Mobile Capital, Local Externalities and Industrialization[1]

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Abstract

This paper seeks to understand how industrialization is distributed geographically when capital is mobile and labor is not. A stylized model of a spatial economy is constructed where individuals not employed in industry work in traditional activities. Results show that convergence across locations is characterized by a succession of catching-up episodes. One one location at a time industrializes; the others stagnate. This occurs whether or not local externalities are present. Investments in infrastructure and education respond to expectations about future industrial activity; pessimism can be self-fulfilling. Free access to technology does not guarantee the industrialization of undeveloped locations. These results cast doubt on whether free movements of capital and technology transfers can foster the rapid industrialization of all countries and regions of the world simultaneously.

In recent years, the international mobility of capital has attracted a lot of attention from policy makers and the general public alike. While workers in developed economies often are busy fighting the relocation of industries to low wage areas, much hope is put in foreign direct investment by developing countries recently converted to the virtues of the free market (e.g., Dicken (1992)). Similarly, in financial circles, emerging markets are the catch word of the day (e.g., Dicheva, Drach and Stefek (1992), Wilcox (1992)). Even within developed economies like the United States and the European Union, it is common for states and regions to compete to attract industrial investors.

To throw some light on these important issues, this paper examines how industries naturally distribute themselves over space if capital is mobile and labor is not. It belongs to a growing literature on the effect of factor mobility on trade (e.g., Norman and Venables (1995)) and growth (e.g., Barro, Mankiw and Sala-I-Martin (1995), Adsera (1994)). We consider a stylized economy with a large number of possible locations for industrial activity. Each of these locations is assumed endowed with a stock of immobile labor resources. Industries locate freely until returns to capital are equalized across industrialized locations. Unlike most growth theory, we adopt Lewis-like framework (see Lewis (1954)) and assume that workers who are not employed in industry work in labor-intensive activities -- e.g., subsistence farming, informal sector activities, export crops. Given these simple assumptions, we show that industries concentrate in small number of locations. Convergence across locations is not smooth and gradual. Instead, it is characterized by a succession of catching-up episodes. Many locations remain unindustrialized for extended periods of time. These results stand in sharp contrast with what would obtain in a neo-classical growth model with mobile capital (e.g., King and Rebelo (1992)). In that case, convergence would be smooth and would benefit all economies equally.

The recent literature on economic growth and industrial location (e.g., Romer (1986, 1990), Matsuyama (1991), Glaeser et al. (1992), Young (1991), Henderson (1988), Abdel-Rahman (1988, 1994), Rodriguez-Clare (1994)) has emphasized the role of agglomeration effects and externalities in industrialization. To verify whether externalities affects industrialization when capital is mobile, we incorporate two types of externalities in the model: pure Marshallian (or technological) externalities; and pecuniary externalities. Industrial relocation takes place from high-wage areas toward newly industrialized locations. Other qualitative results do not change.

The role of human capital in development has been emphasized in much of the recent growth literature (e.g., Mankiw, Romer and Weill (1992), Barro and Sala-I-Martin (1991, 1992), Azariadis and Drazen (1990), Lucas (1993), Stokey (1991)). In the second part of the paper, we expand the model to include knowledge and skills. Results indicate that the location of industries is influenced by the skill level of the labor force whenever (some of) the returns to education are captured by employers. If returns to education are at least partly captured by workers, investment in schooling responds to expectations about future industrial activity; as in Azariadis and Drazen (1990), pessimism can be self-fulfilling. Similar results are obtained for investments in industrial infrastructure and institutions (see also Murphy, Shleifer and Vishny (1989a)).

In the last part of this paper, we examine whether the accumulation of knowledge through research and development affects the location of industries. It has been shown elsewhere that when knowledge spillovers between countries or locations are imperfect, developed locations are at an advantage (e.g., Young (1991), Grossman and Helpman

(1991)). We show that the same is true even when knowledge spills over costlessly and perfectly across space: industrial concentration is still the rule and convergence is not smooth.

The main results of this paper, namely, that industries have a tendency to cluster and that convergence across countries and regions is characterized by catching-up episodes, are quite robust. They do not depend on the existence of local externalities. They are unchanged when the roles of human capital and infrastructure in growth and development are duly acknowledged. They obtain even when technology transfer is costless and instantaneous. The present paper thus generalizes results obtained in more specialized models (e.g., Krugman (1987), Young (1991)). Although it demonstrates that international movements of capital can help certain undeveloped locations to industrialize rapidly, it also cast serious doubts on the ability of capital mobility and free technology transfers to rapidly resolve all income inequalities across countries and regions.

Section 1. The Static Equilibrium with Local Externalities

We begin with the simplest possible model of capital mobility. More realistic features are added in section 3. The simplicity of the model is deceptive, however, and the equilibrium path of our stylized economy is unusual. The static equilibrium is derived in this section, the dynamic path of the economy in section 2. Proofs of all propositions are presented in Appendix.

We consider an economy divided into C distinct locations. Each of them is meant to represent a small country, state, or province open to investment from the rest of the economy but with its own labor market. We follow standard growth theory and assume that all locations produce a single aggregate consumption good Y. Locations are assumed to trade

Y freely and costlessly with each other.[2] Arbitrage thus ensures that the price of Y is the same across locations. The price of final output is taken as numeraire.

There are two factors of production. One, capital k, is assumed perfectly and costlessly mobile across space; the other, labor l, is immobile.[3] Each location $i \in C$ is endowed with its own stock of labor $\bar{L}_i$.

Following Weitzman (1982) and Murphy, Shleifer and Vishny (1989a, 1989b), we assume that two technologies are available to produce commodity Y: a traditional technology using only l, and a modern technology using both k and l. Firms using modern technologies are thought of as 'industries' and the accumulation of such firms is used, as elsewhere (e.g., Lewis (1954), Krugman (1991), Murphy, Shleifer and Vishny (1989a, 1989b)), as a parable for the process of industrialization. With the traditional technology, one unit of labor in location i produces μ_i units of output. Productivity μ_i may vary across locations to capture differences in natural endowments (e.g., land quality, climate). Modern and traditional firms compete with each other. The price of output is determined by the productivity of the traditional competitive fringe.

To allow for the possibility of pecuniary externalities among firms, production by modern firms is assumed to require not only capital and labor but also a variety of locally provided services subject to increasing returns and produced by monopolistically competitive firms (Fujita (1988), Abdel-Rahman (1988, 1994), Riviera-Batiz (1988),

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[2] An earlier version of this paper contained a model where pecuniary externalities resulted from the presence of transportation costs in intermediate inputs. Making intermediate inputs non-tradable considerably simplifies the algebra without subtracting from the main results. Extending the model to allow for costly trade is left for future research.

[3] Alternatively, one could assume that labor and capital are mobile but land is immobile and reinterpret the model as one about cities. In that case, l would be land, k would be the optimal mix of capital and labor, and w the rental price of land. Qualitatively similar results obtain.

Rodriguez-Clare (1994)).[4] Because these services normally require face to face interaction and often must be tailored to the particular needs of local businesses, we assume that they are non-tradable. In equilibrium, the variety of available industrial services depends on the extent of the market. Pecuniary externalities result from the benefits industrial firms derive from the existence of more specialized providers of industrial services. We also allow for Marshallian externalities by letting the productivity of individual firms depend on the presence of other firms at the same location. These externalities are meant to capture a variety of positive and negative agglomeration effects other than access to industrial services.[5] Their contribution to output need not be large; it may even be negative.

Formally, the output of good Y by modern firms in location i is written as:

$$Q_i = a_i \overline{K}_i^{\gamma} K_i^{\delta} L_i^{\beta-\delta} M_i^{1-\beta} \tag{1}$$

Output of modern firms Q_i is measured net of capital depreciation. K_i and L_i denote the aggregate amounts of capital k and labor l used by modern producers of good Y in location i. M_i is a composite good combining various industrial services. The parameter a_i captures inherent locational advantages, like better communications and mineral resources. Other parameters δ, β, α and γ are assumed identical across locations; $\beta \geq \delta$. The $\overline{K}_i^{\gamma}$ term represent Marshallian externalities generated by modern activity: $\overline{K}_i$ is the sum of all capital in location i, and γ is the strength of externalities; it can be negative.

[4] E.g., specialized finance and insurance services, commercial intermediaries, local transportation and warehousing, repair and maintenance of machinery and office equipment, management consulting and auditing, and specialized sub-contractors for the design of product prototypes, special machine parts, and customized software (Jacobs (1969, 1984)).

[5] E.g., better pool of skilled workers attracted by the prospect of short unemployment spells in a large labor market; learning by doing not fully captured by firm owners as employees quit to start their own competing firm; emulation and copying among local firms; circulation of information about new products, production processes, and emerging markets; congestion of public infrastructure; pollution; etc (Henderson (1988), Porter (1990), Arthur (1988, 1990), Glaeser et al. (1992)).

Individual producers treat $\overline{K}_i$ as given. From their perspective, they face constant returns to scale in K_i, L_i and M_i and thus behave as perfectly competitive firms.

M_i is a composite good made of non-tradable industrial services $m_i(j)$:

$$M_i \equiv \left[\int_0^{n_i} m_i(j)^\alpha \, dj\right]^{\frac{1}{\alpha}} \tag{2}$$

n_i measures the variety of available industrial services in location i. The demand for each industrial service thus has constant elasticity $\frac{1}{1-\alpha}$. We assume that industrial services are close substitutes and therefore that the demand for industrial services is elastic, i.e., that $0 < \alpha \leq 1$.[6] Each non-tradable industrial service $m_i(j)$ is produced by a separate, monopolistically competitive firm. One unit of labor is needed to produce one unit of industrial services. Production also requires one unit of capital per firm. It follows that:

$$\overline{K}_i = K_i + n_i \tag{3}$$

Having laid down the production technology and behavioral assumptions, we now solve for the static equilibrium in each location, taking the stock of capital in that location as given. To do so, we first compute the equilibrium number of industrial services n_i^*, and then solve for the labor market equilibrium. We obtain a relationship between the amount of capital in a given location and the return to capital. This relationship is used in section 2 to derive the equilibrium path of the economy over time.

