Endogenous Process Innovation under Piracy and Multinational Enterprise

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Abstract

A $2 \times 2 \times 2$ model with endogenous process innovation describes two regimes for international technology transfer: multinational enterprise, in which the innovating firm receives all rents from foreign and domestic use of the innovation, and piracy, in which some are all of the rents are kept in the technology-receiving country. Piracy increases the unit requirements for the factor which is scarce in the recipient country, and decreases use of its abundant factor, reducing income in the technology recipient. Any piracy regime can be dominated by a combination of no-piracy and transfers from the innovator to the recipient, with increases in both welfare in the recipient country and innovator profits.

Contents

1 Introduction

The development and international transfer of new products and processes is and has been an ubiquitous feature of the modern economy. In addition to its major contribution to economic growth in the highly industrialized countries (Griliches 1988), the exploitation of innovations has motivated or facilitated a substantial portion of the international activities—trade in products, investment, and licensing—of businesses in these countries (National Science Board 1988). Since both R&D expenditures and the stock of scientists and engineers continue to grow, in the United States and in other industrialized countries, technological change will likely maintain its important role in the evolution of the modern economy for the foreseeable future.

Technological change does not affect all agents in an economy equally. Findlay and Grubert (1959),Jones (1970) and Chipman (1970) showed how differential rates of growth in the productivity of different factors could change the terms of trade, factor prices, and the distribution of purchasing power across individuals and countries. Technological change might be immiserizing for some countries. Helleiner (1975) proposed in particular that one regime for the international transfer of technology, multinational enterprise, encourages a labor-saving bias in technological change which tends to reduce growth in the national products of labor-rich less-developed countries.

The ideas contained in the Helleiner proposition had a major impact on policy concerning the international transfer of technology towards less industrialized countries. Codes of Conduct were proposed for the transfer of technology by multinational enterprises, joint ventures with local partners were required, remittances of profits were taxed or restricted, and other policies were developed which tended to discourage multinational enterprise as a vehicle for the international transfer of technology.

The analysis of regimes in economics is an exercise in comparisons. In order to have normative content, the Helleiner proposition must compare the regime which is being criticized—multinational enterprise—to some other arrangement. The object of the present paper is to make such a comparison explicit. A model is developed containing the principal features of the Helleiner proposition: technology developed in an industrialized country for transfer within an enterprise to a less developed country. The alternative regime is described as "piracy": the transfer of technology without compensation from the innovator to the less developed country. It is shown that the move away from a pure multinational-enterprise regime tends to increase the unit requirements for the factor which is scarce in S, in favor of greater savings of L. This tends to reduce gross national product in L-rich S, in direct contradiction to the Helleiner proposition, an effect which is reinforced by adverse movement in the terms of trade. While piracy can increase utility in S even at the less labor-intensive technology, due to the appropriation of rents in S, it is established that any piracy regime can be improved upon by a combination of perfect appropriability of technology—an absence of piracy— and transfers from the innovator to the host. The latter conclusion refines the results of Feenstra and Judd (1982), which asserted the superiority of the technology-transfer tariff over other taxes on international commerce.

Following a brief discussion of the relation of the model's principal features to the existing literature, the assumptions used are listed explicitly, and the framework for endogenous technological change is discussed. The model is then laid out in the case of perfect appropriability, or pure multinational enterprise. Modification of the model follows, to permit uncompensated international transfer of technology, or piracy. The comparative-static analysis of an increase in piracy is then carried out, with evaluation from the standpoint of welfare in the technology recipient. Finally, possible extensions are noted.

The model's conclusions rest upon endogenous variations in the direction of process innovation. The innovator has a fixed stock of research resources, which can produce various combinations of unit input requirements. Once the choice is made, two fixed-coefficient techniques are available: a pre-existing "public" technology, freely available to all, and the innovative technology. The "putty-clay" formulation follows Binswanger (1974); the use of an isoquant to represent innovation possibilities was proposed by Ahmad (1966).

Attention to issues of unemployed or underemployed resources—the object of the Helleiner proposition and much of development economics—requires use of a process-innovation framework. Recent advances in the international economics of technological change (Krugman 1979, Helpman 1984, Jensen and Thursby 1987, Grossman and Helpman 1989) have built upon a product-innovation approach within the framework of monopolistic competition. While this framework provides an equilibrium in the presence of fixed R&D costs, it cannot be applied to the question of factor-saving technological change. However, abandoning this approach requires an alternative specification of the industrial organization of technological change, which can be found in the rent-extracting and rent-diffusing approach commonly used in the industrial-organization literature (Dasgupta and Stiglitz 1980, Kamien and Tauman 1986, Katz and Shapiro 1986). It is useful to think of independent researchers organizing themselves into a team to develop an innovation, which is then sold to the highest bidder, using license fees and royalties to extract the innovator's rent.

With fixed-coefficient technologies used in both countries, failure of factor-price equalization requires specialization in at least one country, which implies that one factor is unemployed. This requirement is acceptable, indeed desirable, in the present context, which considers commerce in technology from the standpoint of a country with a surplus factor in the sense that increases in the employment of that factor do not involve an increase in its price. Within a general-equilibrium framework this requires that the slack factor is either unemployed and free or is available at a fixed price, such as a subsistence wage, from a secondary market, as is described by the dual-market theory of development economics (Meier 1989). Alternatively, one might suppose that the owners of the unemployed resource are paid a transfer out of gross national product (the earnings of the fully employed factor), or are part-owners of this resource.

In the pure-multinational-enterprise form of the model, total control of the innovative technology is the basis for business operations across countries. This technology is the headquarters asset of Helpman (1984) or the firm-specific advantage of Markusen (1984). The requirement that technology be perfectly appropriable is not excessively strong, as high-appropriability regimes do exist, allowing the innovator reasonable control over the use of and rents from the new technology (Levin 1988). Indeed, the present model analyzes explicitly variations in appropriability.

2 Assumptions and Definitions

1. The world is made up of two countries, N and S, two products, a and b, and two factors, K and L.

2. The technology for the production of good b is given by the fixed unit-input requirements (K_b, L_b).

3. Production of good a can take place either with a freely-available public technology, given by the fixed unit-input requirements $\left(K_a^P, L_a^P\right)$, or with

the innovative technology given by $\left(K_a^I, L_a^I\right)$.

4. The innovative technology is picked from a set of techniques which can be achieved with given research resources, found only in Country N and organized within one enterprise, the *innovator*.

5. The innovative technology is non-drastic (Arrow 1971), so that the (single) innovator producing commodity a charges a price equal to the unit cost under the public technology.

6. The innovator is a price taker in factor markets.

7. All consumers in both countries have identical preferences, obeying the Cobb-Douglas utility function

$$U_i = c_{ia}^{\alpha} c_{ib}^{1-\alpha},$$

where c_{ij} is the consumption by individual i of commodity j.

