Advanced Economic Growth: Lecture 8, Technology Diffusion, Trade and Interdependencies: Diffusion of Technology

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Introduction I

- In the models thus far each country is treated as an "island"; its technology is either exogenous or endogenously generated within its boundaries.
- A framework in which *frontier* technologies are produced in advanced economies and then copied or adopted by "follower" countries provides a better approximation.
- Thus, should not only focus on differential rates of endogenous technology generation but on *technology adoption* and *efficient technology use*.
- Exogenous growth models have this feature, but technology is exogenous. Decisions in these models only concern investment in physical capital. In reality, technological advances at the world level are not "manna from heaven".

Introduction II

- Technology adoption involves many challenging features:
  1. Even within a single country, we observe considerable differences in the technologies used by different firms.
  2. It is difficult to explain how in the globalized world some countries may fail to import and use technologies.

Review: Productivity and Technology Differences within Narrow Sectors I

- Longitudinal micro-data studies (often for manufacturing): even within a narrow sector there are significant and persistent productivity differences across plants.
- Little consensus on the causes.
  - Correlation between plant productivity and plant or firm size, various measures of technology (in particular IT technology), capital intensity, the skill level of the workforce.
  - But these correlations cannot be taken to be causal.
- But technology differences appear to be an important factor.
- A key determinant seems to be the skill level of the workforce, though adoption of new technology does not typically lead to a significant change in employment structure.

Review: Productivity and Technology Differences within Narrow Sectors II

- Productivity differences appear to be related to the entry of new and more productive plants and the exit of less productive plants (recall Schumpeterian models).
- But entry and exit account for only about 25% of average TFP growth, with the remaining accounted for by continuing plants.
- Thus models in which firms continually invest in technology and productivity are important for understanding differences across firms and plants and also across countries.

Technology Diffusion I

- Despite technology and productivity differences among firms in similar circumstances, cross-sectional distributions of productivity and technology are not stationary.
- New and more productive technologies diffuse over time.
- Griliches's (1957) study of the adoption of hybrid corn in the US (findings confirmed by others):
  - Slow diffusion affected by local economic conditions.
  - Likelihood of adoption related to the contribution of the hybrid corn in a particular area, the market size and the skill level.
  - S-shape of diffusion.

Technology Diffusion II

- Important lessons:
  - Differences are not only present across countries, but also within countries.
  - Even within countries better technologies do not immediately get adopted by all firms.
- But note causes of within-country and cross-country productivity and technology differences might be different:
  - e.g., within-countries might be due to differences in managerial ability or to the success of the match between the manager and the technology.

Benchmark Model of Diffusion with Exogenous Growth I

- J countries, $j = 1, ..., J$.
- Aggregate production function in country j,

$$Y_j(t) = F(K_j(t), A_j(t) L_j(t)),$$

- F satisfies the standard neoclassical assumptions
- J is large enough so that each country is "small" relative to the rest of the world.
- Income per capita:

$$\begin{aligned} y_j(t) &\equiv \frac{Y_j(t)}{L_j(t)} \\ &= A_j(t) F\left(\frac{K_j(t)}{A_j(t) L_j(t)}, 1\right) \\ &\equiv A_j(t) f(k_j(t)), \end{aligned}$$

Benchmark Model of Diffusion with Exogenous Growth II

- Time is continuous.
- Population growth at the constant rate $n_j \geq 0$ in country j.
- Exogenous saving rate $s_j \in (0, 1)$.
- Depreciation rate of $\delta \geq 0$
- Law of motion of capital for each country:

$$\dot{k}_j(t) = s_j f(k_j(t)) - (n_j + g_j(t) + \delta) k_j(t), \tag{1}$$

where

$$g_j(t) \equiv \frac{\dot{A}_j(t)}{A_j(t)} \tag{2}$$

- $k_j(0) > 0$ and $A_j(0) > 0$ are exogenously given initial conditions.

Benchmark Model of Diffusion with Exogenous Growth III

- World's technology frontier, $A(t)$, grows exogenously at the constant rate:

$$g \equiv \frac{\dot{A}(t)}{A(t)} > 0,$$

with $A(0) > 0$.