Equilibrium on the Market for Industrial Services[7]

We first examine the production of industrial services. As is well known (Dixit and

[6] Without this assumption, producers of industrial services would charge an infinite price; see infra.
[7] This sub-section follows closely Rodriguez-Clare (1994).

Stiglitz (1977), Krugman (1991), Romer (1990)), individual profit maximization by monopolistically competitive firms facing an isoelastic demand curve leads to mark-up pricing:

$$p_i(j) = p_i = \frac{w_i}{\alpha} \tag{4}$$

where $p_i(j)$ is the local price of industrial service j and w_i is the wage rate in location i. Because of symmetry, the prices and output of all industrial services are the same. Define $X_i \equiv n_i m_i$ as the total labor used in the production of industrial services. We have:

$$M_i = [n_i m_i^{\alpha}]^{\frac{1}{\alpha}} = n_i^{\frac{1}{\alpha}} m_i = n_i^{\frac{1-\alpha}{\alpha}} X_i \tag{5}$$

It is easy to verify that the price of one unit of the aggregate commodity M_i is $\frac{p_i}{n_i^{\frac{1-\alpha}{\alpha}}}$: it is decreasing in the number of industrial services in production (see Ciccone and Matsuyama (1994), Rodriguez-Clare (1994) for similar results).

Combining equations (1) and (5), production of final goods by moder firms can be rewritten:

$$Q_i = a_i \overline{K}_i^{\gamma} K_i^{\delta} L_i^{\beta-\delta} X_i^{1-\beta} n_i^{\phi} \tag{6}$$

Parameter $\phi \equiv \frac{(1-\beta)(1-\alpha)}{\alpha}$ captures the strength of pecuniary externalities: it measures by how much production can be increased by raising the number of industrial services while keeping input use constant. Pecuniary externalities are a decreasing function of the degree of substitutability between industrial services. When there is perfect substitutability among them, i.e., when α=1, or when industrial services are not used in production, i.e., when β=1, then ϕ=0.

We now turn to the production of final goods. Let r be the rental price of capital.

Profit maximization in final production requires that the marginal return to each input equals its cost, i.e.:

$$(1-\beta)\frac{Q_i}{M_i} = \frac{p_i}{n_i^{\frac{1-\alpha}{\alpha}}} \tag{7}$$

$$(\beta-\delta)\frac{Q_i}{L_i} = w_i \tag{8}$$

$$\delta\frac{Q_i}{K_i} = r \tag{9}$$

Using equations (4) and (5), equation (7) can be rewritten more simply:

$$X_i = (1-\beta)\alpha\frac{Q_i}{w_i} \tag{7'}$$

Equations (7'-9) must be satisfied in a competitive equilibrium.

With free entry, the equilibrium number of industrial service providers is that at which the pure profit of each industrial services provider $\pi(j)$ is identically 0. By definition, pure profit $\pi(j)$ is:

$$\pi(j) = p_i m_i - w_i m_i - r = [\frac{w_i}{\alpha} - w_i]\frac{X_i}{n_i} - r \tag{10}$$

where we replaced p_i by its value in equation (4) and used the definition of X_i. Plugging equation (7') and (9) into equation (10) and setting it to 0, we obtain a relationship between n_i and K_i. Using the fact that $K_i = \overline{K}_i - n_i$, the equilibrium number of services can be derived as:

$$n_i^* = \frac{(1-\alpha)(1-\beta)}{\delta + (1-\alpha)(1-\beta)}\overline{K}_i \equiv \theta\overline{K}_i \tag{11}$$

It is an increasing function of local capital $\overline{K}_i$: the more industries are present in location i, the more varieties of industrial services are produced.

Armed with equation (11), we can rewrite the production function for final goods in a simpler form. From equations (7') and (8), we get that:

$$X_i = \frac{\alpha(1-\beta)}{\beta-\delta} L_i \tag{12}$$

Plugging equilibrium conditions (11) and (12) into equation (6) and using the fact that $K_i = \bar{K}_i - n_i$, the production function for final goods becomes:

$$Q_i = da_i \bar{K}_i^{\delta+\gamma+\phi} L_i^{1-\delta} \tag{13}$$

where $d \equiv (1-\theta)^{\delta}\theta^{\phi}\left[\frac{\alpha(1-\beta)}{\beta-\delta}\right]^{1-\beta}$. Equation (13) shows that, in equilibrium, Marshallian and pecuniary externalities are formally equivalent.

Labor Market Equilibrium

We now turn to the labor market and solve for the equilibrium level of employment in industries -- L_i -- and industrial services production -- X_i -- that corresponds to a particular value of the capital stock $\bar{K}_i$. Two distinct labor market equilibria need to be considered. In the first, labor used in modern production and industrial services does not exhaust local manpower, i.e. $L_i + X_i < \bar{L}_i$. In this case, modern firms compete for labor with traditional producers and the wage rate equals the (constant) productivity of labor in traditional activities: $w_i = \mu_i$. In the second case, all labor is absorbed in modern production, i.e., $L_i + X_i = \bar{L}_i$. Industrial firms compete among themselves for labor. The wage rate is determined by the productivity of labor in industry.

We begin with the case where $L_i + X_i < \bar{L}_i$ and $w_i = \mu_i$. For any level of capital $\bar{K}_i$, equilibrium on the labor market requires that the productivity of workers in the modern sector be equal to μ_i. Solving for the equilibrium level of industrial employment from equation (8), we get:

$$L_i = d^{\frac{1}{\delta}} a_i^{\frac{1}{\delta}} (\beta-\delta)^{\frac{1}{\delta}} \mu_i^{-\frac{1}{\delta}} \bar{K}_i^{\frac{\delta+\gamma+\phi}{\delta}} \tag{14}$$

To compute the corresponding return to capital, we note that the aggregate profit of all modern firms in location i is:

$$\Pi_i = Q_i - w_i L_i - \frac{p_i}{n_i^{\frac{1-\alpha}{\alpha}}} M_i = Q_i - w_i L_i - p_i X_i$$

The return to one unit of capital in location i is equal to the average profit rate Π_i divided by $\overline{K}_i$. Individual producers face constant returns to scale. The share of revenues that goes to remunerate capital is thus equal to its (perceived) share in output which, from equation (6), can be seen to be δ, i.e.:

$$\Pi_i = \delta Q_i \tag{15}$$

Plugging equations (13) and (14) into equation (15) and dividing through by $\overline{K}_i$, the rate of return to capital can be derived as:

$$\frac{\Pi_i}{\overline{K}_i} = e\, a_i^{\frac{1}{\delta}}\, \mu_i^{\frac{\delta-1}{\delta}}\, \overline{K}_i^{\frac{\delta+\gamma+\phi}{\delta}-1} \tag{16}$$

where $e \equiv \delta d^{\frac{1}{\delta}} (\beta-\delta)^{\frac{1-\delta}{\delta}}$.

Equation (16) indicates how the return to capital in location i evolves with the aggregate level of capital $\overline{K}_i$ after employment and industrial service production have adjusted. It shows that average profits are higher when local conditions are favorable -- high a_i -- and when the traditional sector is not productive -- low μ_i. High incomes in traditional activities indeed translate into higher wages and thus higher production costs.[8] When Marshallian or pecuniary externalities are present and $\gamma+\phi > 0$, returns to capital increase with the total amount of capital in location i. As long as the sum of Marshallian

[8] In our model, final demand is not a source of pecuniary externalities, so that the location of demand has no effect on the location of industries. See Matsuyama (1992) for a discussion. One could, of course, design a model in which final demand is itself a source of pecuniary externalities. See, for instance, Krugman (1991), and Fafchamps and Helms (1996).

and pecuniary externalities is positive, profits increase with the mass of activity. It is not required that Marshallian externalities alone, i.e., γ be positive for the presence of industries to be self-reinforcing.

Now consider the second case in which all labor resources are absorbed in modern production. In equilibrium, therefore, $L_i + X_i = \bar{L}_i$. Replace X_i in this equilibrium condition by its value in equation (12) and derive an equilibrium relationship between L_i and $\bar{L}_i$. Using it in equation (13), using the result in equation (14), and dividing through by $\bar{K}_i$, we get:

$$\frac{\Pi_i}{\bar{K}_i} = f a_i \bar{K}_i^{\delta+\gamma+\phi-1} \bar{L}_i^{1-\delta} \tag{17}$$

where $f \equiv d\delta[\frac{\beta-\delta}{\beta-\delta+\alpha(1-\beta)}]^{1-\delta}$. The equilibrium wage rate equals the marginal return to labor in the modern sector which, using equation (8), can be shown to be:

$$w_i = d(1-\delta)[\frac{\beta-\delta}{\beta-\delta+\alpha(1-\beta)}]^{-\delta} a_i \bar{K}_i^{\delta+\gamma+\phi} \bar{L}_i^{-\delta} \tag{18}$$

Equation (17) indicates that the return to capital increases indefinitely with $\bar{K}_i$ if externalities are sufficiently strong, i.e., if $\gamma+\phi > 1-\delta$. If externalities are weak, however, competition for workers raises the wage rate fast enough for returns to capital to fall; $\Pi_i/\bar{K}_i$ tends to zero as the capital stock gets arbitrarily large. Equations (17) and (18) also show that profits are higher and wages lower when local labor is plentiful. Both are higher when local conditions are good for industry. Key results are summarized in the following proposition:

Proposition 1:

(1) When $L_i + X_i < \bar{L}_i$, then $\frac{\Pi_i}{\bar{K}_i}$ is not a function of $\bar{K}_i$ if $\gamma + \phi = 0$; it increases with $\bar{K}_i$

if $\gamma + \phi > 0$.