8. Under either the public technology or any achievable innovative technology the production of commodity a is L-intensive relative to commodity b, but not sufficiently so to fully employ factors in Country S. There is full employment of factors in N. Therefore,

$$\frac{\bar{K}^S}{\bar{L}^S} < \frac{K_a^j}{L_a^j} < \frac{\bar{K}^N}{\bar{L}^N} < \frac{K_b}{L_b}, \quad j = I, P,$$

where $\left(\bar{K}^i, \bar{L}^i\right)$ are the endowments of factors in country i.

9. Under free trade in commodities, let S specialize in the production of commodity a, under either the public or the innovative technology.

3 The Induced-Innovation Framework

To simplify the exposition, let the innovative technology be chosen from a set of technologies available for given research expenditures. This is a restrictive approach, in the spirit in particular of Ahmad (1966).

In a more general specification (Christian 1993), there is a mapping $A(m)$ from the vector m of expenditures in different research projects into the input-output matrix A. It can be shown that decreasing returns to expenditures in the various projects are sufficient to uniquely determine the distribution of research resources across commodities and research projects, where the research resources in each enterprise share the innovative rents. Furthermore, dual to the $A(m)$ mapping is a minimum-research-effort function, written in the two-factor case for good i as $h_i(K_i, L_i)$, which gives the research resources required to attain unit input requirements (K_i, L_i). In the present context, if there are $\bar{R}$

units of the research resource, used only in industry a, the following minimum research efforts hold:

$$\begin{aligned} h_a(K_a^I, L_a^I) &= \bar{R} \\ h_a(K_a^P, L_a^P) &= 0 \end{aligned}$$

The level set of h_a, for fixed expenditures $\bar{R}$, looks just like the isoquant of elementary production theory. and is often called an *Ahmad isoquant*, following Ahmad (1966). Unlike the neoclassical isoquant, there is no substitution *ex-post*, and the requirements to attain this set may be substantial.

4 The Perfect-Appropriability Equilibrium

Let the innovator in N completely control access to the innovative technology in industry a, and be free to operate in either country. The operation of a single firm in both countries is a representation of multinational enterprise, operating here under conditions of perfectly appropriable technology. Suppose furthermore that there are no barriers to trade in commodities. Under such conditions, a world general equilibrium can be described.

Factor-market equilibrium in N determines production of commodities a and b in N:

$$\bar{K}^N = K_a^N x_a^N + K_b X_b^N \tag{1}$$

and

$$\bar{L}^N = L_a^N x_a^N + L_b X_b^N, \tag{2}$$

where x_i^N is the production of commodity i in country N ($i = a, b$). With non-drastic innovation, the price of commodity a, p_a, is the unit cost under the public technology, while the price of commodity b, p_b, is its unit cost:

$$p_a = K_a^P w_K^N + L_a^P w_L^N \tag{3}$$

and

$$p_b = K_b^P w_K^N + L_b^P w_L^N, \tag{4}$$

where w_j^N is the price in N of factor j ($j = K, L$). With free trade, commodity prices in N yield the terms of trade,

$$p = \frac{p_a}{p_b}. \tag{5}$$

Provided that $p > K_a^I / K_b$, country S will specialize in commodity a, with production limited by the K constraint:

$$x_a^S = \frac{\bar{K}^S}{K_a^I}. \tag{6}$$

With Cobb-Douglas utility, commodity-market equilibrium requires

$$p = \frac{\alpha}{1-\alpha} \frac{X_b^N}{x_a^N + x_a^S}, \tag{7}$$

where α is the Cobb-Douglas parameter.

For any given innovative technology $\left(K_a^I, L_a^I\right)$, equations (1)–(7) determine the real variables x_a^N, x_b^N, x_a^S, and p, and the ratios w_K^N/W_L^N, w_K^N/p and w_K^N/p. Nominal variables p_a, p_b, w_K^N and w_L^N can be found following selection of a numeraire.

To determine the actual technology under perfect appropriability and free trade, consider the rent-maximization problem for the innovator. In N, the innovator pays market-determined prices to the factors of production. In S, there remains unemployed L, so L is free. Since under either the public or the innovative technology S specializes in the production of commodity a, the alternative cost of the K employed by the innovator in S is the production foregone under the public technology. With no obstacles to use of the public technology in S, this must be the cost actually incurred by the innovator, so the world-wide profits, in nominal terms, are

$$\begin{aligned} \pi_a^I &= x_a^N \left(p_a - w_K^N K_a^I - W_L^N L_a^I\right) + p_a \left(x_a^S - \frac{\bar{K}^S}{K_a^P}\right) \\ &= x_a^N \left(p_a - w_K^N K_a^I - W_L^N L_a^I\right) + p_a \left(\frac{\bar{K}^S}{K_a^I} - \frac{\bar{K}^S}{K_a^P}\right). \end{aligned} \tag{8}$$

As the innovating firm by hypothesis recognizes no influence on factor prices, nor does it recognize influence over product prices or on the quantity sold. Rather, the limit price (the public-technology unit-cost) is accepted as given, and the innovating firm supplies the entire market. The firm's choice variables $\left(K_a^I, L_a^I\right)$ enter the maximization problem only as shown in (8), and recursive effects on factor prices, commodity prices and quantities are ignored.

The innovator's rent maximization problem is constrained by the possibilities given by the Ahmad isoquant,

$$h\left(K_a^I, L_a^I\right) = \bar{R}_a. \tag{9}$$

If (8) is maximized subject to (9), the the first-order conditions are

$$w_K^N x_a^N + p_a \frac{\bar{K}^S}{\left(K_a^I\right)^2} + \lambda h_K = 0 \tag{10}$$

and

$$w_L^N x_a^N + \lambda h_L = 0, \tag{11}$$

where λ is the multiplier associated with constraint (9), and h_j is the research requirement for a further one-unit reduction in the use of factor j. Combining

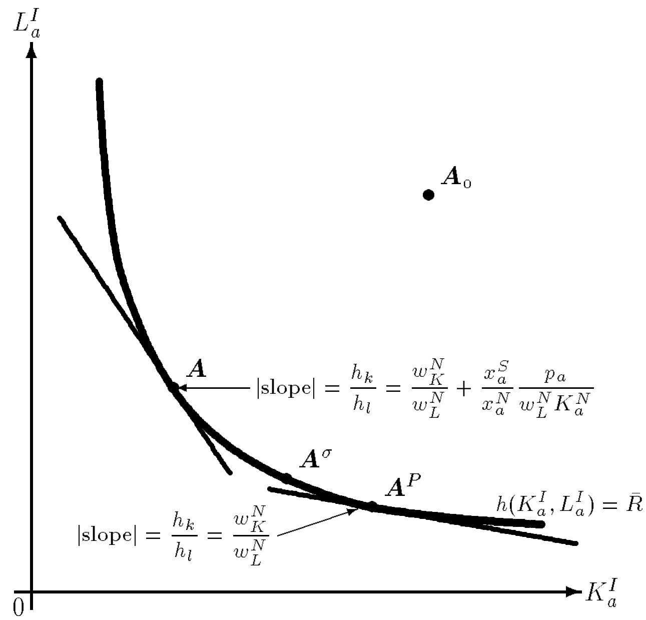

Figure 1: Public technology (A_0) and optimal innovation under perfect appropriability (A) and under pure piracy (A^P).

