model to include some of the issues abstracted in the model. For example, incorporating learning into the innovation process (see, for example, Stokey, 1990, and Grossman and Helpman, 1991c) would further generalize the model. Other interesting extensions include allowing unskilled workers to endogenously become skilled workers, or making technology transfer and/or product obsolescence an endogenous process in the model.

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APPENDIX

The following derivatives are used to determine the signs in table 1. If the effects of a change in wages and prices are the same, then only one of the derivatives is shown.

The effects of a change in the rate of innovation are given by:

$$(A.11) \quad \frac{d(P_1/P_2)}{di_1} = \frac{(1-\theta)(P_1/P_2)^{-1}\alpha_2(r+k_2)}{i_2\alpha_1(r+k_1)} > 0.$$

$$(A.12) \quad \frac{d(p_1/p_o)}{di_1} = \frac{\delta i_2 k_2 L_{2n}}{(k_2+\theta r)} > 0.$$

$$(A.13) \quad \frac{d(p_1/p_o)}{di_2} = \frac{-(1-\theta)(p_1/p_o)^{-1} g i_1 L_o L_{2n} k_2}{(r+k_1)\theta r \left[(k_2+\theta r) \left(\frac{i_1 L_{1n} k_1}{k_1+\theta r} + \frac{i_2 L_{2n} k_2}{k_2+\theta r} \right) \right]^2} < 0.$$

$$(A.14) \quad \frac{dL_1^P}{di_1} = 0.$$

$$(A.15) \quad \frac{dL_1^R}{di_1} = 0.$$

$$(A.16) \quad \frac{dN_{1n}}{di_1} = \frac{(1-\theta)L_{1n}}{(k_1+\theta r)} > 0.$$

$$(A.17) \quad \frac{dN_o}{di_1} = \frac{(1-\theta)k_1 L_{1n}}{g(k_1+\theta r)} > 0,$$

$$\text{where } \delta = \frac{(1-\theta)(p_1/p_o)^{-1}[gL_o/(r+k_1)\theta\alpha_1]}{\{[i_1 L_{1n} k_1/(k_1+\theta r)] + [i_2 L_{2n} k_2/(k_2+\theta r)]\}^2}.$$

The effects of a change in the endowment of skilled labor are given by:

$$(A.21) \quad \frac{d(P_1/P_2)}{dL_{1n}} = 0.$$

$$(A.22) \quad \frac{d(p_1/p_o)}{dL_{1n}} = \frac{-(p_1/p_o)^{-1} g i_2 L_o (r+k_1) \theta \alpha_2}{(k_1+\theta r) A^2} < 0.$$

$$(A.23) \quad \frac{d(p_2/p_o)}{dL_{2n}}.$$

$$(A.24) \quad \frac{dL_{1n}^R}{dL_{1n}} = \frac{(r+k_1)\theta}{k_1+\theta r} > 0.$$

$$(A.25) \quad \frac{dL_{1n}^P}{dL_{1n}} = \frac{(1-\theta)k_1}{k_1+\theta r} > 0.$$

$$(A.26) \quad \frac{dN_{1n}}{dL_{1n}} = \frac{i_1(1-\theta)}{k_1+\theta r} > 0.$$

$$(A.27) \quad \frac{dN_o}{dL_{1n}} = \frac{(1-\theta)i_1k_1}{g(k_1+\theta r)},$$

where

$$A = (r+k_1) \left[\frac{i_1 L_{1n} k_1}{k_1+\theta r} + \frac{i_2 L_{2n} k_2}{k_2+\theta r} \right].$$

The effects of a change in the rate of technology transfer are given by:

$$(A.31) \quad \frac{d(P_1/P_2)}{dk_1} = \frac{-(1-\theta)(P_1/P_2)^{-1} \alpha_1 i_2}{(\alpha_1 i_2 [r+k_1])^2} < 0.$$

$$(A.32) \quad \frac{d(p_1/p_o)}{dk_1} = -\lambda \left[\frac{i_1 L_{1n} k_1}{k_1 + \theta r} + \frac{i_2 L_{2n} k_2}{k_2 + \theta r} + \frac{(r+k_1) i_1 L_{1n} k_1}{(k_1 + \theta r)^2} \right] < 0.$$

$$(A.33) \quad \frac{d(p_1/p_o)}{dk_2} = \frac{-(1-\theta)(p_1/p_o)^{-1} g i_1 L_o i_2 L_{2n} \theta r}{(r+k_1) \theta \alpha \left[(k_2 + \theta r) \left(\frac{i_1 L_{1n} k_1}{k_1 + \theta r} + \frac{i_2 L_{2n} k_2}{k_2 + \theta r} \right) \right]^2} < 0.$$

$$(A.34) \quad \frac{dL_1^P}{dk_1} = \frac{\theta(\theta-1)L_{1n}r}{(k_1 + \theta r)^2} < 0.$$

$$(A.35) \quad \frac{dL_1^R}{dk_1} = \frac{(1-\theta)L_{1n}\theta r}{(k_1 + \theta r)^2} > 0.$$

$$(A.36) \quad \frac{dN_{1n}}{dk_1} = \frac{-i_1(1-\theta)L_{1n}}{(k_1 + \theta r)^2} < 0.$$

$$(A.37) \quad \frac{dN_o}{dk_1} = \frac{(1-\theta)i_1 L_{1n} \theta r}{g(k_1 + \theta r)^2} > 0,$$

where

$$\lambda = (1-\theta) \left(\frac{P_1}{P_o} \right)^{-1} \theta \alpha_1 \left[[r+k_1] \left[\frac{i_1 L_{1n} k_1}{k_1 + \theta r} + \frac{i_2 L_{2n} k_2}{k_2 + \theta r} \right] \right]^2.$$

The effect of a change in the technology parameter are given by:

$$(A.41) \quad \frac{d(P_1/P_2)}{d\alpha_1} = \frac{-(1-\theta)(P_1/P_2)^{-1}i_2(r+k_1)i_1\alpha_2(r+k_1)}{[i_2\alpha_1(r+k_1)]^2} < 0.$$

$$(A.42) \quad \frac{d(p_1/p_o)}{d\alpha_1} = \frac{-(1-\theta)(p_1/p_o)^{-1}gi_1L_o\delta}{(\alpha_1\delta)^2} < 0.$$

$$(A.43) \quad \frac{d(W_1/W_2)}{d\alpha_1} = \theta\alpha_2^{-\theta}(\alpha_1)^{\theta-1} \left[\frac{i_1(r+k_2)}{i_2(r+k_1)} \right]^{1-\theta} > 0.$$

$$(A.44) \quad \frac{d(w_1/w_o)}{d\alpha_1} = \theta(\alpha_1)^{\theta-1}\phi > 0.$$

$$(A.45) \quad \frac{dL_1^P}{d\alpha_1} = 0.$$

$$(A.46) \quad \frac{dL_1^R}{d\alpha_1} = 0.$$

$$(A.47) \quad \frac{dN_{1n}}{d\alpha_1} = 0.$$

$$(A.48) \quad \frac{dN_o}{d\alpha_1} = 0.$$

TABLE 1
COMPARATIVE STATIC RESULTS

	i_1	L_{1n}	k_1	α_1
P_1/P_2	+	0	-	-
W_1/W_2	+	0	-	+
P_1/P_0	+	-	-	-
W_1/W_0	+	-	-	+
W_2/W_0	-	-	-	0
L_1^P	0	+	-	0
L_1^R	0	+	+	0
N_{1n}	+	+	-	0
N_0	+	+	+	0

* For conditions that determine the effect of a change in these parameters, see appendix.

** The effects are ambiguous.