(2) When $L_i + X_i = \overline{L}_i$, then $\frac{\Pi_i}{\overline{K}_i}$ decreases with $\overline{K}_i$ if $\gamma+\phi < 1-\delta$. Furthermore,

$\lim_{\overline{K}_i \to \infty} \frac{\Pi}{\overline{K}_i} = 0$.[9]

(3) When $L_i + X_i < \overline{L}_i$, then $w_i = \mu_i$. When $L_i + X_i = \overline{L}_i$, then w_i increases with $\overline{K}_i$.

Section 2. The Dynamic Path of the Economy

Having described the static equilibrium in each location, we now examine how our decentralized, perfectly competitive economy evolves over time. For simplicity, we assume that each location is populated by identical consumers sharing the same utility function and discount rate $\rho > 0$.[10] Incomes are composed of local wages and returns to capital. Consumers' intertemporal optimization problem can be written:

$$Max_{\{c_t^i,\, A_t^i\}} \sum_{t=1}^{\infty} \left(\frac{1}{1+\rho} \right)^t U_i(c_t^i)$$

subject to

$$A_{t+1}^i = w_t^i + (1 + r_t)A_t^i - c_t^i \tag{19}$$

and a set of initial conditions $A_0^i = \overline{A}^i$ for all $i \in C$. Assets A_t^i represent capital that consumers accumulate directly through the ownership of firms, or indirectly through financial assets.

As is well known (e.g., Lucas and Stokey (1989), King and Rebelo (1993)), if consumers face declining returns to their assets, they accumulate wealth up to the point

[9] As shown by Jones and Manuelli (1990), the neo-classical growth model does not necessarily imply that returns to capital eventually fall to zero.

[10] Similar qualitative results would obtain even if consumers have different utility functions and discount rates. The reason is that, when capital is fully mobile, industrial location is separable from local preferences.

where r_t equals ρ. When this happens, the economy reaches a steady state and stops growing. Until then, consumers find it optimal to accumulate assets and the economy grows. In order to characterize the equilibrium path of the economy, therefore, all we need to know is how r_t evolves as a function of A_t^i.

To do so, we begin by noting that since, by assumption, no capital is required in the labor-intensive sector, all capital goes to finance industries:

$$\sum_{i \in C} A_t^i = \sum_{i \in C} \overline{K}_t^i \equiv \overline{K}_t \qquad (20)$$

We assume that financial markets are perfect and that there is no uncertainty, so that asset returns are the same for loans and equity.[11] Consequently, they are treated as perfect substitutes; financial intermediation is transparent. Spatial arbitrage ensures that capital goes where returns are highest and that asset returns are equated across industrialized locations. Given that capital is perfectly mobile, the geographical location of industries does not depend on who accumulates capital; industrialization is separable from local preferences and income distribution. If residents of, say, location *i* accumulate more than they wish to invest locally, local consumption and investment are together less than local output and there is surplus in the balance of trade. This surplus translates into financial flows to the rest of the economy as residents in *i* invest, directly or indirectly, in other locations and accumulate financial claims on firms located elsewhere.

We derive the equilibrium path of the economy in two steps. First we derive a relationship between the economy-wide stock of capital $\overline{K}_t$ at time *t* and the return to that capital, assuming that industries locate optimally. We then discuss the optimal

[11] This is undoubtedly a strong and unrealistic assumption (e.g., Frankel (1992)). It is made to focus the attention on what one may expect if capital markets were perfect and investors free to raise funds anywhere. Capital market imperfections are indeed often blamed for the lack of industrialization and growth in many developing countries (e.g., Nurkse (1952), Barro, Mankiw and Sala-I-Martin (1995)).

accumulation path of capital and show that the economy converges to a steady state, provided that $\gamma + \phi < 1-\delta$.

The Geographic Pattern of Industrialization

The rate of return to capital r_t depends on where industries locate. To keep the notation simple, we normalize all production function by positing that each location is endowed with one unmovable unit of capital, i.e., $\bar{K}_0^i = 1$. The return to the first additional unit of capital that locates in i, denoted $\underline{r}^i$, is thus:

$$\underline{r}^i = e a_i^{\frac{1}{\delta}} \mu_i^{\frac{\delta-1}{\delta}} \tag{21}$$

Arbitrage requires that $\frac{\Pi_t^i}{\bar{K}_t^i}$ be the same in all locations where $\bar{K}_t^i > 1$. If not, capital would instantaneously flow in or out of that location until arbitrage gains can no longer be made. Rank locations according to the return to the first unit of capital: $\underline{r}^1 > \cdots > \underline{r}^i \cdots > \underline{r}^C$. We now show that, as long as the economy grows, i.e., $\Delta\bar{K}_t \equiv \bar{K}_{t+1} - \bar{K}_t > 0$, the location of industries over time follows a simple pecking order.

The case where externalities are absent is considered first and illustrated in Figure 1a.[12] The first unit of mobile capital locates at the best location $\underline{r}^1$. As long as labor is not all absorbed in industry, the return to capital remains equal to $\underline{r}^1$ (Proposition 1.1). Eventually, when all workers are in industry, a turning point à la Lewis (1954) is reached beyond which wages begin to rise, driving up cost and lowering returns to capital (Propo-

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[12] Figures 1 to 3 are constructed by numerical simulation. Parameter values are as follows: $\delta = 0.3$; $\beta = 0.7$; $\alpha = 0.8$; $\mu_i = 1$ and $\underline{L}_i = 10$ for $i \in \{1, 2, 3, 4\}$; $A_1 = 1.7$; $A_2 = 1.65$; $A_3 = 1.6$; $A_4 = 1.55$. Note that $\phi = 0.075$. For Figure 1, $\gamma = -0.075$; for Figures 2 and 3, we assume that Marshallian externalities are negative: $\gamma = -0.06$. $\Delta\bar{K}_t$ is computed as $s\, Y_t \frac{r_t - \rho}{\underline{r}^1 - \rho}$ where $Y_t = \sum_{i \in C} Y_t^i$ and $\rho = 0.04$. The value of the parameter s is chosen for best graphical results. In Figure 1, $s = 0.2$.

sitions 1.2 and 1.3). When returns to capital in the first location drop to $\underline{r}^2$, all new investments momentarily switch to the second location (Figure 1b, point *a*). When all workers in location two have joined the modern sector, wages there begin to rise as well (point *b*), driving down the economy-wide rate of return on capital. For a while, capital goes to both locations, driving wages further up in both places until the return to capital equals $\underline{r}^3$, at which point location 3 begins to industrialize (see Figure 1b, point *c*). The process is then repeated for other locations. The equilibrium location of capital is unique as long as no two locations share exactly the same $\underline{r}^i$. If they do, the location of capital is momentarily indeterminate. Arbitrage requires, however, that industries exhaust local labor supply in both locations at the same time. Thereafter, location is again fully determined.

The model thus predicts a geographical pattern of industrialization that is quite different from the standard neo-classical model. Unlike in Solow (1956) and King and Rebelo (1993), undeveloped areas do not as a rule grow faster than developed areas. Furthermore, only one location takes off at a time; others remain undeveloped until their turn comes to ’take off’ (Rostow (1956)):

Proposition 2: When capital is spatially mobile and workers earn a strictly positive income in the traditional sector, locations industrialize in pecking order: the best location industrializes first; the second best location industrializes next, etc. While they are waiting for their turn, locations remain entirely traditional.

When externalities are present, the situation is complicated by the possibility of multiple equilibrium paths. The reason is that externalities make industries gregarious: when many industries are, say, in location *A*, others wish to join them; if they happen to be in location *B* instead, it is towards *B* that other industries converge. As a result, the economy has a large number of spatial equilibrium paths. Most of these paths are implausible and uninteresting as they imply they industries switch in a coordinated haphazard fashion from location to location. To eliminate them, we assume that firms are unable to coordinate location decisions among themselves. Firms may find it individually profitable to move to a particular location and other firms may join them to benefit from externalities, but we assume that firms cannot jointly decide to move together to any particular location. In other words, we assume that there is coordination failure:

Assumption of Absence of Coordination (AAC): As $\bar{K}_t$ increases, individual firms may individually switch location instantaneously and costlessly, but firms are unable to jointly decide to relocate, all at the same time, from *i* to *j*.[13]

The AAC assumption makes it easy to derive the location of industries as a function of the aggregate stock of capital. If local externalities are strong, i.e., if $\gamma + \phi > 1-\delta$, all industries pile up in the best location: the first firm goes there and all the others follow to enjoy the benefits of ever increasing externalities. No other location ever industrializes. This equilibrium is unappealing, and we shall ignore it in the rest of this paper. We focus our attention on the more interesting case where externalities are weak, i.e., when $\gamma + \phi < 1-\delta$. In this case, proposition (2) still applies. The location of industries follows a pecking order: the most suitable location industrializes first, followed by the second most suitable location, etc (see Figures 2a and 2b).