(10) and (11), profit maximization implies

$$\frac{h_K}{h_L} = \frac{w_K^N}{w_L^N} + \frac{x_a^S}{x_a^N}\frac{p_a}{w_L^N K_a^I}, \tag{12}$$

a condition which is illustrated in Figure 1 at point $\boldsymbol{A}$, and which completes the model for an economy with free trade in commodities and perfectly appropriability of innovations. Note that for x_a^S close to zero, h_K/h_L is close to w_K^N/w_L^N, which is Kennedy's induced-innovation condition when factor prices in the home country completely determine the direction of technological change (Kennedy 1964).

5 Equilibrium with Piracy

Suppose that the authorities in country S permit partial or full copying of the innovation. In particular, let producers in S have access to unit K requirement

$$K_a^S = \sigma K_a^I + (1-\sigma)K_a^P. \tag{13}$$

The innovator must then pay the K-resources used in S the value of their alternative use, or $p_a\left(\bar{K}^S/K_a^S\right)$, so that the innovator's rent-maximization problem becomes

$$\max_{K_a^I, L_a^I}\left\{x_a^N\left(p_a - w_K^N K_a^I - W_L^N L_a^N\right) + p_a\left(\frac{\bar{K}^S}{K_a^I} - \frac{\bar{K}^S}{K_a^S}\right)\right\} \tag{14}$$

subject to

$$h\big(K_a^I, L_a^I\big) = \bar{R}_a,$$

with first-order conditions

$$w_K^N x_a^N + p_a\left(\frac{\bar{K}^S}{\left(K_a^I\right)^2} - \frac{\bar{K}^S}{\left(K_a^S\right)^2}\frac{dK_a^S}{dK_a^I}\right) + \lambda h_K = 0 \tag{15}$$

and

$$w_L^N x_a^N + \lambda h_L = 0. \tag{16}$$

Substituting from (13), and noting that $dK_a^S/dK_a^I = \sigma$, equation (15) can be rewritten as

$$w_K^N x_a^N + p_a\left(\frac{\bar{K}^S}{\left(K_a^I\right)^2} - \frac{\sigma\bar{K}^S}{\left(\sigma K_a^I + (1-\sigma)K_a^P\right)^2}\right) + \lambda h_K = 0. \tag{17}$$

Note that for $\sigma = 0$, corresponding to perfect appropriability, (17) is identical to (15), while for $\sigma = 1$, or pure piracy, (17) and (16) yield the Kennedy condition $h_k/h_L = w_K^N/w_L^N$, as at point $\boldsymbol{A}^P$ in Figure 1. For an intermediate value of σ, the innovator picks a technology such as that at $\boldsymbol{A}^\sigma$, which is more K-intensive than the perfect-appropriability point $\boldsymbol{A}$.

In the analysis of the innovator's maximization problem, the changes in output in N which are necessary to maintain factor market equilibrium are ignored: it is assumed that the innovator takes factor-market conditions as parametric, and does not calculate the changes in relative prices that necessarily follows a change in the good a production technology. However, in full equilibrium, quantities and prices used in the optimization problem must also clear factor and commodity markets.

To analyze the effects of a piratical policy upon welfare in S, it is necessary to consider the effects of the policy upon commodity prices. Consumption possibilities for S depend on the terms of trade for exports from S, which in turn depend upon output in S and N of the two goods. As σ increases, K_a^I increases and L_a^I decreases, so that production of commodity a in N must increase if factor-market equilibrium is to be maintained. Does this increase outweigh the decrease in production in S following the increase in the unit K requirement? If so, does the consequent adverse effect on the terms of trade outweight the increase in the earnings of S resources (GNP) following greater piracy? Answers to these questions are developed in the comparative-static exercise which follows.

6 Comparative Statics: Increased Piracy

The model with piracy can usefully be reduced, which permits a fairly transparent graphical analysis. Equations (1) and (2) can be solved to give x_a^N in terms of the parameters and the endogenous commodity-a technology. Using these substitutions, as well as (6), equation (7) can be rewritten as

$$p = \frac{\alpha}{1-\alpha} \frac{x_b^N\left(K_a^I, L_a^I\right)}{x_a^N(K_a^I, L_a^I) + x_a^S(K_a^I)}. \tag{18}$$

Let commodity b be the numeraire. Then $p = r_a$, and equations (3) and (4) can be solved to give w_j^N in terms of the parameters and p. Making the resulting substitutions, as well as those for commodity quantities, into (17) and (11), and combining,

$$\frac{h_K}{h_L}\left(K_a^I, L_a^I\right) = \frac{w_K^N}{w_L^N}\left(p\right) + \frac{p\bar{K}^S}{w_L^N\left(p\right) \cdot x_a^N\left(K_a^I, L_A^I\right)}\left[\frac{1}{[K_a^I]^2} - \frac{\sigma}{[K_a^S]^2}\right], \tag{19}$$

where the parentheses in (18) and (19) indicate the endogenous terms in the implicit-function partially-reduced forms for included endogenous quantities and ratios. Equations (18), (19) and the the innovation constraint (9) form a three-equation partially reduced system to determine p, K_a^I and L_a^I, where equation (18) describes the combinations of the three remaining endogenous variables which are consistent with world commodity-market equilibrium and with factor-market equilibrium in N, while equations (9) and (19) describe rent-maximizing innovation at equilibrium factor prices and commodity prices and quantities.

Points consistent with market equilibrium (18) are traced in $\left(p, K_a^I\right)$ space of Figure 2 as the schedule $\boldsymbol{M}-\boldsymbol{M}$. To find the slope of $\boldsymbol{M}-\boldsymbol{M}$, differentiate (18) with respect to K_a^I, where L_a^I is interpreted as an implicit function of K_a^I using (9), so that $dL_a^I = -h_K/h_L$:

$$\left.\frac{dp}{dK_a^I}\right|_{MM} = \frac{\alpha}{(1-\alpha)\left(x_a^N + x_a^S\right)^2}\left\{\left(x_a^N + x_a^S\right)\frac{dx_b^N}{dK_a^I} - x_b^N\left(\frac{dx_a^N}{dK_a^I}\frac{dx_a^S}{dK_a^I}\right)\right\}. \tag{20}$$

In the Appendix it is shown that a sufficient condition for the right-hand side of (20) to be negative is that h_K/h_L be non-negative. As this holds by hypothesis, the $\boldsymbol{M}-\boldsymbol{M}$ schedule is drawn with negative slope in Figure 2. For points above and to the right of $\boldsymbol{M}-\boldsymbol{M}$, demand for commodity a is insufficient to clear the market in N for factor L, which is equivalent to excess demand for factor K; this imbalance can be corrected either by a lower price for L-intensive commodity a, or by reduced demand for factor K, achieved by lovering the unit K requirement of commodity a.

