Technological Diffusion

Introduction

- In the neoclassical growth model, per capita output grows in the long run only because of exogenous technological progress.
- The interesting insights about growth involve the convergence behavior along the transition path.
- Because of diminishing returns to capita economies grow faster when they start further below their steady-state positions.
- Thus, the determinants of the steady-state positions are held fixed, poorer places are predicted grow faster in per capita terms.

Introduction

- The endogenous growth theory, initiated by Romer (1987, 1990) and Aghion and Howitt (1992), explains long-term growth from a model of technological progress.
- The private research that underlies commercial discovery is motivated along Schumpeterian lines by the flow of profit that accrues to an innovator.
- Since the profit flow depends on some form of monopoly power, the resulting equilibrium tends not to be Pareto optimal.

Introduction

- The strong point of the recent theories is that they endogenize the rate of technical change, a variable that is unexplained in the neoclassical growth model.
- Thus, the long-term growth rate becomes an endogenous variable that depends on the underlying parameters and disturbances in the model.
- However, the new theories are less attractive in that they tend to lose the prediction of conditional convergence.

Introduction

- In a multieconomy setting, the key issue is how rapidly the discoveries made in leading economies diffuse to follower economies. We shall find in this chapter that the diffusion of technology gives us another reason to predict a pattern of convergence across economies.
- The main idea we are going to study is that follower countries tend to catch up to the leaders because imitation and implementation of discoveries are cheaper than innovation.
- This mechanism tends to generate convergence even if diminishing returns to capital or to R&D do not apply.

Setup of the model

- There are two countries, denoted by i = 1,2. The production function in each country is of the Spence (1976)/Dixit and Stiglitz (1977) type:

$$Y_i = A_i \cdot (L_i)^{1-\alpha} \cdot \sum_{j=1}^{N_i} (X_{ij})^{\alpha}, \tag{1}$$

- where $0 < \alpha < 1$, Y_i is output, L_i is labor input, X_{ij} is the quantity employed of the *j*th type of nondurable intermediate good, and N_i is the number of types of intermediates available in country i. The technology in equation 1 can be accessed by all agents in country i, and production occurs under competitive conditions.

Setup of the model

- The output in country 1 is physically the same as that in country 2.
- The total quantities of labor in each country, L_1 and L_2, are constants and correspond to the populations of each country.

Setup of the model

- The productivity parameter, A_i, can represent variations across countries in the level of technology; that is, differences in output that arise for given values of the N_i, L_i, and X_{ij}´s.
- In practice, however, the main source of differences in the A_i is likely to be variations in government policies, as reflected in infrastructure services, tax rates, the degree of maintenance of property rights, and the rule of law.
- The effects of these policies on outcomes are analogous to those from pure differences in the levels of technology. Thus, the measures of government policy used in empirical studies, are empirical counterparts of the A_i.

Setup of the model

- Trade is assumed to be balanced between the two countries; that is, domestic output Y_i equals total domestic expenditures.
- These expenditures are for consumption, production of intermediates, and R&D aimed at learning about new varieties of intermediates.
- An agent can learn by inventing a new type of good or by imitating a product that is known in the other country.
- Units of C_i or X_{ij} each require one unit of Y_i. The invention of a new variety of product requires a lump-sum outlay of η_i units of Y_i.

Setup of the model

- Suppose, to begin, that country 1 is the technological leader, whereas country 2 is the follower.
- Specifically, $N_1(0) > N_2(0)$, and all of the varieties of intermediates initially in country 2 are also known in country 1.
- Assume, for now, that all discoveries of new types of products occur in country 1 . Country 2 imitates the intermediate goods known in country 1 but does not invent anything.