[13] It is possible to find historical circumstances in which large numbers of people suddenly move from one location to another, taking along their financial and human capital -- e.g., Antwerp merchants to Amsterdam in the 16th century, the Californian gold rush, Jews to Israel, business people from mainland China to Taiwan in 1949. These exceptional circumstances are ignored here.

Along a stable equilibrium path, only one new location can take off at a time, even if several have the same $\underline{r}^i$. To see why, suppose the contrary, i.e., that two new locations *A* and *B* have attracted industries. This situation is unstable: if profits in *A* get infinitesimally above those in *B*, capital instantly moves from *B* to *A*, raising profits in *A* and lowering profits in *B*, until all *A* and *B*'s capital is in *A*.

There are nevertheless important differences between economies with and without local externalities. These differences are illustrated in Figures 2a and 2b and summarized in the following proposition:

Proposition 3: Assume $0 < \gamma + \phi < 1 - \delta$.

(1) Let $\overline{K}_n^w$ and $\overline{K}_n^o$ be the levels of total capital at which the *n*th location industrializes when $\gamma+\phi=0$ and when $\gamma+\phi>0$, respectively. Then $\overline{K}_n^w > \overline{K}_n^o$.

(2) Let w_n^w and w_n^o be the wage in location n as location $n+1$ begins industrializing when $\gamma+\phi=0$ and when $\gamma+\phi>0$, respectively. Then $w_n^w > w_n^o$.

(3) Let $\overline{K}_n$ be the stock of capital in location n and $\overline{K}$ be the stock of total capital. Define $\kappa_n \equiv \left.\frac{\partial \overline{K}_n}{\partial \overline{K}}\right|_{w_n = \mu_n}$. Then $\kappa_n > \kappa_{n-1} > \cdots > \kappa_1 = 1$.

(4) The stock of capital in locations $i = \{1, ..., n\}$ goes down as location $n+1$ begins industrializing.

(5) For any parameter vector and $\overline{L}_i < \infty$ and any $j > i$, there exist a $\overline{L}_j \gg \overline{L}_i$ such that the stock of capital in location i momentarily falls to zero as location j industrializes. Capital eventually flows back to location i as wages in j rise.

Part (1) of proposition 3 states that total capital and thus industrial activity are concentrated in a smaller number of locations when local externalities are present. Part (2) means that, just before industries relocate, the wage gap between industrialized and non-industrialized locations is larger with externalities than without. Part (3) means that each newly industrialized location industrializes faster than its predecessor (see Adsera (1994) for a similar result). This phase of rapid growth may be termed *catching up*. The reason is found in part (4): newly industrialized locations attract not only fresh capital but also existing capital that chooses to relocate away from already industrialized locations toward low-wage areas. As the number of locations from which capital is drawn increases, and as the stock of production plants to be relocated grows, so does the speed of the catching-up process. The downside is that already developed locations deindustrialize; catching up takes place partly at their expense (Figure 2b). If a new location is sufficiently rich in cheap labor resources, part (5) indicates that an already industrialized location may lose all its industries, only to recover them after wages in the new location rise sufficiently.

The model implies that the main engine of growth during catching-up need not be externalities. Cost advantages alone can explain why newly industrializing locations attract large amounts of domestic and foreign capital to industry. The simulations pictured in Figures 2a and 2b, for instance, were generated with $\gamma+\phi = 0.015$: more than 98% of the rise in industrial output is due to increased capital and labor use. This feature is consistent with empirical work that has documented the massive amounts of investment that went on in the four dragons during their catching-up phase (Kim and Lau (1994), Young (1992)) and that has argued that most of the growth in catching-up countries is due to increased capital and labor use (Mankiw, Romer and Weil (1992)).

The Equilibrium Path

We now characterize the long run behavior of the economy. We assume for simplicity that no $\underline{r}^i = \rho$. The relationship between $\bar{K}_t$ and r_t that results from the geographical arbitrage described in the previous sub-section can be summarized as follows:

Proposition 4: (1) If $\gamma + \phi < 1-\delta$, then $\underline{\lim}_{K \to \infty} r_t = 0$.

(2) If $\gamma + \phi = 0$, then r_t is a non-increasing function of $\bar{K}_t$.

The intuition behind Proposition 4 is straightforward. As in neo-classical growth models, labor resources in any location are fixed. Provided $\gamma + \phi < 1-\delta$, output is less than linear in the accumulable factor, capital. The return to capital r_t thus must eventually fall as the stock of capital increases and labor resources get exhausted in all locations. It is then easy to show that the economy has at least one long run steady state to which it converges:

Proposition 5: Provided that $\gamma + \phi < 1-\delta$:

(1) The decentralized competitive economy has at least one long run stable steady state at which $r_t = r = \rho$.

(2) The steady state cannot occur in the middle of the catching-up process.

The intuition behind Proposition 5 is simple. From proposition 4, returns to capital must eventually fall below the discount rate ρ. When the return on savings gets low enough, accumulation stops. Until then, consumers accumulate assets and the economy as a whole grows. The existence of weak local externalities does not alter these conclusions. It is not required that residents of all locations share the same utility function or that $U_i(c)$ take a specific form.

A immediate corollary of Propositions 4 and 5 is that unattractive locations never industrialize while attractive locations always industrialize. In the presence of externalities, intermediate locations may or may not industrialize, depending on parameter values and expectations regarding wages and interest rate.[14] Formally, let $\overline{r}^i$ be the higher return to capital that can be attained in location *i*, i.e.:

$$\overline{r}^i = f^{\frac{1}{1-\delta}} a_i^{\frac{1}{1-\delta}} \underline{r}^{i\,\frac{-\delta}{1-\delta}} \overline{L}_i \tag{22}$$

We have:

Proposition 6: In a decentralized competitive economy starting with no mobile capital, i.e., with $\overline{K}_0 = C$:

(1) locations such that $\underline{r}^j > \rho$ always industrialize

(2) locations such that $\overline{r}^j < \rho$ never industrialize

(3) locations such that $\underline{r}^j < \rho < \overline{r}^j$ industrialize or not depending on expectations and model parameters.

A consequence of Proposition 6 is that, when local externalities are absent -- and thus $\underline{r}^i = \overline{r}^i$ for all $i \in C$ -- the economy has a single stable steady state. The existence of a single stable steady state does not, however, imply convergence in the usual sense (e.g., Barro and Sala-I-Martin (1991, 1992), Mankiw, Romer and Weil (1992)): some locations remain unindustrialized in the long run.

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[14] With local externalities, multiple steady states and thus multiple equilibrium paths may arise. What distinguishes one equilibrium path from another is expectations about future wages and rates of interest. In order to accept rates of returns on saving that are temporarily below ρ, individual consumers must anticipate that wages and returns to capital will rise in the future. If they do not, they will refuse to save further and accumulation stops. To reach a higher equilibrium, investors have to be optimistic about is the capacity of non-industrialized locations to successfully generate local externalities. A complete treatment of these issues is beyond the scope of this paper and is left for future research.

Only in the absence of local externalities is the decentralized economy efficient. With externalities, decentralized equilibria are inefficient. Without coordination, the order in which locations industrialize need not be optimal: a small place with a high $\underline{r}^i$ but a low $\overline{r}^i$ may industrialize before a place with a slightly lower $\underline{r}^j$ but much larger $\overline{r}^j$. In this case, the economy would be better off skipping location *i* and moving directly to location *j*. Furthermore, the absence of coordination assumption prevents capital from moving to a new location early to avoid declining profit rates. By coordinating the movement of industries before wages rise above μ_i, higher returns to capital could be achieved. A detailed analysis of policy implications is left for future research.

Section 3. Infrastructure, Human Capital, and Technology

Using a simple model in which the accumulation of physical capital is the sole engine of growth, we have shown that locations industrialize in a pecking order. We now demonstrate that this result is robust to generalizations of the model that include other factors influencing growth, like investment in modern infrastructure and institutions, human capital, and technology. In addition, we show that industrialized locations have more incentives than non-industrialized ones to build industrial infrastructure, establish supportive institutions, educate their population, and develop new technologies. In certain circumstances, this generates poverty traps driven by pessimistic expectations, as in Ciccone and Matsuyama (1994). Throughout this section, we assume that $0 \leq \gamma+\phi < 1-\delta$.

Infrastructure and Institutions

Industries cannot flourish without adequate local infrastructure and a supportive institutional environment. A simple extension of the model can illustrate the role played by infrastructure and institutions. Redefine a_i, the parameter capturing local industrial conditions, as $a_i I_t^i$ and let I_t^i represent the productivity gain generated by modern infrastructure and institutions. Assume for simplicity that μ_i is not a function of I_t^i: industry requires infrastructures and institutions different from those supporting traditional production. Equation (13) then becomes:

$$Q_t^i = d\ a_i\ I_t^i\ (\overline{K}_t^i)^{\delta+\gamma+\phi}(L_t^i)^{1-\delta} \qquad (13')$$

Infrastructure and institutions are produced locally: $I_t^i = f(u_{t-1}^i)$ where u_{t-1}^i is the amount of final output diverted to man, maintain, service, and upgrade infrastructure and institutions. Industrial productivity increases with u but at a decreasing rate: $f'(.) \geq 0$ and $f''(.) < 0$. We also assume that $\lim_{u \to \infty} f''(u) = 0$. The function $f(.)$ is normalized so that $f(0) = 1$.

Individuals in each location invest in infrastructure and institutions optimally.[15] Arbitrage ensures that, in equilibrium, the return on investments in infrastructure and institutions is equal to the return on savings, r_t. The choice of u_t^i is thus determined by the following optimality condition:

$$\frac{Q_{t+1}^i}{I_{t+1}^i} f'(u_t^i) \leq r_t \qquad (23)$$

with strict equality if $u_t^i > 0$. The existence of a bounded solution is guaranteed by the assumption that $\lim_{u \to \infty} f''(u) = 0$. Using equation (23), we can characterize the pattern of investment in modern infrastructure and institutions as follows:

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[15] Since infrastructures and institutions often are public goods, we implicitly assume that local residents, who by construction are all identical, can organize to provide the level of u_t^i that is optimal for their location.