Full equilibrium of the model involves simultaneous satisfaction of the rent maximization conditions (9) and (19). Combinations of K_a^I, p, σ, and (implicitly) L_a^I which are consistent with rent maximization can be found. For a given

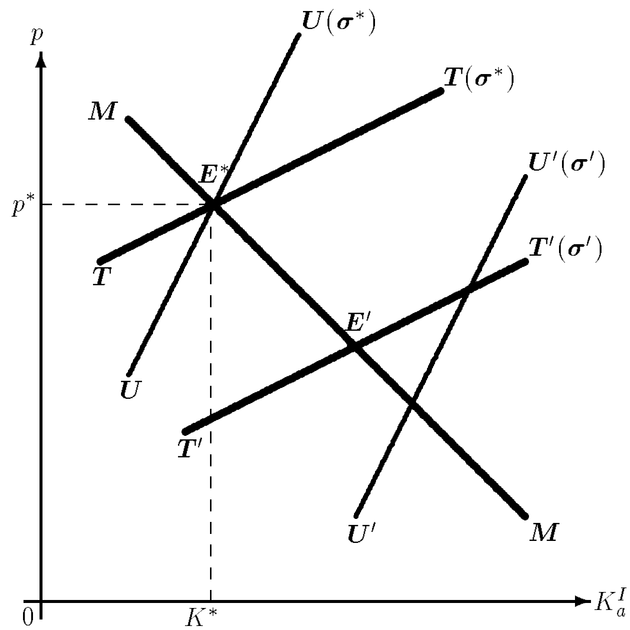

Figure 2: Effects of increasing piracy: innovation-choice schedule moves from $T{-}T(\sigma^*)$ to $T'{-}T'(\sigma')$, constant-utility schedule shifts from $U{-}U(\sigma^*)$ to $U'{-}U'(\sigma')$; equilibrium point E' represents increased utility in S.

intellectual-property rule in S, such as σ^*, and terms of trade p^*, one can find the innovator's best choice of technology, characterized by the unit K-requirement K^*. If either p or σ changes, then the optimizing choice of innovative technology also changes.

For given σ, combinations of K_a^I and p consistent with rent maximization can be plotted, such as, for $\sigma = \sigma^*$, the schedule $\boldsymbol{T}{-}\boldsymbol{T}(\boldsymbol{\sigma}^*)$ of Figure 2. Changes in σ correspond to shifts in the $\boldsymbol{T}{-}\boldsymbol{T}$ schedule. In the Appendix it is shown that if the second-order conditions hold for rent-maximization(14), and holding constant the quantities of good a that are expected to be produced in country N,, then (1) the $\boldsymbol{T}{-}\boldsymbol{T}$ schedule is positively sloped, and (2) an increase in σ—increased piracy—shifts $\boldsymbol{T}{-}\boldsymbol{T}$ to the right.

For given σ, such as σ^*, general equilibrium is represented by the intersection of the $\boldsymbol{M}{-}\boldsymbol{M}$ and $\boldsymbol{T}{-}\boldsymbol{T}$ schedules, as at $\boldsymbol{E}^*$ in Figure 2, with technology K^* and commodity price p^*. As the $\boldsymbol{M}{-}\boldsymbol{M}$ schedule remains constant for changes in σ, the full-equilibrium effects of increasing piracy in S can be represented by the move from $\boldsymbol{E}^*$ to $\boldsymbol{E}'$, with lower p and higher K_a^I.

To describe the shape and movement of $\boldsymbol{T}{-}\boldsymbol{T}$, apply (9) to (19), differentiate totally, and rearrange to get

$$\left[H' + \frac{p}{w_L^N x_a^N}\frac{x_a^S}{K_a^I}\left(\tau_K + \frac{2(1-\tau)}{K_a^I}\right)\right] dK_a^I =$$

$$\left[W' + \frac{1-\tau}{w_L^N x_a^N}\frac{\bar{K}^S}{(K_a^I)^2}\left(1 - \frac{p}{w_L^N}\frac{\partial w_L^N}{\partial p}\right)\right] dp - \frac{p}{w_L^N x_a^N}\frac{\bar{K}^S}{(K_a^I)^2}\tau_\sigma d\sigma,$$

where $H(K_a^I) \equiv h_K/h_L$, $W(p) \equiv w_K/w_L$, and $\tau(K_a^I, \sigma) = \sigma\left(K_a^I/K_a^S\right)^2$, so that

$$\left.\frac{dp}{dK_a^I}\right|_{TT} = \frac{H' + \frac{p}{w_L^N x_a^N}\frac{x_a^S}{K_a^I}\left(\tau_K + \frac{2(1-\tau)}{K_a^I}\right)}{W' + \frac{1-\tau}{w_L^N x_a^N}\frac{\bar{K}^S}{(K_a^I)^2}\left(1 - \frac{p}{w_L^N}\frac{\partial w_L^N}{\partial p}\right)} > 0, \qquad (21)$$

$$\left.\frac{dK_a^I}{d\sigma}\right|_{TT} = \frac{-\frac{p}{w_L^N x_a^N}\frac{\bar{K}^S}{(K_a^I)^2}\tau_\sigma}{H' + \frac{p}{w_L^N x_a^N}\frac{x_a^S}{K_a^I}\left(\tau_K + \frac{2(1-\tau)}{K_a^I}\right)} > 0, \qquad (22)$$

and

$$\left.\frac{dp}{d\sigma}\right|_{TT} = \frac{W' + \frac{1-\tau}{w_L^N x_a^N}\frac{\bar{K}^S}{(K_a^I)^2}\left(1 - \frac{p}{w_L^N}\frac{\partial w_L^N}{\partial p}\right)}{\frac{p}{w_L^N x_a^N}\frac{\bar{K}^S}{(K_a^I)^2}\tau_\sigma} < 0. \qquad (23)$$

The derivation of the signs of equations (21)–(23) is shown in the Appendix.

An increase in σ unambiguously reduces production in S, as well as decreasing production in N of commodity b. But the terms-of-trade deterioration and reduced output need not reduce welfare in S: the owners in S of factor K receive greater payments, measured in physical units of commodity a. To determine whether welfare in S improves or deteriorates following increased piracy, it is necessary to consider effects on welfare of simultaneous changes in factor income and commodity prices.