Innovation in country 1

- The setup for country 1 is similar to that described in Romer (1990).
- An inventor of an intermediate of type j is assumed to retain a perpetual monopoly over the use of this good for production in country 1.
- If intermediate j is priced in country 1 at P_{1j} , then the flow of monopoly profit to the inventor is:

$$\pi_{1j} = (P_{1j} - 1) \cdot X_{1j}, \qquad (2)$$

Innovation in country 1

- The production function in equation 1 implies that the marginal product of intermediate j in the production of output is:

$$\partial Y_1/\partial X_{1j} = A_1\alpha \cdot L_1^{1-\alpha} \cdot (X_{1j})^{\alpha-1}.$$

- The demand function for intermediate j form all the producers of goods in country 1:

$$X_{1j} = L_1 \cdot (A_1\alpha/P_{1j})^{1/(1-\alpha)}. \tag{3}$$

Innovation in country 1

- Equation (3) in (2):

$$P_{1j} = P_1 = 1/\alpha > 1. \quad (4)$$

- The monopoly price is the same at all points in time and for all intermediates.
- The result in equation 4 implies that the total quantity produced of intermediate j in country 1 is:

$$X_{1j} = X_1 = L_1 \cdot A_1^{1/(1-\alpha)} \cdot \alpha^{2/(1-\alpha)}. \quad (5)$$

Innovation in country 1

- This quantity is the same for all intermediates j and at all points in time (because L_1 constant).
- Substitution of the result from equation 5 into the production function in equation 1 implies that country 1 's total output is:

$$Y_1 = A_1^{1/(1-\alpha)} \cdot \alpha^{2\alpha/(1-\alpha)} \cdot L_1 N_1. \tag{6}$$

- Hence, output per worker rises with the productivity parameter and the number of varieties. The variable N_1 represents the state of technology in country 1. Increases in N_1 lead to equiproportionate expansions in output per worker.

Innovation in country 1

- Equation 4 and 5 in 2 implies

$$\pi_{1j} = \pi_1 = (1-\alpha) \cdot L_1 \cdot (A_1)^{1/(1-\alpha)} \cdot \alpha^{(1+\alpha)/(1-\alpha)}. \tag{7}$$

- Since the profit flow is constant, the present value of profits from date t onward is:

$$V_1(t) = \pi_1 \cdot \int_t^{\infty} \exp\left[-\int_t^s r_1(v) \cdot dv\right] \cdot ds,$$

where $r_1(v)$ is the real interest rate at time v in country 1.

Innovation in country 1

- If there is free entry into the R&D business and if the equilibrium quantity of R&D is nonzero at each point in time, then $V_1(t)$ must equal the constant cost of invention at each point in time. This condition implies that $r_1(v)$ is constant over time and given by

$$r_1 = \pi_1/\eta_1, \tag{8}$$

Innovation in country 1

- Consumers in country 1 are of the usual Ramsey type with infinite horizons. At time 0, these consumers seek to maximize:

$$U_1 = \int_0^\infty e^{-\rho t} \cdot [(C_1^{1-\theta} - 1)/(1-\theta)] \cdot dt, \tag{9}$$

- Maximization of utility subject to a standard budget constraint yields:

$$\dot{C}_1/C_1 = (1/\theta) \cdot (r_1 - \rho). \tag{10}$$

Innovation in country 1

- If γ_1 denotes the growth rate, then:

$$\gamma_1 = (1/\theta) \cdot (r_1 - \rho) = (1/\theta) \cdot (\pi_1/\eta_1 - \rho), \tag{11}$$

Imitation in country 2

- The form of the production function, equation 1, is the same in country 2 as in country 1.
- Country 2 is technologically behind initially in the sense that $N_2(0) < N_1(0)$.
- The parameters A_2 and L_2 and the innovation cost η_2 may differ from their counterparts in country 1.
- The copying and adaptation of one of country 1 's intermediates for use in country 2 requires a lump-sum outlay $\nu_2(t)$, where $\nu_2(0) < \eta_2$, so that imitation is initially more attractive than innovation for country 2.

Imitation

- A crucial assumption in the model is that the costs of imitation are nontrivial; that is, innovations cannot be transferred to other locations at negligible cost.
- Mansfield, Schwartz,and Wagner (1981) studied the cost of imitation in the United States for 48 product innovations that were made in the chemical, drug, electronics, and machinery industries.
- They found that the cost of imitation averaged 65 percent of the cost of innovation.

Imitation

- Griliches (1957) found in U.S. regional data that the time at which hybrid corn was introduced and the rate at which this innovation spread depended on measures of the cost of absorption and the eventual profitability of the new technology.
- The date of introduction tended to be sooner the more similar an area's preferred hybrids were to those developed initially in the corn belt (the location to which most of the early research on hybrid corn was directed).
- The rate of absorption was faster the greater the market size and the larger the potential improvement in crop yields.