Proposition 7: (1) I_t^i is an increasing function of expected industrial output in location *i* and a decreasing function of r_t.

(2) If anticipated industrial output is zero, $I_t^i = 0$.

(3) Industrialization follows a pecking order that is influenced by expectations.

(4) The economy eventually reaches a stable steady state where $\bar{K}$ and I^i are constant.

The first two parts of proposition 7 indicate that modern infrastructure and institutions are abundant in industrialized areas but inexistent in backward regions that expect to remain so. The reason is that investment in industrial infrastructure and institutions is not profitable when there are no industries. Part (3) of proposition 7 indicates that the pecking order in which locations industrialize is influenced by local expectations. If residents in an arbitrary location *i* anticipate that industries are coming there soon, they will invest in I_{t+1}^i, thereby making their location more attractive to industry. If, on the contrary, they do not believe industries will come, they will refrain from making the investment, thereby failing to attract industries. Irreversible investment in infrastructure and institutions thus opens the door to multiple equilibrium paths driven by expectations. The last part of proposition 7 demonstrates that the accumulation of modern infrastructure and institutions does not, by itself, lead to permanent growth.

Human Capital

The recent literature on growth has emphasized the role of human capital accumulation in the growth process (e.g. Mankiw, Romer and Weil (1992), Lucas (1993), Azariadis and Drazen (1990), Stokey (1991)). In this paper we consider two possible definitions of human capital: as the level of education and skills workers accumulate through schooling and experience; and as the level of scientific and technological knowledge the human race accumulates over the course of history. We consider education and skills first.

We follow Barro, Mankiw and Sala-I-Martin (1995) and assume that physical capital is mobile while human capital is not. Since workers have finite lives, useful skills have to be taught anew to each generation. For notational simplicity, let us assume that human capital depreciates in one period. Unlike other authors (e.g., Lucas (1988), Azariadis and Drazen (1990)), we ignore human capital externalities: the productivity of the training technology is assumed constant over time. The accumulation of knowledge and its effect of the productivity of education are treated separately later. We assume that all workers receive directly from their parents the skills required for traditional production and ignore the cost of conveying those skills. To keep things as simple as possible, we further assume that industrial skills are useless in the traditional sector.[16]

Formally, let e_t^i stand for the efficiency of a worker in location i at time t. We posit that $e_t^i = e(s_{t-1}^i)$: labor efficiency increases with the level of schooling s_{t-1} in the preceding period. As before, we assume that $e(0) = 1$, $e'(.) \geq 0$, $e''(.) < 0$ and $\lim_{s \to \infty} e'(s) = 0$. We normalize units so that one unit of schooling costs one unit of final output.

We follow the modern literature on human capital accumulation and assume that workers invest optimally in schooling, weighing the gain from higher wages against the cost of education s_t^i. All workers being identical, they all invest in the same amount of

[16] Schultz (1961) has argued that literacy and numeracy increase the productivity of even traditional farmers and craftsmen. The available evidence seems to indicate that farmers benefit most from schooling when agriculture and crafts are modernizing (Lockheed, Jamison and Lau (1980), Phillips (1987)) and that the returns to formal education are stronger in the modern sector (e.g., Vijverberg (1993)).

human capital but only $\frac{L_{t+1}^{i} + X_{t+1}^{i}}{\bar{L}_i}$ of them end up working in industry. The others remain in the traditional sector where schooling does not increase their productivity. We assume that workers in the modern sector are paid their efficiency wage.[17] Arbitrage requires that the marginal return to schooling cannot exceed the rate of interest on tangible assets:

$$w_{t+1}^{i} \frac{L_{t+1}^{i} + X_{t+1}^{i}}{\bar{L}_i} e'(s_t^i) \leq r_t \tag{24}$$

with equality if $s_t^i > 0$. Since industrial employers pay workers according to their job efficiency, they do not derive any benefit from a highly educated labor pool. This yields the following proposition:

Proposition 8: When workers in the modern sector are paid their efficiency wage:

(1) Schooling s_t^i is an increasing function of the expected wage rate w_{t+1}^i and of the expected proportion of workers in the modern sector $\frac{L_{t+1}^{i} + X_{t+1}^{i}}{\bar{L}_i}$; it is a decreasing function of r_t.

(2) If expected industrial output in the future is zero, $s_t^i = 0$.

(3) When $s_t^i > 0$, the wage per worker is higher in industry than in the traditional sector.

(4) The pecking order of industrialization is unaffected by schooling.

(5) The industrialization of new locations is delayed compared to an economy with no schooling technology $e(.)$.

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[17] This is a strong assumption. Making the polar assumption that all efficiency gains from schooling are captured by employers leads to the unrealistic predictions that no worker invests in schooling unless it is totally subsidized, and that all workers in the modern sector are paid the same wage irrespective of their qualifications. Reality probably lies somewhere in between (see the discussion below).

(6) The economy eventually reaches a stable steady state.

The proposition predicts that industrialized locations have a better educated labor force than non-industrialized ones: since they have both a higher proportion of workers in industry and a higher wage, workers find it in their interest to invest in education. Workers in non-industrialized locations derive no benefit from schooling, so there is no reason for them to invest in it.[18] In partially industrialized locations, returns to schooling may be sufficient to trigger positive levels of s_t^i but all trained workers need not find employment in the modern sector. Our model thus exhibits features similar to the Harris and Todaro (1970) model: it is consistent with the existence of an income gap between traditional and modern activities (e.g., Jamal (1984), Jamal and Weeks (1988)) and of unemployment among college graduates in many poor countries (e.g., JASPA (1982), Eicher (1985)).

Part (4) of Proposition 8 stipulates that introducing schooling in the model does not alter the pecking order of industrialization. Locations cannot therefore jump ahead of others by subsidizing education. This prediction hinges dramatically on the assumption that workers capture all the gains from investment in education. If we make a less extreme assumption and posit that some of the benefits from schooling accrue to employers, then locations with a better educated labor force will enjoy a higher $\underline{r}_t^i$. Investing in education could then change the order of industrialization. As in the case of infrastructure and institutions, expectations regarding future industrial wages and employment could trigger investment in schooling and thus influence the timing of indus-

[18] In practice, even non-industrialized countries and locations have a bureaucracy and an army. Many parents in those places send their kids to school in the hope they will secure a job in the civil service or the military (JASPA (1982), Eicher (1985)).

trialization.

Part (5) shows that, thanks to human capital accumulation, industrialized locations slow down the decline in profit rates, prolong their industrialization, raise local wages, and further widen the income gap between them and non-industrialized locations. Including human capital in the model does not, however, modify the main conclusion from section 2: locations industrialize one at a time.

Knowledge and Technology

Since Solow's (1957) seminal work, technological change has been recognized as a major engine of long-term growth. Recently, Romer (1986, 1990) revisited the issue and cast it in terms of knowledge accumulation. We now incorporate into our model the accumulation of scientific knowledge and its transformation into new techniques, products, and skills (e.g., Solow (1957), Romer (1990)). We show that industrial locations have more incentive than others to invest in science and technology, even if their discoveries spill over to non-industrialized locations. Science and technology do not eliminate the existence of a pecking order of industrialization.

We introduce technology in the simplest possible way by assuming that the efficiency of capital depends on the current level of technology in the total economy, denoted T_t.[19] Technological innovations are produced with a research production function $t(v_t^i, T_t)$ where v_t^i is the cost of research at time t in location i, expressed in units of

[19] There are other ways in which technology could be incorporated in the model. One could, for instance, assume that scientific knowledge raises the productivity of the educational system and thus the number of skills that can be acquired in a given unit of time. As long, however, as the efficiency of labor does not increase so rapidly that industrialized locations forever maintain their advantage, Proposition 8 would be largely unaffected. Alternatively, one may also assume that new varieties n of industrial services must be invented before being produced. Romer (1990) and Ciccone and Matsuyama (1994) offer a thorough treatment of this issue.

final output. We assume that $t(0,T) = 0$, $\frac{\partial t(v,T)}{\partial v} \geq 0$, $\frac{\partial^2 t(v,T)}{\partial v^2} < 0$ and $\lim_{v \to \infty} \frac{\partial t(v,T)}{\partial v} = 0$. The function $t(v,\ T)$ is allowed to depend on T to capture the idea that the existing stock of scientific knowledge facilitates the development of new technologies (as in Romer (1990)).

Technology accumulates over time according to:

$$T_{t+1} = T_t + \sum_{i \in C} t(v_t^i,\ T_t) \tag{25}$$

Innovations are sold at a price equal to the capital they save. To capture the imperfect excludability of knowledge, we assume that the revenue from the sale of innovations produced in location i is proportional to the stock of capital in that location only; other locations benefit from free knowledge spillovers.[20]

Private investment in research must satisfy:

$$\overline{K}_{t+1}^i\ t'(v_t^i,\ T_t) = r_t \tag{26}$$

We get the following proposition:

Proposition 9:

(1) Investment in knowledge and technology is undertaken exclusively by industrialized locations.

(2) If function $t(v,\ T)$ is non-decreasing in T, the economy grows faster as the number of industrialized locations increases.

(3) Locations industrialize in a pecking order.

[20] This assumption obviously abstract from difficulties in the transfer of technology across locations. It is meant to demonstrate that obstacles to technology transfer are not required to explain the lack of convergence across locations.