It is straightforward to identify combinations of K_a^I and terms of trade p which are consistent with constant welfare in country S, where "welfare" is a function of consumption in S of the two commodities, and can be measured by the Cobb-Douglas utility function. GNP for the constrained optimization in S is derived solely from payments to the owners in S of factor K, which are employed exclusively by the innovator for the production of commodity a. These payments are made (or at least are measured) in units of the exportable good. Since the best alternative use of these resources, at equilibrium world prices, is the production of the commodity using the public, or pirated, technology, purchasing power in terms of the numeraire is

$$Y^S = p\left(\frac{\bar{K}^S}{K_a^S(K_a^I, \sigma)}\right).$$

To find the combinations of p and K_a^I consistent with given utility, derive the indirect utility function, which with Cobb-Douglas preferences is

$$U\left(p, K_a^I, \sigma\right) = C\frac{\bar{K}^S}{K_a^S(K_a^I, \sigma)}p^{1-\alpha} \tag{24}$$

where C is an irrelevant constant. For any combination $\left(p, K_a^I\right)$ such as (p^*, K^*) on the $\boldsymbol{M}-\boldsymbol{M}$ schedule in Figure 2, there is a level set of U for given policy σ^*,

$$U\left(p, K_a^I\right) = U(p^*, K^*, \sigma^*)\,,$$

traced as $\boldsymbol{U}-\boldsymbol{U}(\boldsymbol{\sigma}^*)$ in Figure 2, with changes in σ represented by shifts in the schedule. Differentiating (24) totally for constant U and simplifying gives

$$0 = -\frac{p\sigma}{K_a^S}dK_a^I + (1-\alpha)dp - \frac{p}{K_a^S}\left(K_a^I - K_a^P\right)d\sigma,$$

so that the slope and shifts of $\boldsymbol{U}-\boldsymbol{U}(\boldsymbol{\sigma}^*)$ are:

$$\left.\frac{dp}{dK_a^I}\right|_{UU} = \frac{p\sigma}{(1-\alpha)K_a^S} > 0, \tag{25}$$

$$\left.\frac{dK_a^I}{d\sigma}\right|_{UU} = \frac{K_a^P - K_a^I}{\sigma} > 0, \tag{26}$$

and

$$\left.\frac{dp}{d\sigma}\right|_{UU} = \frac{\left(K_a^I - K_a^P\right)p}{(1-\alpha)K_a^S} < 0. \tag{27}$$

Points above and to the left of $\boldsymbol{U}-\boldsymbol{U}(\boldsymbol{\sigma}^*)$ represent increased utility compared to the situation at (p^*, K^*). An increase in σ from σ^* to σ' is represented in Figure 2 by a rightward shift in $\boldsymbol{U}-\boldsymbol{U}$.

The two schedules $\boldsymbol{U}-\boldsymbol{U}(\boldsymbol{\sigma}^*)$ and $\boldsymbol{U}'-\boldsymbol{U}'(\boldsymbol{\sigma}')$ show the combinations (p, K_a^I) consistent with the same utility, given two intellectual-property regimes σ^* and σ'. With greater appropriation by S of innovation rents, at σ', the original combination (p^*, K^*) yields increased utility: E^* is now above and to the left of the level curve representing the pre-change utility level. But E^* is no longer an equilibrium point. The $\boldsymbol{T}-\boldsymbol{T}$ schedule has also shifted to the right, so that the equilibrium point moves down to the right on the $\boldsymbol{M}-\boldsymbol{M}$ schedule, to E'. As drawn, E' is above and to the left of $\boldsymbol{U}'-\boldsymbol{U}'(\boldsymbol{\sigma}')$, indicating that the increase in σ has improved welfare in S.

Whether an increase in σ improves or harms welfare in S depends upon the slopes of the $\boldsymbol{T}-\boldsymbol{T}$ and $\boldsymbol{U}-\boldsymbol{U}$ schedules, and on the magnitudes of their shifts following a change in σ. Table 1 shows the relationship between these characteristics and the welfare results in S of an increase in piracy. Two unambiguous results should be noted. If $\boldsymbol{T}-\boldsymbol{T}$ is steeper than and shifts to the right as least as much as $\boldsymbol{U}-\boldsymbol{U}$, then an increase in σ is immiserizing (and a decrease in σ would improve welfare in S). If $\boldsymbol{T}-\boldsymbol{T}$ shifts to the right less than and is not as steep as $\boldsymbol{U}-\boldsymbol{U}$, then an increase in σ improves welfare (and a decrease in σ is immiserizing).

Table 1: Direction of change in welfare in S following increased piracy of innovative technology, for different constant-utility ($U-U$) and rent-maximization ($T-T$) schedules.

	$\left.\frac{dp}{dK_a^I}\right\|_{UU} > \left.\frac{dp}{dK_a^I}\right\|_{TT}$	$\left.\frac{dp}{dK_a^I}\right\|_{UU} < \left.\frac{dp}{dK_a^I}\right\|_{TT}$
$\left.\frac{dK_a^I}{d\sigma}\right\|_{UU} > \left.\frac{dK_a^I}{d\sigma}\right\|_{TT}$	+	+/−
$\left.\frac{dK_a^I}{d\sigma}\right\|_{UU} < \left.\frac{dK_a^I}{d\sigma}\right\|_{TT}$	+/−	−

7 Two Policy Propositions

The terms which determine whether or not a particular policy change is welfare-enhancing depend themselves on the values of σ. It is therefore impossible to draw general policy conclusions about the behavior of a welfare-maximizing government in S. It is possible, however, to derive conditions where a no-piracy policy is non-optimal from the standpoint of S; this is the task of Proposition 1. However, it is also shown, in Proposition 2, that any increase in σ, for any initial point, represents deterioration in world welfare, in the sense that the original point is a potential Pareto improvement.

Proposition 1 *If* (i) $x_a^S \leq x_a^N$ *and if* (ii)

$$\frac{L_b}{K_b} \geq \frac{L_a^P}{K_a^P + (K_a^P - K_a^I)} - \frac{\left(K_a^P - K_a^I\right) w_K^N / w_L^N}{K_a^P + (K_a^P - K_a^I)},$$

evaluated at $\sigma = 0$, then an increase in the piracy rate σ improves welfare in the technology-receiving country S.

