

14.461: Technological Change, Lecture 9

Productivity Differences Across Countries

Daron Acemoglu

MIT

October 7 2011.

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.

Simple Model of Technology Diffusion: Exogenous World Growth Rate

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

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

- 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 (continued)

- 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:

$$C_j(t) + X_j(t) + \zeta_j Z_j(t) \leq Y_j(t), \quad (2)$$

- 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 (continued)

- *Innovation possibilities frontier:*

$$\dot{N}_j(t) = \eta_j \left(\frac{N(t)}{N_j(t)} \right)^\phi Z_j(t), \quad (3)$$

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.,

$$\dot{N}(t) = gN(t). \quad (4)$$

- 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 v_j^* .

Steady State Equilibrium II

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

$$v_j^* = \left(\frac{\eta_j \beta L_j}{\zeta_j r^*} \right)^{1/\phi}, \quad (5)$$

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 (5) 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 (5) 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 $(N_1(0), \dots, N_J(0))$, the equilibrium path of $(N_1(t), \dots, N_J(t))$ converges to $(\nu_1^* N(t), \dots, \nu_J^* N(t))$.

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 (4) with:

$$N(t) = \frac{1}{J} \sum_{j=1}^J N_j(t). \quad (6)$$

- $N(t)$ 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, (6) 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, v_j^* , should satisfy (5).

Steady State Equilibrium II

- Dividing both sides of (6) by $N(t)$ implies that in the steady-state world equilibrium:

$$\frac{1}{J} \sum_{j=1}^J v_j^* = 1$$

$$\frac{1}{J} \sum_{j=1}^J \left(\frac{\eta_j \beta L_j}{\zeta_j (\rho + \theta g)} \right)^{1/\phi} = 1, \quad (7)$$

which uses v_j^* from (5) and substitutes for r^* as a function of the world growth rate.

- The only unknown in (7) 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:

$$\frac{1}{J} \sum_{j=1}^J \left(\frac{\eta_j \beta L_j}{\zeta_j \rho} \right)^{1/\phi} > 1. \quad (8)$$

- By usual arguments, when this condition is satisfied, there will exist a unique $g^* > 0$ that will satisfy (7) (if this condition were violated, (7) would not hold, and we would have $g = 0$ as the world growth rate).

Summary of Steady State Equilibrium

Proposition Suppose that (8) holds and that the solution g^* to (7) 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 $j = 1, \dots, J$ increases the world growth rate.

Remarks

- ① Taking the world growth rate given, the structure of the equilibrium is very similar to that before.
- 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: same discount rates and focus on steady-state equilibria (transitional dynamics are now more complicated, since the “block recursiveness” of the dynamical system is lost).

Appropriate and Inappropriate Technologies and Productivity Differences

- Why does rapid diffusion of ideas not remove all, or at least most, cross-country technology differences?
- “Technology” differences and income gaps can remain substantial even with free flow of ideas because technologies of the world technology frontier may be *inappropriate* to the needs of specific countries.
- Technologies and skills consist of bundles of complementary attributes that vary across countries
- Three versions of this story. Appropriateness stemming from differences in:
 - ① exogenous (e.g., geographic) conditions,
 - ② capital intensity,
 - ③ skill intensity.

Inappropriate Technologies. Example: Health Innovations

- Productivity in country j at time t , $A_j(t)$, is a function of whether there are effective cures against certain diseases affecting their populations.
- Two different diseases, heart attack and malaria.
- $j = 1, \dots, J'$ are affected by malaria and not by heart attacks.
- $j = J' + 1, \dots, J$ are affected by heart attacks, not malaria.
- If the disease affecting country j has no cure, $A_j(t) = \underline{A}$.
- When a cure is introduced, $A_j(t) = \bar{A}$.
- A new cure against heart attacks is discovered and becomes freely available to all countries.
- Productivity in countries $j = J' + 1, \dots, J$ increases from $\underline{A}$ to $\bar{A}$, but productivity in countries $j = 1, \dots, J'$ remains at $\underline{A}$.

Inappropriate Technologies

- Technologies of the world frontier may be “inappropriate” to the needs of some of the countries (the J' countries).
- A technological advance that is freely available to all increases productivity in a subset of the countries and creates cross-country income differences.
- Could issues of the sort be important? Yes and no:
 - Over 90% of the world R&D is carried out in OECD economies; technologies should be optimized for the conditions in OECD countries.
 - But, other than the issue of disease, there are not many obvious *fixed* country characteristics that will create this type of “inappropriateness”.
 - The issue is much more likely to be important in the context of whether new technologies will function well at different *factor intensities*.