(4) Growth may continue forever, depending on the function $t(v, T)$.

(5) The wage gap between industrialized and non-industrialized locations increases in T.

(6) Industrialized locations are the main immediate beneficiaries of knowledge and technology spillovers.

Part (1) of Proposition 9 states that research and development take place exclusively in industrialized locations, a feature in general accordance with observation (see also Grossman and Helpman (1991)). Part (2) indicates that the economy as a whole benefits from the coexistence of several industrial centers.[21] Part (3) demonstrates that industrialization occurs one location at a time even in the presence of technological spillovers, as illustrated in Figure 3.[22] Part (4) indicates that introducing technology in the model can account for long lasting growth. Parts (5) and (6) show that technological innovations benefit mostly industrialized locations and exacerbate wage differentials between developed and undeveloped locations.

Conclusions

To explore the pattern of industrial location that one may expect from increased internationalization of economic activity and financial liberalization, we have constructed a model of a stylized economy where workers are immobile but capital moves freely between multiple locations. To verify the possible role of agglomeration effects, we allow for both Marshallian and pecuniary externalities. The latter are, as in Ciccone and Matsuyama (1994) and Rodriguez-Clare (1994), derived from the existence of fixed

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[21] Romer (1986) and Goodfriend and McDermott (1995) provide evidence that growth in industrialized countries has followed a slowly increasing trend over time.

[22] Figure 3 was constructed by numerical simulation using $t(v) = \chi v^{\kappa}$ with $\kappa = 0.5$ and $\chi = 0.0015$.

costs in the production of non-tradable industrial services and from complementarities between industrial services in final output. In our model, Marshallian and pecuniary externalities are shown to be formally equivalent. The model accommodates positive agglomeration effects together with negative feedbacks due to congestion.

We demonstrate the existence of a pecking order of industrialization. This finding does not require the existence of local externalities. Rather, it is derived from a Lewis-like assumption that workers not employed in modern industries work in labor-intensive traditional activities. Although movements of capital can help a few locations grow very rapidly and ’catch up’ with the rest of industrialized locations, other locations are predicted to stagnate for extended periods of time -- and may even never industrialize.

In the second part of the paper, we consider a series of extensions of the base model to incorporate investment in infrastructure and institutions; schooling; and technological change. None of these extensions modify our central result, which is that industrialization follows a pecking order. We note that self-fulfilling expectations may affect the decision to invest in infrastructure, institutions, or schooling: if the residents of a particular location are pessimistic about the future, they may optimally decide not to undertake investments that would make their location attractive to industries. Knowledge spillover and free technology transfer do not guarantee the industrialization of undeveloped locations. On the contrary, they tends to benefit locations that are already industrialized and speed up growth there.

Taken together, these results cast doubt on the ability of foreign direct investment, free movements of capital, and even free technology transfers to foster the rapid industrialization of all countries and regions of the world simultaneously. Only a handful of locations at a time may reap from financial and economic liberalization the benefits that they anticipate in terms of rapid industrialization and growth. They also suggest that more caution should be applied when interpreting the role of human capital in the development process. Our results indeed suggest that subsidizing education need not foster industrialization. Finally, our model helps clarify the role of local externalities in growth: agglomeration effects and other positive feedbacks may only make a marginal contribution to output growth, and yet play a critical role in attracting industries to a particular location.

Appendix: Proofs of Propositions

Proofs of Proposition 1 and 2: See text.□

Proof of Proposition 3: A new location i begins industrializing when the profit rate in an already industrialized location j becomes equal to $\underline{r}^i$. Using equation (17), the level of capital in j at which location i begins industrializing can be written:

$$\bar{K}^j = \left[\frac{\underline{r}_i}{f a_j \bar{L}_j^{1-\delta}}\right]^{\frac{1}{\delta+\gamma+\phi-1}}$$

Differentiating with respect to γ or ϕ yields a positive expression, thereby demonstrating that $\bar{K}^j$ increases with externalities. This proves part (1). Part (2) follows immediately from equation (18).

Part (4) results from an arbitrage argument: as profit rates in the newly industrialized location rise thanks to location externalities, capital must flow out of already industrialized locations so as to equalize rates of return to mobile capital. Part (3) follows from part (4) and is a consequence of the fact that locations who industrialize late attract capital from an ever increasing number of industrialized locations. Part (5) is an immediate consequence of the fact that

$$\lim_{\bar{K}_i \to \infty} e\, a_i^{\frac{1}{\delta}}\, \mu_i^{\frac{\delta-1}{\delta}}\, \bar{K}_i^{\frac{\delta+\gamma+\phi}{\delta}-1} = 0$$

This completes the proof.□

Proof of Proposition 4: Part (1) follows from proposition (1.2) and from the assumptions that the number of locations is finite and that $\bar{L}_i < \infty$ in all locations. Part (2) follows from proposition (2): as the stock of total capital increases, locations with lower and lower $\underline{r}^i$ industrialize. In the absence of local externalities, $\frac{\partial r}{\partial \bar{K}}$ is either 0 -- when one industrializing location is not congested -- or declining -- when all industrializing locations are congested (Figure 1a).□

Proof of Proposition 5:

Existence of a steady state: Along the competitive path, the following Euler equation must be satisfied for each consumer in each location:

$$U'(c^i_{t+1}) = \frac{1+\rho}{1+r_{t+1}} U'(c^i_t)$$

where $c^i_t = w^i_t + (1-r_t)A^i_t - A^i_{t+1}$. The transversality condition must also be satisfied, i.e. the discounted value of future wealth must remain bounded. Let $\bar{K}_*$ be the level of total capital at which $r_* = \rho$. That level of capital determines wage rates in each location w^i_*. There exist many distributions of individual assets A^i_* such that $\sum_i A^i_* = \bar{K}_*$. Setting $\bar{K}_t$ to $\bar{K}_*$ and A^i_t to A^i_* for all i satisfies the Euler equation and the transversality condition of each individual. This proves that a steady state exists. In the presence of local externalities, there may be several $\bar{K}_*$ at which $r_t = \rho$ and thus several steady states.

Existence of a stable steady state: We prove stability in three steps. First we show that steady states are unstable for which a location is in the middle of the catching-up process and thus where $\left.\frac{\partial r_t}{\partial \bar{K}_t}\right|_{\bar{K}_t = \bar{K}_*} > 0$. Next, we show that steady states state where $\left.\frac{\partial r_t}{\partial \bar{K}_t}\right|_{\bar{K}_t = \bar{K}_*} < 0$ are stable. Finally we note that, provided that $\gamma + \phi < 1-\delta$, there always exist at least one $\bar{K}_*$ at which the above derivative is negative and thus at least one stable steady state.

(a) Consider a steady state at which $\left.\frac{\partial r_t}{\partial \bar{K}}\right|_{\bar{K} = \bar{K}_s} > 0$: one location is in the process of catching-up. Suppose all A^i_* are constant. Consider what happens if an individual accumulates a bit of capital above $\bar{K}_*$. This raises r_{t+1}. It also lowers the wage rate w^i_{t+1} in all deindustrializing locations. The wage in the catching-up location does not change (see Proposition 1). With r_{t+1} higher than ρ and $w^i_{t+1} \leq w^i_t$, others want to save more as well: the economy moves away from $\bar{K}_*$. Similarly, if one individual saves less, r_{t+1} falls, wages rise, and others too want to save less. The steady state is therefore unstable. This proves part (2).

(b) Now consider a steady state at which $\left.\frac{\partial r_t}{\partial \bar{K}}\right|_{\bar{K} = \bar{K}_s} < 0$ and consider what happens if an individual accumulates a bit of capital above $\bar{K}_*$. This lowers r_{t+1} and raises the wage rate in all industrialized locations. With r_{t+1} lower than ρ and $w^i_{t+1} \geq w^i_t$, others want to save less: the economy moves back to $\bar{K}_*$. Similarly, if one individual saves less, r_{t+1} rises, wages fall, and others want to save more. The steady state is therefore stable.

(c) Finally, by Proposition 4, we know that, as long as $\gamma + \phi < 1 - \delta$, the return to capital must eventually fall and that, at the limit, it tends to zero. A large enough $\bar{K}_*$ must therefore exist at which $r_* = \rho$ and $\left.\frac{\partial r_t}{\partial \bar{K}}\right|_{\bar{K} = \bar{K}_s} < 0$. This completes the proof of part (1).□

Proof of Proposition 6: Parts (1) and (2) follow immediately from Propositions 4 and 5. Part (3) follows from the fact that if $\bar{r}^j > \rho$, then there must be a higher level of total capital at which returns to capital in location j fall to ρ, and thus a stable steady state in which location j industrializes. This steady state, however, cannot always be reached by a decentralized economy with zero initial capital. Indeed, since $\underline{r}^j < \rho$, industrializing location j requires that r_t must temporary fall below ρ. If $\bar{r}^j$ is sufficiently above ρ and the time required for r_t to rise again above ρ is short, then individual consumers may be lulled by the promise of high future rewards and optimally choose to accumulate capital even when $r_t < \rho$. If, on the other hand, $\bar{r}^j$ is only slightly above ρ and the time necessary to reach high rates of return is long, individual consumers may prefer to dissave when r_t falls below ρ. In this case, no decentralized equilibrium with zero initial capital can reach the steady state in which location j industrializes. See Ciccone and Matsuyama (1994) for a detailed discussion of a model with similar features.