- $A_j(t) \leq A(t)$ for all j and t.
- Each country's technology progresses as a result of *absorbing* the world's technological knowledge:

$$\dot{A}_j(t) = \sigma_j (A(t) - A_j(t)) + \lambda_j A_j(t), \quad (3)$$

where $\sigma_j \in (0, \infty)$ and $\lambda_j \in [0, g)$ for each $j = 1, ..., J$

- σ_j=*technology absorption* rate. Corresponds both to adoption and to *adaptation*

Benchmark Model of Diffusion with Exogenous Growth IV

- σ_j varies because of differences in human capital or other investments and also because of institutional or policy barriers affecting technology adoption.
- Formulation implies that:
  - Countries that are relatively "backward" will tend to grow faster, because they have more technology to absorb or more room for *catch-up* (Gerschenkron).
  - Technological progress can happen "locally" as well, building upon the knowledge stock of country j, $A_j(t)$, at rate λ_j
  - Despite globalization, technology transfer between countries is a slow:
    - ★ With $\sigma_j < \infty$, $A_j(t) < A(t)$ will imply that $A_j(t + \Delta t) < A(t + \Delta t)$, at least for $\Delta t > 0$ and sufficiently small.

Benchmark Model of Diffusion with Exogenous Growth V

- Define
$$a_j(t) \equiv \frac{A_j(t)}{A(t)}$$
- $a_j(t)$ is an inverse measure of the proportional technology gap between country j and the world or alternatively as an inverse measure of country j's *distance to the frontier*
- Thus:
$$\dot{a}_j(t) = \sigma_j - (\sigma_j + g - \lambda_j) a_j(t). \tag{4}$$
with $a_j(0) \equiv A_j(0) / A(0) > 0$.
- Dynamics are determined by $2J$ differential equations. For each j, we have one of (1) and one of (4).

Benchmark Model of Diffusion with Exogenous Growth VI

- *Block recursiveness* simplifies the analysis:
  - the law of motion of (4) for country j only depends on $a_j(t)$, so it can be solved without reference to the law of motion of $k_j(t)$ and to the law of motion of $\left\{k_{j'}(t), a_{j'}(t)\right\}_{j' \neq j}$.
  - Once (4) is solved, then (1) becomes a first-order nonautonomous differential equation in a single variable. Nonautonomous because it has $g_j(t)$ on the right-hand side, which can be determined as:

$$g_j(t) = \frac{\dot{a}_j(t)}{a_j(t)} + g.$$

Steady State Equilibrium I

- *World equilibrium*: allocation $\left\{ [k_j(t), a_j(t)]_{t \geq 0} \right\}_{j=1}^{J}$ such that (1) and (4) are satisfied for each $j = 1, ..., J$ and for all t, starting with the initial conditions $\{k_j(0), a_j(0)\}_{j=1}^{J}$.
- *Steady-state world equilibrium*: equilibrium with $\dot{k}_j(t) = \dot{a}_j(t) = 0$ for each $j = 1, ..., J$.
- The "steady-state equilibria" will exhibit constant growth, so also a *balanced growth path equilibria*.

Steady State Equilibrium II

Proposition In the above-described model, there exists a unique steady-state world equilibrium in which income per capita in all countries grows at the same rate $g > 0$. Moreover, for each $j = 1, ..., J$, we have

$$a_j^* = \frac{\sigma_j}{\sigma_j + g - \lambda_j}, \tag{5}$$

and k_j^* is uniquely determined by

$$s_j \frac{f\left(k_j^*\right)}{k_j^*} = n_j + g + \delta.$$

The steady-state world equilibrium $\left\{k_j^*, a_j^*\right\}_{j=1}^J$ is globally stable in the sense that starting with any strictly positive initial values $\left\{k_j(0), a_j(0)\right\}_{j=1}^J$, the equilibrium path $\left\{k_j(t), a_j(t)\right\}_{j=1}^J$ converges to $\left\{k_j^*, a_j^*\right\}_{j=1}^J$.

Steady State Equilibrium Characteristics

1. Unique steady-state world equilibrium that is globally stable.
2. Despite different saving and technology absorption rates, income per capita in all economies grows at the same rate of the world technology frontier, g (advantages of backwardness).
3. But differences in saving rates and absorption rates translate into *level differences*.
    - e.g, a society with a low σ_j will initially grow less, until it is sufficiently behind the world technology frontier to grow at the world rate, g.
4. Societies with low σ_j, λ_j and saving rates will be poorer.
5. There is no interaction among countries. Each country's steady-state income per capita (and path of income per capita) only depends on the world technology frontier and its own parameters.