Capital-Labor Ratios and Inappropriate Technologies I

- Atkinson and Stiglitz (1969): technological change shifts isoquants (increasing productivity) at a given capital-labor ratio.
- Technological changes are localized for specific capital-labor ratios:
 - e.g, discovery that favors firm that is using a type of tractor with a single worker can be used by any other firm employing the same tractor with a single worker, but not by firms using oxen or less (or even more) advanced tractors.
- Implications for cross-country income differences: technologies developed for high capital-intensive production processes in OECD countries may be of little use to labor-abundant less-developed economies (Basu and Weil, 1998).

Capital-Labor Ratios and Inappropriate Technologies II

- Production technology for all countries in the world:

$$Y = A(k | k') K^{1-\alpha} L^{\alpha},$$

- Output per worker:

$$y \equiv \frac{Y}{L} = A(k | k') k^{1-\alpha},$$

where $k = K/L$.

- $A(k | k')$ is the (total factor) productivity of technology designed to be used with k' when used instead with k .
- Suppose that

$$A(k | k') = A \min \left\{ 1, \left(\frac{k}{k'} \right)^{\gamma} \right\}$$

for some $\gamma \in (0, 1)$.

Capital-Labor Ratios and Inappropriate Technologies III

- New technologies developed in richer economies, with greater k .
- Productivity in country with capital-labor ratio $k < k'$ will be

$$y = A(k | k') k^{1-\alpha} = A k^{1-\alpha+\gamma} (k')^{-\gamma}. \quad (9)$$

- (9) implies less-developed countries will be less productive even when producing with the same techniques.
- Moreover this productivity disadvantage will be larger when the gap between k and k' is greater.
- Might be important for understanding cross-country income differences:
 - With $\alpha \approx 2/3$, an economy with $k' = 8k$ would only be twice as rich, when there is no issue of inappropriate technologies.
 - But if $\gamma = 2/3$, the difference would be eightfold.

Endogenous Technological Change and Appropriate Technology I

- The evidence discussed before suggests differences in human capital may be particularly important in the adoption of technology.
- Moreover, the past 30 years have witnessed the introduction of skill-biased technologies.
- A mismatch between the skill requirements of frontier technologies and skills of workers in less-developed countries may be more important than differences in capital intensity.
- Model here emphasizes implications of this mismatch, uses ideas of directed technical change, and provides tractable multi-sector growth model (Acemoglu and Zilibotti, 2001).

Endogenous Technological Change and Appropriate Technology II

- Two groups of countries, North and South.
- Two types of workers, skilled and unskilled.
- Two differences between North and South:
 - 1 All R&D and new innovations take place in the North; the South copies. Because of lack of intellectual property rights in the South, the main market of new technologies will be Northern firms.
 - 2 The North is more skill-abundant:

$$H^n / L^n > H^s / L^s,$$

- Many Northern and many Southern countries.
- No population growth.

Endogenous Technological Change and Appropriate Technology III

- All countries have access to the same set of technologies; no issue of slow technology diffusion, all differences in productivity arise from mismatch between technology and skills.
- All economies admit a representative household with the standard preferences with $n_j = 0$ for all countries.
- The final good in each country is produced as:

$$Y_j(t) = \exp \left[\int_0^1 \ln y_j(i, t) di \right] \quad (10)$$

- Total output is spent on $C_j(t)$, $X_j(t)$, and also in the North on $Z_j(t)$.

Endogenous Technological Change and Appropriate Technology IV

- Technology for producing intermediate i in country j at time t :

$$y_j(i, t) = \frac{1}{1-\beta} \left[\int_0^{N_L(t)} x_{L,j}(i, v, t)^{1-\beta} dv \right] [(1-i)l_j(i, t)]^\beta (11) \\ + \frac{1}{1-\beta} \left[\int_0^{N_H(t)} x_{H,j}(i, v, t)^{1-\beta} dv \right] [i\omega h_j(i, t)]^\beta.$$

- where:

- $l_j(i, t)$ =unskilled workers working in intermediate i in country j at time t , and $h_j(i, t)$ is defined similarly.
- $x_{L,j}(i, v)$ =machines of type v used with unskilled workers, and $x_{H,j}(i, v)$ is defined similarly.
- $N_L(t)$ and $N_H(t)$ =number of machine varieties available to be used with skilled and unskilled workers.

Endogenous Technological Change and Appropriate Technology V

- Note:
 - Intermediates can be produced using two alternative technologies, one using skilled and the other using unskilled.
 - Pattern of *cross-industry comparative advantage*: skilled (unskilled) workers relatively more productive in higher (lower) indexed intermediates.
 - Skilled workers have an *absolute advantage*, captured $\omega > 1$.
 - $N_L(t)$ and $N_H(t)$ not indexed by j : all technologies are available to all countries.
- Final good sectors and the labor markets are competitive.