By construction, whenever an equilibrium path exists in which an intermediate location industrializes, another equilibrium path exists in which it does not. Let $\tilde{K}$ be the level of total capital at which all the locations for which $\underline{r}^i > \rho$ industrialize and r_t falls to ρ for the first time. Setting $\bar{K}_t = \tilde{K}$ and r_t to ρ for all subsequent periods is clearly an equilibrium path, and it is an equilibrium path in which none of the intermediate locations industrializes. Whether location j industrializes or not thus depends on expectations regarding future interest rates and wages and thus on which equilibrium path happens to be picked.□

Proof of Proposition 7: To prove part (1), totally differentiate equation (2). Part (2) follows from equation (2). To show part (3) note that $\underline{r}^i$ can now be rewritten:

$$\underline{r}_t^i \equiv e\ a_i\ I_t^{i\ \frac{1}{\delta}}\ \mu_i^{\frac{\delta-1}{\delta}}$$

From parts (1) and (2) we know that I_t^i depends on past expectations about industrial output in location i. High expectations about $\bar{K}_{t+1}^i$ raise u_t^i, and thus I_t^i and $\underline{r}_t^i$. Since the pecking order in which industrialization takes place depends on the ordering of $\underline{r}_t^i$'s, optimism about a location can trigger a non-null u_t^i and help that location jump ahead of others. This proves part (3). To demonstrate part (4), set r_t to ρ in equation (2). In non-industrialized locations, $u = 0$ by part (2). In a stable steady state no location is partially industrialized (Proposition 5.2). Consider a fully industrialized location i. For a high enough $\bar{K}^i$, $\frac{f'(u)Q(\bar{K}^i)}{a_i\, f(u)}$ eventually falls below ρ. This completes the proof.□

Proof of Proposition 8: Part (1) can be shown by totally differentiating equation (24). Part (2) follows from equation (24). Part (3) is a consequence of our assumptions regarding the productivity of educated workers who are rationed out of the modern sector and end up in the traditional sector. Part (4) results from the fact that $\underline{r}^i$ does not depend on e_t^i when workers are paid their efficiency wage. Part (5) results from the fact that schooling increases the effective labor force available in a location, reduces wages per unit of effective labor, and thus retards the time at which profits in that location fall below initial profits in the next location. Part (6) can be shown in a way similar to Proposition 7.4.□

Proof of Proposition 9: Part (1) is obtained by totally differentiating equation (26). Part (2) results from the existence of spill-over effects: as more locations industrialize, more locations invest in research, and T increases faster. To demonstrate part (3), note that the return to initial capital in non-industrialized locations increases with the stock of technology:

$$\underline{r}_t^i = T^{\frac{\delta+\gamma+\phi}{\delta}}\, \underline{r}^i$$

Returns to capital also increase in congested locations as a result of technological change, but at slower rate $T^{\delta+\gamma+\phi}$. The productivity gap between industrialized and non-industrialized locations is reduced over time but the pattern of industrial relocation is not affected: when returns in industrialized locations fall below $\underline{r}_t^i$, relocation takes place. To show that growth may persist indefinitely, suppose that $t(v,\ T) \equiv \log(v)$. Then $v_t^i = \frac{\bar{K}_t^i}{r_t}$

and

$$T_t = \sum_{s=0}^{t-1} \sum_{i \in C} \frac{\overline{K}_s^i}{r_s} \tag{27}$$

Equation (27) shows that technology is forever raising the return to capital even if capital and interest rate are kept constant. In equilibrium, technology improvements forever lead to further capital investment and further technological improvement. To show that growth may eventually stop, suppose that $t(v,\ T) = \log(v)(\overline{T} - T)$. In this case, there is an upper limit to the stock of technology that can be accumulated. As $T_t \to \overline{T}$, accumulation of technology stops and so does growth. Part (5) follows from the fact that T raises wages only in industrialized locations. Part (6) is an immediate consequence of part (5).□

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Figure 1a. Return to Capital Without Externalities