Summary of Steady State Equilibrium

Proposition Let steady-state income per capita level of country j be $y_j^*(t) = \exp(gt)\, y_j^*$. Then y_j^* is increasing in σ_j, λ_j and s_j and decreasing in n_j and δ. It does not depend on $\sigma_{j'}, \lambda_{j'}$, $s_{j'}$ and $n_{j'}$ for any $j' \neq j$.

Consumer Optimization

- Representative household's preferences at time $t = 0$:

$$U_j = \int_0^\infty \exp\left(-\left(\rho - n_j\right)t\right)\left[\frac{\tilde{c}_j\left(t\right)^{1-\theta} - 1}{1-\theta}\right]dt, \tag{6}$$

  where $\tilde{c}_j\left(t\right) \equiv C_j\left(t\right)/L_j\left(t\right)$ and all countries have the same time discount rate, ρ.

- Flow resource constraint:

$$\dot{k}_j\left(t\right) = f\left(k_j\left(t\right)\right) - c_j\left(t\right) - \left(n_j + g_j\left(t\right) + \delta\right)k_j\left(t\right),$$

  where $c_j\left(t\right) \equiv \tilde{c}_j\left(t\right)/A_j\left(t\right) \equiv C_j\left(t\right)/A_j\left(t\right)L_j\left(t\right)$.

Summary of Consumer Optimization

Proposition Consider the above-described model with consumer optimization with preferences given by (6) and suppose that $\rho - n_j > (1-\theta) g$. Then, there exists a unique steady-state world equilibrium where for each $j = 1, ..., J$, a_j^* is given by (5) and k_j^* is uniquely determined by

$$f'\left(k_j^*\right) = \rho + \delta + \theta g,$$

and consumption per capita in each country grows at the rate $g > 0$.

Moreover, the steady-state world equilibrium is globally saddle-path stable in the sense that starting with any strictly positive initial values $\{k_j(0), a_j(0)\}_{j=1}^J$, initial consumption to effective labor ratios are $\{c_j(0)\}_{j=1}^J$ and the equilibrium path $\{k_j(t), a_j(t), c_j(t)\}_{j=1}^J$ converges to $\left\{k_j^*, a_j^*, c_j^*\right\}_{j=1}^J$.

The Role of Human Capital in Technology Diffusion I

- Nelson and Phelps and Ted Schultz: main role of human capital is not to increase productivity in existing tasks but in facilitating the adoption of new technologies.
- i.e., σ_j is an increasing function of the human capital of the workforce. Hence, high human capital societies will be richer.
- Implications are different than in Becker-Mincer approach, which accounts for role of human capital in the aggregate production function.

The Role of Human Capital in Technology Diffusion II

- Nelson-Phelps-Schultz view: the main role of human capital will be during technological change and in the process of technology adoption.
- But in this view it is unclear whether the contribution of human capital will be reflected in the wages: depends on whether the benefits are internalized or take the form of externalities.
- As in the Becker-Mincer approach, if there are significant external effects, many of the empirical strategies will understate the role of human capital.

Barriers to Technology Adoption

- Parente and Prescott: variant of the neoclassical growth model in which investments affect technology absorption, and countries differ in the "barriers" they place on firms in this process.
- Can be captured by interpreting σ_j as a function of property rights institutions or other institutional or policy features.
- This perspective is useful, but still unsatisfactory:
  1. Exactly how these institutions affect technology adoption is left as a black box.
  2. Why some societies choose to create barriers against technology adoption while others do not is left unexplained.

Technology Diffusion and Endogenous Growth: Exogenous World Growth Rate I

- Endogenous technological change model with expanding machine variety and lab equipment specification.
- Aggregate production function of economy $j = 1, ..., J$ at time t:

$$Y_j(t) = \frac{1}{1-\beta}\left[\int_0^{N_j(t)} x_j(v,t)^{1-\beta} dv\right] L_j{}^{\beta}, \tag{7}$$

- L_j is constant over time, x's depreciate fully after use.
- Each variety in economy j is owned by a technology monopolist; sells machines embodying this technology at the profit maximizing (rental) price $\chi_j(v,t)$.
- Monopolist can produce each unit of the machine at a cost of $\psi \equiv 1-\beta$ units on the final good.