Applying (25) to the case where $\sigma = 0$, the $\boldsymbol{U-U}$ schedule is horizontal at the no-piracy equilibrium, shown as $\boldsymbol{E}_0$ in Figure 3. However, applying (26), $\lim_{\sigma\to 0} \left.\frac{dK_a^I}{d\sigma}\right|_{UU} = \infty$, so that the results listed in Table 1 cannot be used. Instead, since $\boldsymbol{T-T}$ has positive slope at $\sigma = 0$, a sufficient condition for welfare-improving piracy is that the downward shift in $\boldsymbol{U-U}$ be at least as great as the simultaneous downward shift in $\boldsymbol{T-T}$, or

$$1 \geq \frac{\left(\frac{dp}{d\sigma}\right)_{TT}}{\left(\frac{dp}{d\sigma}\right)_{UU}},$$

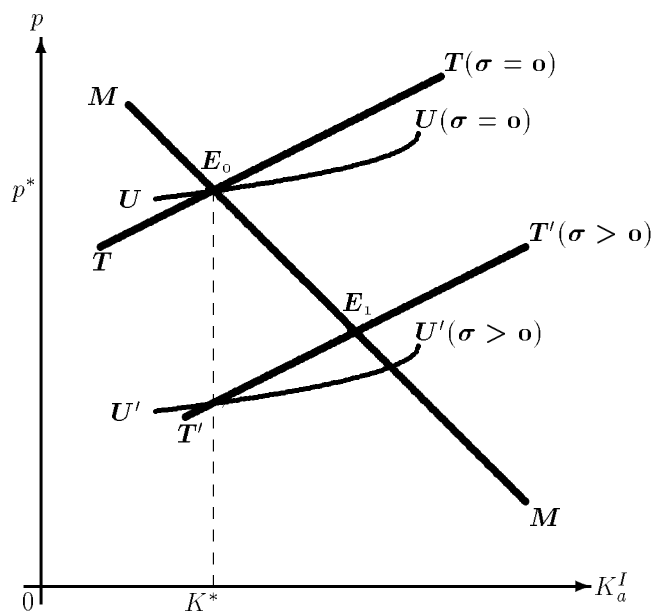

Figure 3: Perfect appropriability ($\sigma = 0$) is suboptimal for S if $\left.\frac{dp}{d\sigma}\right|_{UU} \geq \left.\frac{dp}{d\sigma}\right|_{TT}$
.

evaluated at $\sigma = 0$. Applying (23) and (27), it may be shown that

$$\frac{\left(\frac{dp}{d\sigma}\right)_{TT}}{\left(\frac{dp}{d\sigma}\right)_{UU}} = (1-\alpha)\left(\frac{K_a^I}{K_a^P}\right)^2 \left(\frac{x_a^S}{x_a^N + K_a^P/K_a^I}\right)\left(\frac{pK_b - K_a^P}{K_a^P - K_a^I}\right). \qquad (28)$$

The first two terms in this expression are individually less than 1; the third term is strictly less than 1 if condition *(i)* holds; it is established as a Lemma in the appendix that the last term is less than or equal to one if and only if condition *(ii)* holds. Thus, the validity of Proposition 1 is established.

Note that condition *(ii)* is more easily satisfied the greater the reduction in the unit K requirement: as K_a^I falls from K_a^P to 0, the last multiplicative terms of (28) become small. This is intuitively pleasing: the greater the unit factor savings from an innovation, the greater the incentive to steal it.

Proposition 2 *Let $\pi(\sigma)$ be the innovator's rents if country S practices intellectual property policy σ, and let $U(\sigma, T)$ measure utility in country S with policy σ, where S receives in addition a transfer T. Then for any $\sigma > 0$, there exists a transfer $T(\sigma)$ such that* (i) $U(0, T(\sigma)) > U(\sigma, 0)$ *and* (ii) $\pi(o) - T(\sigma) > \pi(\sigma)$.

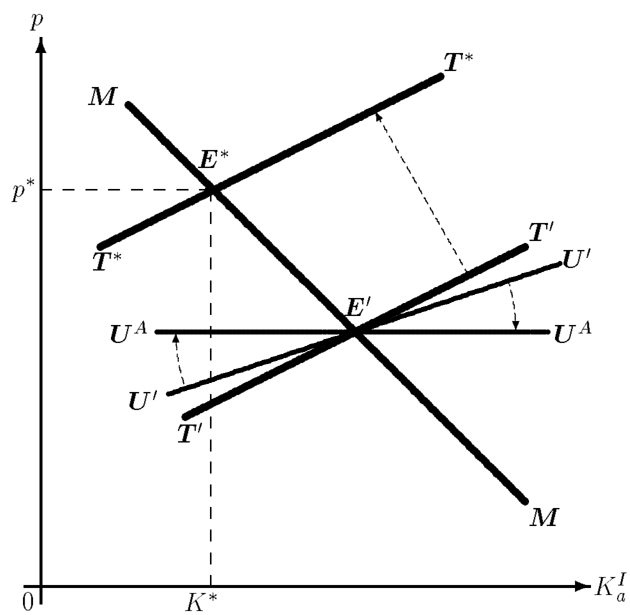

Figure 4: Transfers to S and no piracy (E^*) yields higher utility in S and higher innovation rents than does piracy regime E').

Proposition 2 states that any piracy, $\sigma > 0$, is an inferior arrangement from the standpoint of both the innovator and country S, since there exist transfers from the innovator to S which, when accompanied by a no-piracy policy in S, provide both higher utility in S and higher rents to the innovator than are possible under any positive σ. The validity of the proposition is established in the remainder of this section.

For any σ, the first-order conditions (15) and (16), combined with the innovation-constraint (9), yield the unit K requirement chosen by a rent maximizing innovator, which may be described as $K_a^I(\sigma)$. Suppose that an arrangement might be made whereby instead of pirating technology, resources in S receive $\bar{K}^S/K_a^S(\sigma)$, the payment that they would have received with a policy of σ-piracy. At the same time, S sets $\sigma = 0$. That is, resources in S are paid their alternative costs $\bar{K}^S/K_a^P$, plus a transfer $T(\sigma) = \bar{K}^S/K_a^S(\sigma) - \bar{K}^S/K_a^P$.

Applying (25), when $\sigma = 0$ utility in S is independent of the coefficient K_a^I that is actually chosen, and the $\boldsymbol{U}-\boldsymbol{U}$ schedule becomes a horizontal line passing through the piracy point $\boldsymbol{E}'$ in Figure 4. From (19), when $\sigma = 0$ the innovator's decision is independent of the technology actually available in S, so the arrangement can be represented as a simple shift of the $\boldsymbol{T}-\boldsymbol{T}$ schedule up and to the left, with general equilibrium at the no-piracy point $\boldsymbol{E}^*$. As this point is above the $\boldsymbol{U}'-\boldsymbol{U}'$ schedule representing utility at $\sigma > 0$, the elimination of the transfer, accompanied by the transfer, improves utility in S, establishing conclusion (i) of the proposition.

To establish conclusion (ii) of the proposition, note that with the transfer $T(\sigma)$ resources in S are paid the same as they would have been with piracy σ and no transfer. The innovator could have chosen the new technology represented by $\boldsymbol{E}'$, and earned the same rents as would have been received with no transfer. However, this is not profit-maximizing; the technology at $\boldsymbol{E}^*$ must therefore yield a higher level of rents. Thus, the innovator, as well as S, is better off with the transfer and no piracy.