Imitation

- Nelson and Phelps (1966) conjectured that the cost v_2 would be lower the more abundant human capital was in the receiving location.

Imitation in country 2

- Since we are assuming that the cost of innovation is constant, the discovery of new types of products do not encounter diminishing returns.
- As mentioned before, this assumption can be rationalized from the idea that the number of potential inventions is unbounded.
- Imitation differs from innovation in that the number of goods that can be copied at any point in time is limited to the finite number that have been discovered elsewhere.
- Specifically, country 2 can select for imitation only from the uncopied subset of the N1 goods that are known in country 1.

Imitation in country 2

- As N_2 increases relative to N_1, the cost of imitation is likely to rise. This property would hold, for example, if the products known in country 1 varied in terms of how costly they were to adapt for use in country 2.

- The goods that were easier to imitate would be copied first, and the cost v_2 that applied at the margin would increase with the number already imitated. This property is captured here by assuming that v_2 is an increasing function of N_1/N_2:

$$\nu_2 = \nu_2(N_2/N_1), \tag{12}$$

where $\nu_2' > 0$.[4]

Imitation in country 2

- For $N_1/N_2 < 1$, the imitation cost v_2 tends to be less than η_2 because copying is cheaper than discovery. But v_2 can exceed η_2 when $N_1/N_2 < 1$.

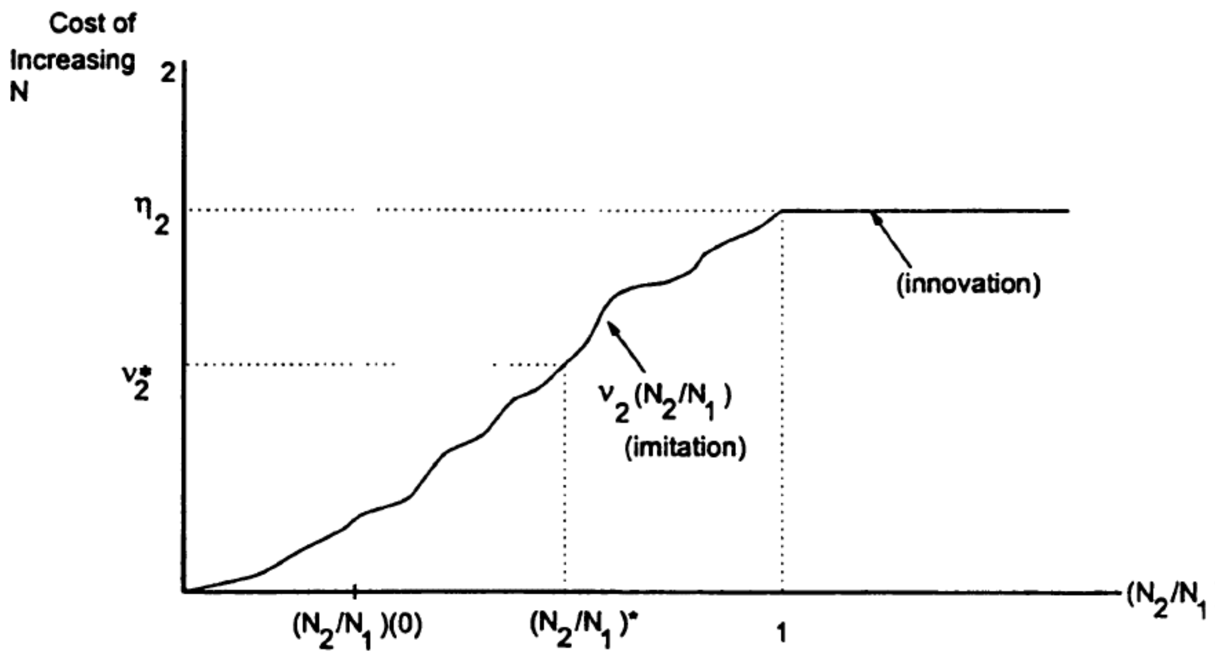

Figure 1. Cost of technological change in country 2 (for the environment in which $v_2^* < \eta_2$).