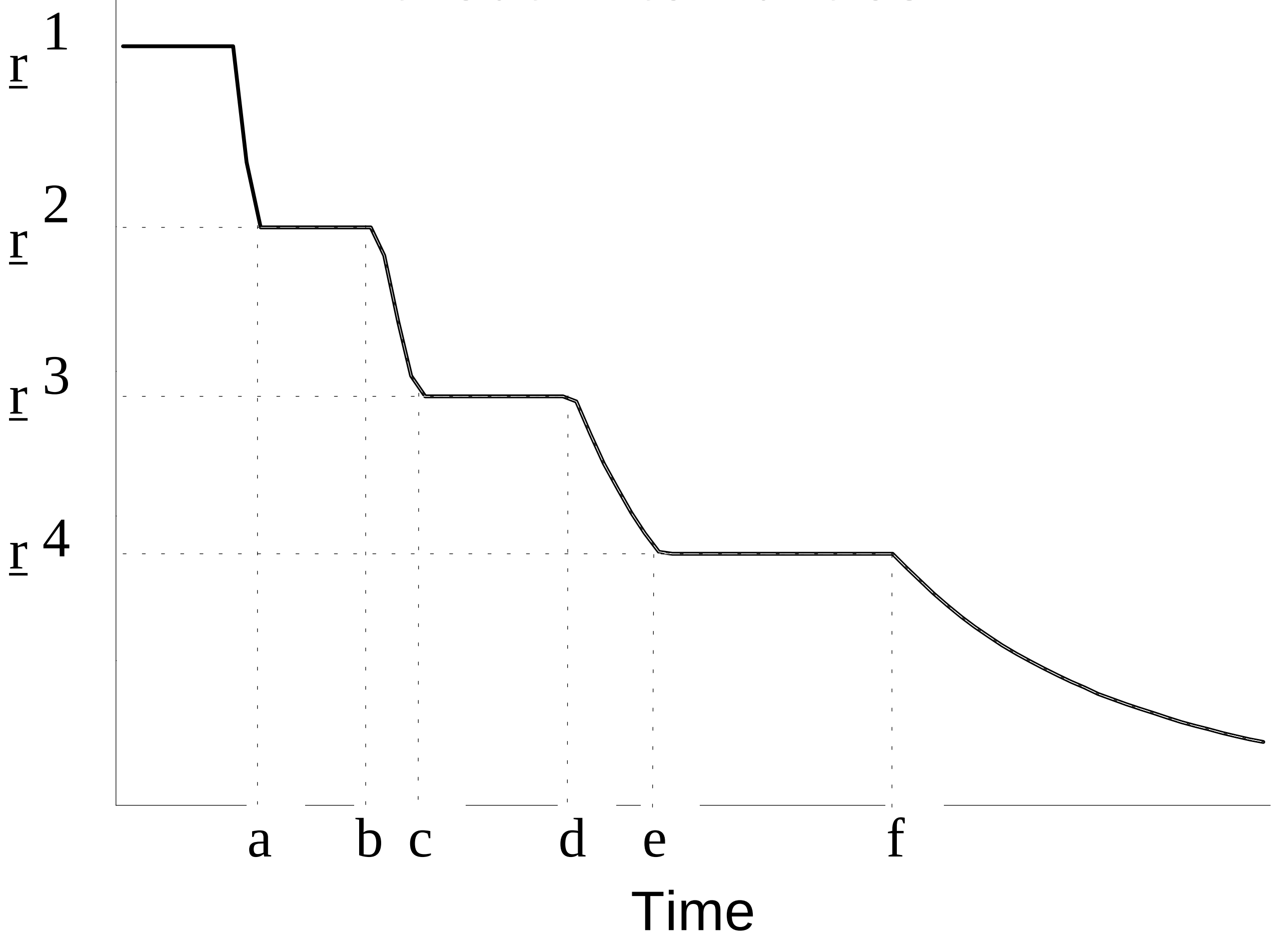

Figure 1b. Accumulation of Capital Without Externalities

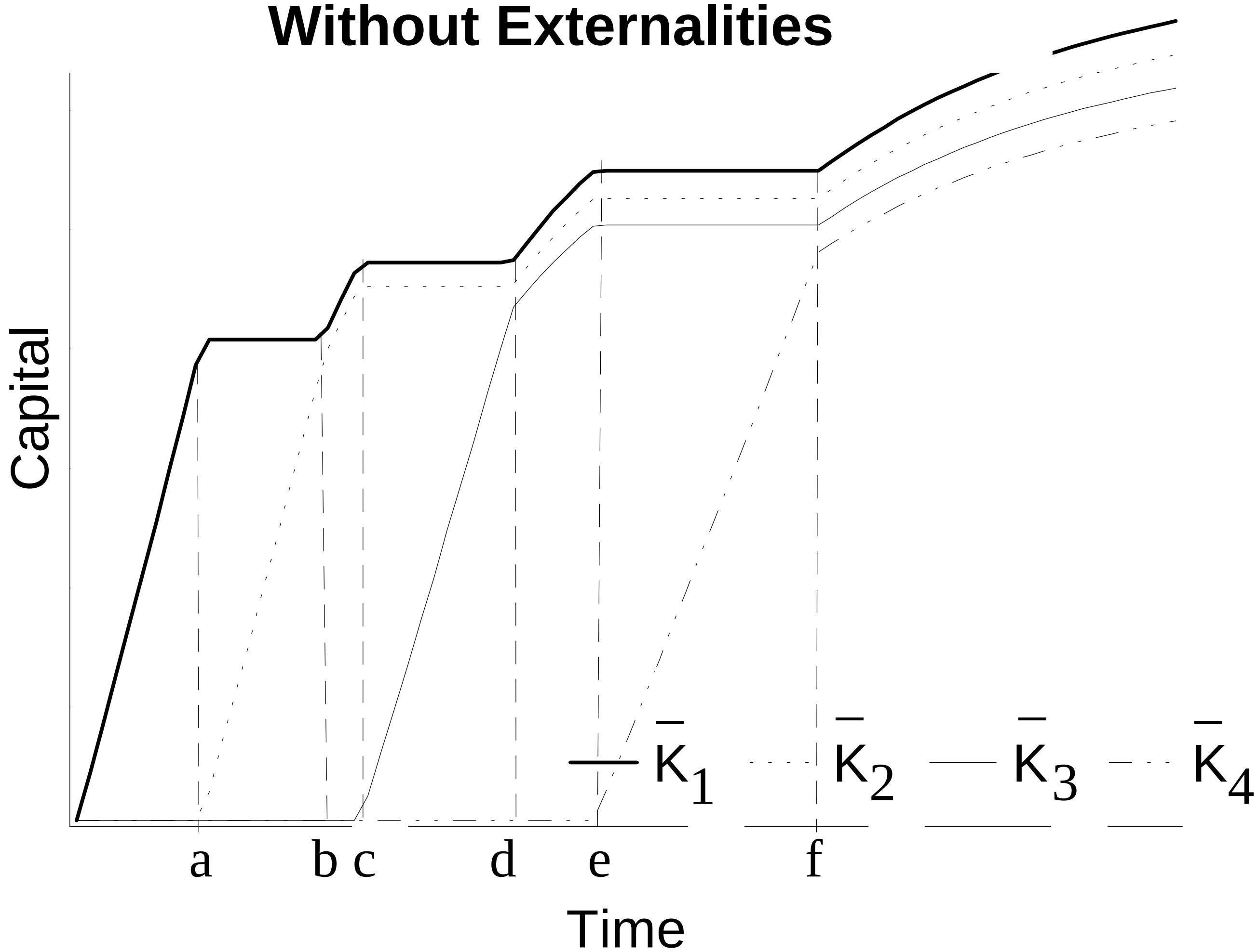

Figure 2a. Return to Capital With Externalities

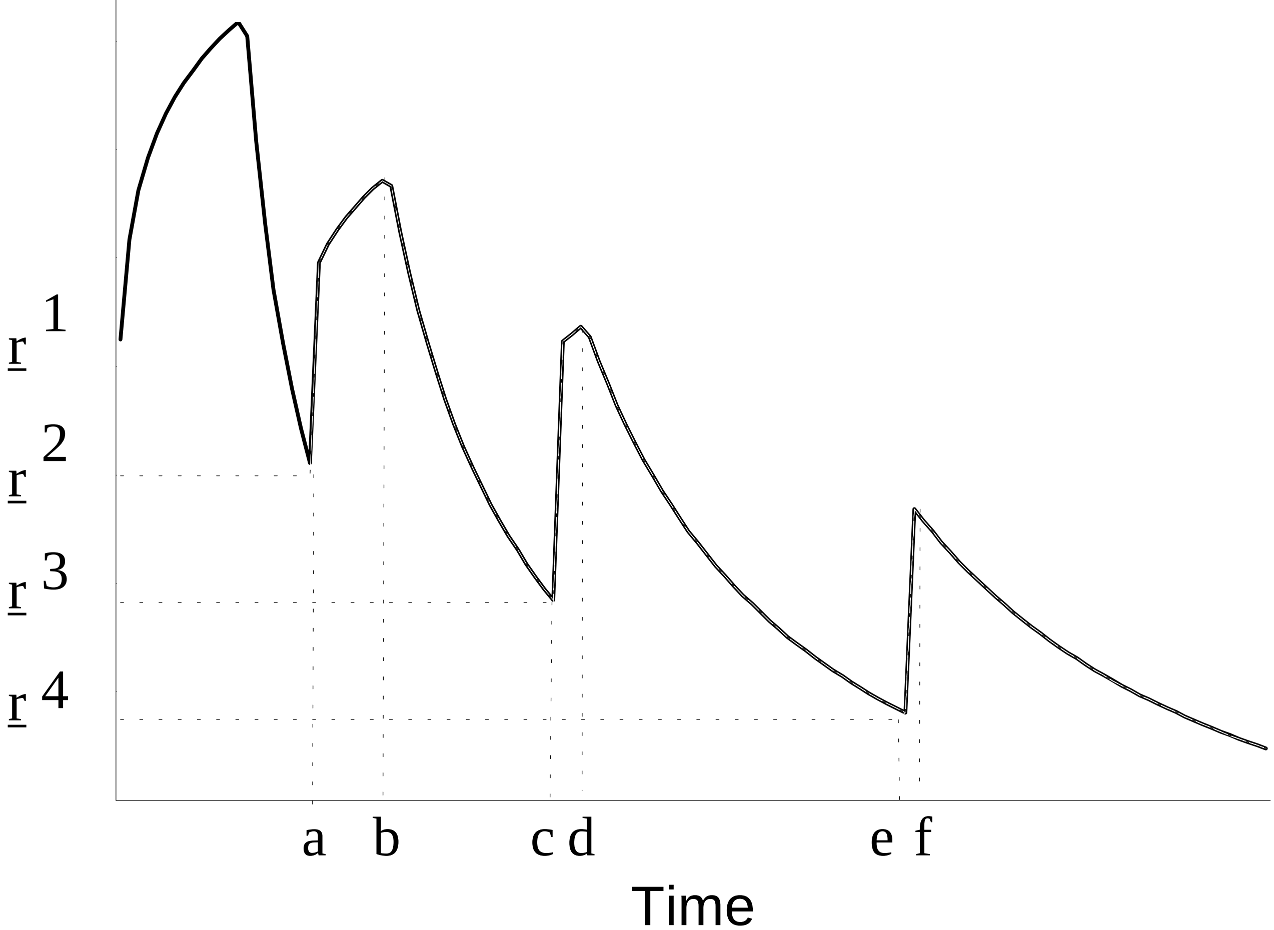

Figure 2b. Accumulation of Capital With Externalities

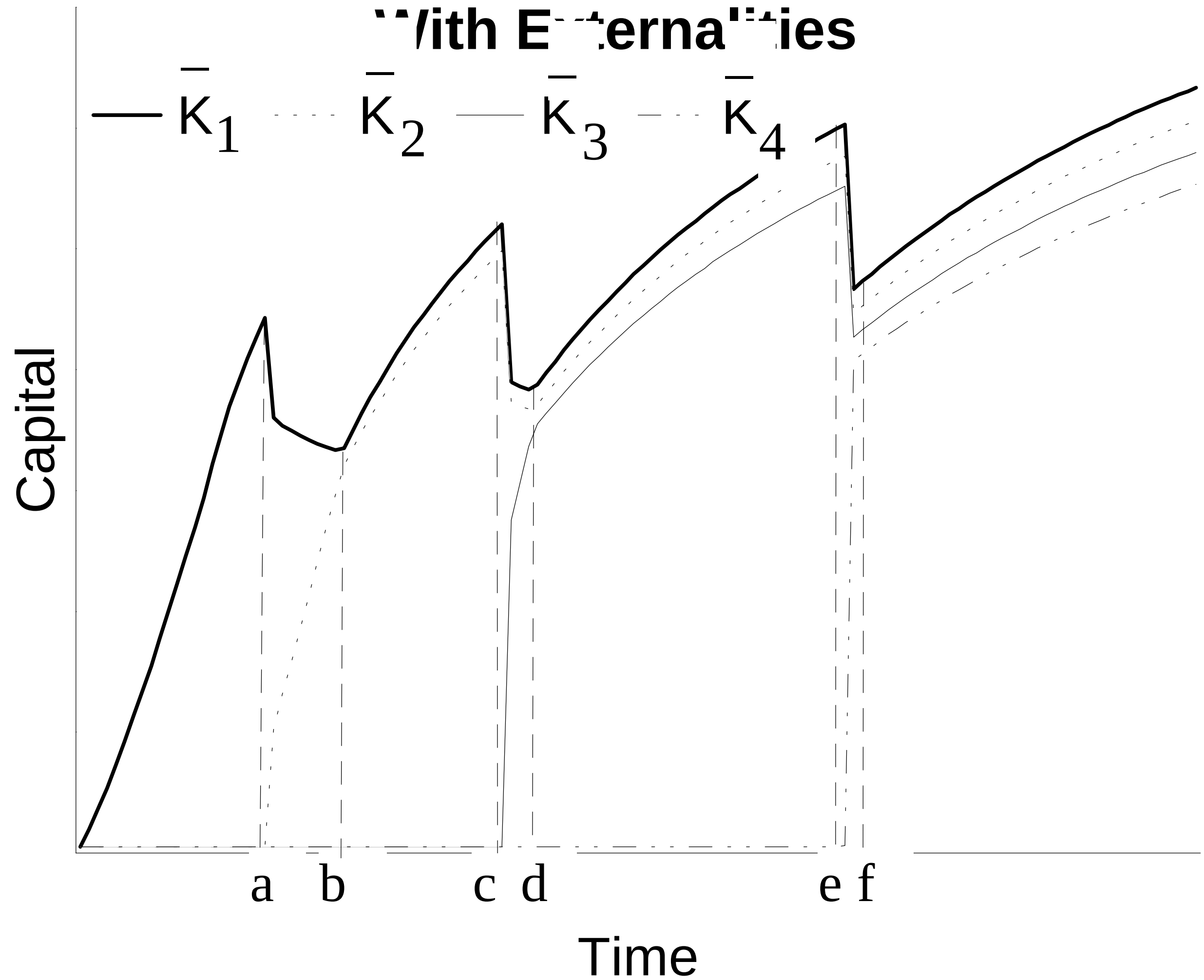

Figure 3. Return to Capital With Technological Change