8 Extensions

Two extensions to the model deserve mention. First, it is straightforward to show that the principal results, as summarized in Propositions 1 and 2, hold for other S policies τ which extract a portion of the total innovative rents generated in S. Rather than being understood as a function of the proportion of the savings in K which are made public in S, τ can be interpreted as a proportional tax on repatriated earnings, or as a share of profits which must be shared with local partners who invested on favorable terms, or even as a function of the period of patent protection. In all cases, the innovator can avoid part of the tax burden by paying less attention to conditions in S when choosing directions for research.

The second principal extension involves making exogenous not only the direction but also the degree of effort of research and development. In a rent-extracting framework, there are two complementary approaches to this task. First, a fixed stock of a research resource might be divided between industries, with inter-industry equilibrium requiring equalization of rents per unit of research resource across industries. Second, research resources might be drawn forth from an elastic supply by their payment, which again can be specified as a share of rents. In either case, piracy in S reduces total rents, which in turn drives down both the level of research in the industry involved, and reduces savings of the scarce factor K. The argument presented here is thereby strengthened.

One might cite a host of strong assumptions used in the development of this model as candidates for refinement, such as the requirement that coefficients of production are constant *ex-post*, that the results of research are known with certainty, or that one factor is free in the technology-importing country. Relaxing these assumptions is a worthwhile program, whether one's goal is to advance the scientific explanation and prediction of the rate and direction of technological change, or simply to demonstrate the impact of optimization in research upon the political choice of regimes for the international transfer of technology. The present article may be interpreted in the latter context, as a contribution to a debate in political economy, and as a challenge to adherents of restrictions on multinational enterprise to show that relaxing the strong assumptions changes significantly the strong conclusions.

A Mathematical Appendix

A.1 Proof: $h_K/h_L \leq 0 \;\; \Rightarrow \;\; dp/dK_a^I\big|_{MM} < 0$

Solving (1) and (2),

$$x_a^N = \frac{\bar{K}^N L_b - \bar{L}^N K_b}{K_a^I L_b - K_b L_a^I}$$

and

$$x_b^N = \frac{\bar{L}^N K_a^I - \bar{K}^N L_a^I}{K_a^I L_b - K_b L_a^I},$$

while (6) gives

$$x_a^S = \frac{\bar{K}^S}{K_a^I}.$$

Then (18) can be rewritten

$$p = \frac{\alpha}{1-\alpha} \frac{\bar{L}^N K_a^I - \bar{K}^N L_a^I}{\bar{K}^N L_b - \bar{L}^N K_b + \bar{K}^S L_b - \bar{K}^S K_b \left(L_a^I / K_a^I\right)}$$

so that

$$\left.\frac{dp}{dK_a^I}\right|_{MM} = \frac{\alpha}{(1-\alpha)\left(\bar{K}^N L_b - \bar{L}^N K_b + \bar{K}^S L_b - \bar{K}^S K_b \left(L_a^I/K_a^I\right)\right)^2}\left\{M\right\},$$

where, using $dL_a^I/dK_a^I = -h_K/h_L$,

$$\begin{aligned}
M &= \left(\bar{K}^N L_b - \bar{L}^N K_b + \bar{K}^S L_b - \bar{K}^S K_b \frac{L_a^I}{K_a^I}\right)\left(\bar{L}^N + \bar{K}^N \frac{h_K}{h_L}\right) \\
&\quad - \left(\bar{L}^N K_a^I - \bar{K}^N L_a^I\right)\left(\bar{K}^S K_b\right)\left(\frac{1}{K_a^I}\frac{h_k}{h_L} + \frac{L_a^I}{\left(K_a^I\right)^2}\right) \\
&= \frac{h_K}{h_L}\left(\bar{K}^N + \bar{K}^S\right)\left(\bar{K}^N L_b - \bar{L}^N K_b\right) + \bar{L}^N\left(\bar{K}^N L_b - \bar{L}^N K_b\right) \\
&\quad + \frac{\bar{K}^S}{K_a^I}\left[\bar{L}^N\left(K_a^I L_b - K_b L_a^I\right) - K_b\left(\bar{L}^N K_a^I - \bar{K}^N L_a^I\right)\right] \\
&< 0 \\
&\quad \Longleftrightarrow \;\; \frac{dp}{dK_a^I} < 0.
\end{aligned}$$

Multiplying through by $\left[-\left(\bar{K}^N+\bar{K}^S\right)\left(\bar{K}^N L_b-\bar{L}^N K_b\right)\right]^{-1}<0$ and rearranging, the condition for a downward-sloping $\boldsymbol{M}-\boldsymbol{M}$ becomes

$$\begin{aligned}
\frac{h_K}{h_L} &< \frac{-\bar{L}^N}{\bar{K}^N+\bar{K}^S}\left\{1+\frac{\bar{K}^S}{K_a^I}\left[\frac{K_a^I L_b-K_b L_a^I}{\bar{K}^N L_b-\bar{L}^N K_b}-\frac{K_b}{\bar{L}^N}\left(\frac{K_a^I \bar{L}^N-\bar{K}^N L_a^I}{\bar{K}^N L_b-\bar{L}^N K_b}\right)\right]\right\} \\
&= \frac{-\bar{L}^N}{\bar{K}^N+\bar{K}^S}\left\{1+\frac{x_a^S}{x_a^N}\left(1-\frac{x_b^N L_b}{\bar{L}^N}\right)\right\} \\
&= \frac{-\bar{L}^N}{\bar{K}^N+\bar{K}^S}\left\{1+\frac{x_a^S}{x_a^N}\left(\frac{x_a^N L_a^I}{\bar{L}^N}\right)\right\} < 0.
\end{aligned}$$

A sufficient condition is therefore that h_L be negative and h_K be non-positive, which holds by hypothesis.

A.2 Slope and σ-shift of the $T-T$ Schedule

Let $H\left(K_a^I\right)=\frac{h_K}{h_L}\left(K_a^I, L_a^I\left(K_a^I\right)\right), W(p)=\frac{w_K^N}{w_L^N}\left(p\right)$, and $\tau\left(K_a^I,\sigma\right)=\sigma\cdot\left[\frac{K_a^I}{K_a^S\left(K_a^I,\sigma\right)}\right]^2$. Then (19) can be rewritten

$$H\left(K_a^I\right)=W(p)+\frac{p}{w_L^N(p)\cdot x_a^N}\frac{\bar{K}^S}{\left[K_a^I\right]^2}\left[1-\tau\left(K_a^I,\sigma\right)\right].$$

Differentiating totally, substituting $x_a^S=\bar{K}^S/K_a^I$, and rearranging,

$$\begin{aligned}
&\left[H'+\frac{p}{w_L^N K_a^I}\frac{x_a^S}{x_a^N}\left(\tau_K+\frac{2(1-\tau)}{K_a^I}\right)\right]dK_a^I \\
&= \left[W'+\frac{1-\tau}{w_L^N K_a^I}\frac{x_a^S}{x_a^N}\left(1-\frac{p}{w_L^N}\frac{\partial w_L^N}{\partial p}\right)\right]dp-\frac{p}{w_L^N K_a^I}\frac{x_a^S}{x_a^N}\tau_\sigma d\sigma. \qquad (29)
\end{aligned}$$