Imitation in country 2

- Suppose that an agent in country 2 pays $v_2(t)$ to imitate the jth variety of the intermediate from country 1 . We assume that this agent retains a perpetual monopoly right over the use of the intermediate for production in country 2.

- The monopoly price is then $P_{2j} = P_2 = 1/\alpha$

Imitation in country 2

- Moreover,

$$X_{2j} = X_2 = L_2 \cdot (A_2)^{1/(1-\alpha)} \cdot \alpha^{2/(1-\alpha)}, \tag{13}$$

$$Y_2 = (A_2)^{1/(1-\alpha)} \cdot \alpha^{2\alpha/(1-\alpha)} \cdot L_2 N_2, \tag{14}$$

$$\pi_{2j} = \pi_2 = (1-\alpha) \cdot L_2 \cdot (A_2)^{1/(1-\alpha)} \cdot \alpha^{(1+\alpha)/(1-\alpha)}. \tag{15}$$

The ratio of the per-worker products, y_i, for the two countries is

$$y_2/y_1 = (A_2/A_1)^{1/(1-\alpha)} \cdot (N_2/N_1). \tag{16}$$

Imitation in country 2

- The present value of profits from imitation of intermediate j in country 2 is

$$V_2(t) = \pi_2 \cdot \int_t^{\infty} \exp\left[-\int_t^{s} r_2(v) \cdot dv\right] \cdot ds, \tag{17}$$

- Here we have that

$$V_2(t) = \nu_2(N_2/N_1). \tag{18}$$

Imitation in country 2

- Substitution of the formula for $V_2(t)$ from equation 17 and differentiation of both sides of equation 18 with respect to time yields:

$$r_2 = \pi_2/v_2 + \dot{v}_2/v_2. \tag{19}$$

- If v_2 is rising, then the expanding value of the monopoly right implies a capital gain. This gain adds to the "dividend rate“.

Imitation in country 2

- Consumers

$$\dot{C}_2/C_2 = (1/\theta) \cdot (r_2 - \rho). \tag{20}$$

Steady state

- In the steady state, N_2 grows at the same rate as N_1, so that v_2 remains constant in accordance with 12. The ratio N_2/N_1 therefore equals a constant, denoted $(N_2/N_1)^*$. Assume for now that the parameters are such that $0<(N_2/N_1)^*<1$.
- In the steady state

$$\gamma_{Y_2} = \gamma_{C_2} = \gamma_{N_2} = \gamma_1 = \gamma_2$$

- Since $\gamma_{C_1} = \gamma_{C_2}$

$$r_2^* = r_1 = \pi_1/\eta_1, \tag{21}$$

Steady state

- Since $r_2^* = r_1$, equations 19 and 8 imply

$$\pi_2/\nu_2^* = \pi_1/\eta_1,$$

- Using the results for profits

$$\nu_2^* = \eta_1 \cdot (\pi_2/\pi_1) = \eta_1 \cdot (A_2/A_1)^{1/(1-\alpha)} \cdot (L_2/\mathrm{L}_1). \tag{22}$$

- The assumption, thus far, is that country 2 never chooses to innovate. This behavior is optimal for agents in country 2 if $v_2(t) < \eta_2$ applies along the entire path.

Steady state

- Since v_2 is an increasing function of N_2/N_1, the required condition is $v_2^* < \eta_2$, which implies from equation 22

$$(A_2/A_1)^{1/(1-\alpha)} \cdot (L_2/L_1) \cdot (\eta_1/\eta_2) < 1. \tag{23}$$

- In other words, country 2 has to be intrinsically inferior to country 1 in combination of productivity parameters, labor, and cost of innovating.
- If the inequality in 23 holds, then country 2 never has to innovate (because $v_2(t) < \eta_2$ applies throughout).

Steady state

- Since $(N_2/N_1)^* < 1$, equation 16 implies that the steady-state ratio of per-worker product, $(y_2/y_1)^*$, is less than one if $A_2 < A_1$.
- (Note that $A_2 > A_1$ can be consistent inequality in 23 if L2 < L1 or $\eta_2 > \eta_1$.)
- Thus, the follower country's per-worker output is likely to fall short of the leader's per- worker output even in the steady state. The potential to imitate therefore does not generally provide a strong enough force to equalize the levels of per- worker product in the long run.

Additional issues

- Foreign investment
- Capital imports