Technology Diffusion and Endogenous Growth: Exogenous World Growth Rate II

- No international trade, so firms in country j can only use technologies supplied by technology monopolists in their country.
- Each country admits a representative household with the same preferences as before except $n_j = 0$ for all j.
- Resource constraint for each country:

$$C_j(t) + X_j(t) + \zeta_j Z_j(t) \leq Y_j(t), \tag{8}$$

- ζ_j: potential source of differences in the cost of technology adoption across countries (institutional barriers as in Parente and Prescott, subsidies to R&D and to technology, or other tax policies).

Technology Diffusion and Endogenous Growth: Exogenous World Growth Rate III

- *Innovation possibilities frontier*:

$$\dot{N}_j(t) = \eta_j \left(\frac{N(t)}{N_j(t)} \right)^{\phi} Z_j(t), \tag{9}$$

where $\eta_j > 0$ for all j, and $\phi > 0$ and is common to all economies.

- World technology frontier of varieties expands at an exogenous rate $g > 0$, i.e.,

$$\dot{N}(t) = gN(t). \tag{10}$$

- Flow profits of a technology monopolist at time t in economy j:

$$\pi_j(t) = \beta L_j.$$

Steady State Equilibrium I

- Suppose a steady-state (balanced growth path) equilibrium exists in which $r_j(t)$ is constant at $r_j^* > 0$. Then the net present discounted value of a new machine is:

$$V_j^* = \frac{\beta L_j}{r_j^*}.$$

- If the steady state involves the same rate of growth in each country, then $N_j(t)$ will also grow at the rate g, so that $N_j(t)/N(t)$ will remain constant, say at ν_j^*.

Steady State Equilibrium II

- In that case, an additional unit of technology spending will create benefits equal to $\eta_j \left(\nu_j^*\right)^{-\phi} V_j^*$ counterbalanced against the cost of ζ_j. Free-entry (with positive activity) then requires

$$\nu_j^* = \left(\frac{\eta_j \beta L_j}{\zeta_j r^*}\right)^{1/\phi}, \tag{11}$$

where given the preferences, equal growth rate across countries implies that r_j^* will be the same in all countries ($r^* = \rho + \theta g$).

Steady State Equilibrium III

- Higher ν_j implies that country j is technologically more advanced and thus richer
- Thus (11) shows that countries with higher η_j and lower ζ_j, will be more advanced and richer.
- A country with a greater labor force will also be richer (scale effect): more demand for machines, making R&D more profitable.

Summary of Equilibrium

Proposition Consider the model with endogenous technology adoption described in this section. Suppose that $\rho > (1-\theta)\, g$. Then there exists a unique steady-state world equilibrium in which relative technology levels are given by (11) and all countries grow at the same rate $g > 0$.

Moreover, this steady-state equilibrium is globally saddle-path stable, in the sense that starting with any strictly positive vector of initial conditions $N(0)$ and $(N_1(0), \ldots, N_J(0))$, the equilibrium path of $(N_1(t), \ldots, N_J(t))$ converges to $(\nu_1^* N(t), \ldots, \nu_J^* N(t))$.

Technology Diffusion and Endogenous Growth: Endogenous World Growth Rate I

- More satisfactory to derive the world growth rate from the technology adoption and R&D activities of each country.
- Modeling difficulties:
  - Degree of interaction among countries is now greater.
  - More care needed so that the world economy grows at a constant endogenous rate, while there are still forces that ensure relatively similar growth rates across countries. Modeling choice:
    - ★ Countries grow at permanently different long run rates, e.g. to approximate long-run growth differences of the past 200 or 500 years
    - ★ Countries grow at similar rates, e.g. like the past 60 years or so.
- Since long-run differences emerge straightforwardly in many models, focus here on forces that will keep countries growing at similar rates.