The slope along $\boldsymbol{T}-\boldsymbol{T}$ is therefore

$$\left.\frac{dp}{dK_a^I}\right|_{TT}=\frac{H'+\frac{p}{w_L^N K_a^I}\frac{x_a^S}{x_a^N}\left(\tau_K+\frac{2(1-\tau)}{K_a^I}\right)}{W'+\frac{1-\tau}{w_L^N K_a^I}\frac{x_a^S}{x_a^N}\left(1-\frac{p}{w_L^N}\frac{\partial w_L^N}{\partial p}\right)}. \qquad (30)$$

The first term of the denominator of (30) is negative:

$$W(p)=\frac{w_K^N}{w_L^N}\left(p\right)=\frac{pL_b-L_a^P}{K_a^P-pK_b},$$

so that

$$\begin{aligned}
W'(p) &= \frac{\left(K_a^P-pK_b\right)L_b-\left(-K_b\right)\left(pL_b-L_a^P\right)}{\left(K_a^P-pK_b\right)^2} \\
&= \frac{K_a^P L_b-K_b L_a^P}{\left(K_a^P-pK_b\right)^2}<0.
\end{aligned}$$

To show that the denominator of (30) is negative, it then suffices to show that the second term is also negative:

$$w_L^N = \frac{K_a^P - pK_2}{K_a^P L_b - K_b L_a^P} \implies \frac{\partial w_L^N}{\partial p} = \frac{-K_b}{K_a^P L_b - K_b L_a^P} > 0$$

$$\implies \frac{p}{w_L^N}\frac{\partial w_L^N}{\partial p} = \frac{-pK_b}{K_a^P - pK_2} > 1.$$

To show that the numerator of (30) is negative, consider the second-order conditions for the maximization problem (14), which are derived from its first-order conditions, written as

$$\left.\begin{array}{rcl} -w_K^N x_a^N - \frac{p\bar{K}^S}{(K_a^S)^2}(1-\tau) - \lambda h_K & = & 0, \\ -w_L^N x_a^N - \lambda h_L & = & 0, \\ h\big(K_a^I, L_a^I\big) & = & 0. \end{array}\right\}$$

If the Jacobian matrix of this system is negative definite, then its solution maximizes (14), and

$$\begin{aligned} 0 &< \left| \begin{array}{ccc} 2(1-\tau)\frac{p\bar{K}^S}{(K_a^I)^3} + \frac{p\bar{K}^S}{(K_a^I)^2}\tau_K - \lambda h_{KK} & -\lambda h_{KL} & -h_K \\ -\lambda h_{LK} & -\lambda h_{LL} & -h_L \\ -h_K & -h_L & 0 \end{array} \right| \\ &= -h_L^2\left(2(1-\tau)\frac{p\bar{K}^S}{(K_a^I)^3} + \frac{p\bar{K}^S}{(K_a^I)^2}\tau_K\right) + \lambda h_L^2 h_{KK} + \lambda h_K^2 h_{LL} - 2\lambda h_K h_L h_{KL}, \end{aligned}$$

which implies, after substituting $x_a^S = \bar{K}^S/K_a^I$,

$$\frac{\lambda}{h_L^2}\left(h_L^2 h_{KK} + h_K^2 h_{LL} - 2h_K h_L h_{KL}\right) > 2(1-\tau)\frac{px_a^S}{(K_a^I)^2} + \frac{px_a^S}{K_a^I}\tau_K.$$

Since

$$\lambda = -\frac{w_L^N x_a^N}{h_L} > 0,$$

the condition becomes

$$\begin{aligned} &\frac{1}{h_L^2}\left(h_L h_{KK} + \frac{h_K}{h_L}h_K h_{LL} - h_K h_{KL} - \frac{h_K}{h_L}h_L h_{KL}\right) \\ &< \quad -\frac{p}{w_L K_a^I}\frac{x_a^S}{x_a^N}\left(\frac{2(1-\tau)}{K_a^I} + \tau_K\right). \end{aligned}$$

The left-hand side of this expression is the change in the absolute value of the slope of the Ahmad isoquant as K_a^I increases, $d\left(h_k/h_L\right)/dK_a^I \equiv H'$. Since it is less than the right-hand side, the numerator of (30) is negative, as is the denominator, and a consequence of the second-order conditions for rent-maximization is that the $\boldsymbol{T}-\boldsymbol{T}$ schedule has positive slope.

To show that the $\boldsymbol{T}-\boldsymbol{T}$ schedule shifts to the right when σ increases, set $dp = 0$ in (29) and solve to find

$$\frac{dK_a^I}{d\sigma} = \frac{-\frac{p}{w_L^N x_A^N}\frac{\bar{K}^S}{(K_a^I)^2}\tau_\sigma}{H' + \frac{p}{w_L^N K_a^I}\frac{x_a^S}{x_a^N}\left(\tau_K + \frac{2(1-\tau)}{K_a^I}\right)}. \tag{31}$$

It was shown above that the denominator of (31) is negative if the second-order conditions for rent-maximization are satisfied. Then the $\boldsymbol{T}-\boldsymbol{T}$ schedule shifts to the right with an increase in σ if and only if

$$0 < t_\sigma = \left(\frac{K_a^I}{K_a^S}\right)^2 \left(1 - \frac{\sigma\left(K_a^I - K_a^P\right)}{K_a^S}\right),$$

which holds since $K_a^I < K_a^P$.

A.3 Proof of Lemma used in Proposition 1

The lemma used in Proposition 1 is:

$$\frac{pK_b - K_a^P}{K_a^P - K_a^I} \leq 1 \quad \Leftrightarrow$$

$$\frac{L_b}{K_b} \geq \frac{L_a^P}{K_a^P + (K_a^P - K_a^I)} - \frac{\left(K_a^P - K_a^I\right)\frac{w_K^N}{w_L^N}}{K_a^P + (K_a^P - K_a^I)} \tag{32}$$

Proof Multiply (32) through by w_L/w_K, add 1 to both sides, and simplify:

$$\frac{w_K^N K_b + w_L^N L_b}{w_K^N K_B} \geq \frac{w_L^N L_a^P + w_K^N K_a^P}{(2K_a^P - K_a^I)\, w_K}.$$

The numerator on the right-had side is p_a, while the numerator on the left-hand-side is p_b. Eliminating w_K and cross-multiplying then gives

$$2K_a^P - K_a^I \geq \frac{p_a}{p_b}K_b = pK_b \quad \Leftrightarrow \quad K_a^P - K_a^I \geq pK_b - K_a^P \quad \Leftrightarrow \quad \frac{pK_b - K_a^P}{K_a^P - K_a^I} \leq 1.$$

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