Technology Diffusion and Endogenous Growth: Endogenous World Growth Rate II

- Replace the world growth equation (10) with:

$$N(t) = \frac{1}{J} \sum_{j=1}^{J} N_j(t). \tag{12}$$

- $N(t)$ is no longer the "world technology frontier": it represents average technology in the world, so $N_j(t) > N(t)$ for at least some j.
- Disadvantage of the formulation: contribution of each country to the world technology is the same. But qualitative results here do not depend on this.
- Main result: pattern of cross-country growth will be similar to that in the previous model, but the growth rate of the world economy, g, will be endogenous, resulting from the investments in technologies made by firms in each country.

Steady State Equilibrium I

- Suppose there exists a steady-state world equilibrium in which each country grows at the rate g.
- Then, (12) implies $N(t)$ will also grow at g.
- The net present discounted value of a new machine in country j is

$$\frac{\beta L_j}{r^*},$$

- No-arbitrage condition in R&D investments: for given g, each country j's relative technology, ν_j^*, should satisfy (11).

Steady State Equilibrium II

- Dividing both sides of (12) by $N(t)$ implies that in the steady-state world equilibrium:

$$\begin{aligned} \frac{1}{J}\sum_{j=1}^{J}\nu_j^* &= 1 \\ \frac{1}{J}\sum_{j=1}^{J}\left(\frac{\eta_j \beta L_j}{\zeta_j(\rho+\theta g)}\right)^{1/\phi} &= 1, \end{aligned} \tag{13}$$

  which uses ν_j^* from (11) and substitutes for r^* as a function of the world growth rate.
- The only unknown in (13) is g.
- Moreover, the left-hand side is clearly strictly decreasing in g, so it can be satisfied for at most one value of g, say g^*.

Steady State Equilibrium IIII

- A well-behaved world equilibrium would require the growth rates to be positive and not so high as to violate the transversality condition. The following condition is necessary and sufficient for the world growth rate to be positive:

$$\frac{1}{J}\sum_{j=1}^{J}\left(\frac{\eta_j \beta L_j}{\zeta_j \rho}\right)^{1/\phi} > 1. \tag{14}$$

- By usual arguments, when this condition is satisfied, there will exist a unique $g^* > 0$ that will satisfy (13) (if this condition were violated, (13) would not hold, and we would have $g = 0$ as the world growth rate).

Summary of Steady State Equilibrium

Proposition Suppose that (14) holds and that the solution g^* to (13) satisfies $\rho > (1-\theta)\, g^*$. Then there exists a unique steady-state world equilibrium in which growth at the world level is given by g^* and all countries grow at this common rate. This growth rate is endogenous and is determined by the technologies and policies of each country. In particular, a higher η_j or L_j or a lower ζ_j for any country $j = 1, ..., J$ increases the world growth rate.

Steady State Equilibrium Remarks

1. Taking the world growth rate given, the structure of the equilibrium is very similar to that beore.
2. The same model now gives us an "endogenous" growth rate for the world economy. Growth for each country appears "exogenous", but the growth rate of the world economy is endogenous.
3. Technological progress and economic growth are the outcome of investments by all countries in the world, but there are sufficiently powerful forces in the world economy through technological spillovers that pull relatively backward countries towards the world average, ensuring equal long-run growth rates for all countries in the long run.
4. Equal growth rates are still consistent with *large level differences* across countries.
5. Several simplifying assumptions:
    1. Same discount rates.
    2. Only described the steady-state equilibrium. Transitional dynamics are now more complicated, since the "block recursiveness" of the dynamical system is lost.

Main Lessons I

1. We can make considerable progress in understanding technology and productivity differences across nations by positing a slow process of technology transfer across countries.
2. It seems reasonable to assume that technologically backward economies will only slowly catch up to those at the frontier.
3. An important element of models of technology diffusion is that they create a built-in advantage for countries (or firms) that are relatively behind
4. This catch-up advantage for backward economies ensures that models of slow technology diffusion will lead to differences in income levels, not necessarily in growth rates.
5. Thus a study of technology diffusion enables us to develop a model of world income distribution, whereby the position of each country in the world income distribution is determined by their ability to absorb new technologies from the world frontier.

Main Lessons II

6. This machinery is also useful in enabling us to build a framework in which, while each country may act as a neoclassical exogenous growth economy, importing its technology from the world frontier, the entire world behaves as an endogenous growth economy, with its growth rate determined by the investment in R&D decisions of all the firms in the world.
7. Technological interdependences across countries implies that we should often consider the world equilibrium, not simply the equilibrium of each country on its own.