Endogenous Technological Change and Appropriate Technology VI

- A technology monopolist produces machines at marginal cost ψ and sets prices $p_{L,j}^x(\nu, t)$ and $p_{H,j}^x(\nu, t)$.
- These prices do not depend on i , since machines are not sector-specific, but skill-specific.
- Profit maximization by the final good producers leads to the demands for machines:

$$x_{L,j}(i, \nu, t) = \left[p_j(i, t) ((1-i)l_j(i, t))^\beta / p_{L,j}^x(\nu, t) \right]^{1/\beta},$$

$$x_{H,j}(i, \nu, t) = \left[p_j(i, t) (i\omega h_j(i, t))^\beta / p_{L,j}^x(\nu, t) \right]^{1/\beta},$$

where $p_j(i, t)$ = relative price of intermediate i in country j at time t in terms of the final good (the numeraire in each country).

Endogenous Technological Change and Appropriate Technology VII

- In each Southern economy a “technology” firm adopts the new technology invented in the North (at no cost) and acts as the monopolist supplier of that machine for the producers in its own country.
- The marginal cost of producing machines for this firm is the same as the inventor in the North ($\psi = 1 - \beta$).
- Symmetry between the North and the South: price and thus demand for machines will take the same form in all countries.
- Thus output in sector i in any country j is:

$$y_j(i, t) = \frac{1}{1 - \beta} p_j(i, t)^{(1-\beta)/\beta} [N_L(t) (1 - i) l_j(i, t) + N_H(t) i \omega h_j(i, t)] \quad (12)$$

- For each economy, $N_L(t)$ and $N_H(t)$ are the state variables.

Endogenous Technological Change and Appropriate Technology: Threshold sector

Proposition In any country j , given the world technologies $N_L(t)$ and $N_H(t)$, there will exist a threshold $l_j(t) \in [0, 1]$ such that skilled workers will be employed only in sectors $i > l_j(t)$, that is, for all $i < l_j(t)$, $h_j(i, t) = 0$, and for all $i > l_j(t)$, $l_j(i, t) = 0$.

Moreover, prices and labor allocations across sectors will be such that: for all $i < l_j(t)$, $p_j(i, t) = P_{L,j}(t) (1 - i)^{-\beta}$ and $l_j(i, t) = L_j / l_j(t)$, while for all $i > l_j(t)$, $p_j(i, t) = P_{H,j}(t) i^{-\beta}$ and $h_j(i, t) = H_j / (1 - l_j(t))$ where the positive numbers $P_{L,j}(t)$ and $P_{H,j}(t)$ can be interpreted as the price indices for labor-intensive and skill-intensive intermediates.

Endogenous Technological Change and Appropriate Technology VIII

- The technology for the final goods sector in (10) implies:

$$\frac{P_{H,j}(t)}{P_{L,j}(t)} = \left(\frac{N_H(t) \omega H_j / (1 - l_j(t))}{N_L(t) L_j / l_j(t)} \right)^{-\beta}. \quad (13)$$

- The threshold sector $l_j(t)$ in country j at time t is indifferent between using skilled and unskilled workers (and technologies) for production, thus

$$P_{L,j}(t) (1 - l_j(t))^{-\beta} = P_{H,j}(t) l_j(t)^{-\beta}$$

- Combining with (13):

$$\frac{P_{H,j}(t)}{P_{L,j}(t)} = \left(\frac{N_H(t)}{N_L(t)} \frac{\omega H_j}{L_j} \right)^{-\beta/2}, \quad (14)$$

Endogenous Technological Change and Appropriate Technology IX

- Equilibrium threshold $l_j(t)$ is uniquely pinned down by

$$\frac{l_j(t)}{1 - l_j(t)} = \left(\frac{N_H(t) \omega H_j}{N_L(t) L_j} \right)^{-1/2}. \quad (15)$$

- Combining, total output in economy j is:

$$Y_j(t) = \exp(-\beta) \left[(N_L(t) L_j)^{1/2} + (N_H(t) \omega H_j)^{1/2} \right]^2, \quad (16)$$

- And the skill premium:

$$\frac{w_{H,j}(t)}{w_{L,j}(t)} = \omega \left(\frac{N_H(t)}{N_L(t)} \right)^{1/2} \left(\frac{\omega H_j}{L_j} \right)^{-1/2} \quad (17)$$

- (16) shows the multi-sector model leads to allocation so that output is identical to that given a constant elasticity of substitution production function with elasticity of substitution equal to 2.

Endogenous Technological Change and Appropriate Technology X

- More generally: by changing the pattern of comparative advantage of skilled and unskilled workers in different sectors, one can obtain aggregate production functions of any elasticities of substitution.
- The type of technologies, $N_L(t)$ and $N_H(t)$, will impact economies with different factor proportions differently.
- For example, consider the case $H^S = 0$. Then an increase in $N_H(t)$ will increase productivity in the North, but will have no effect in the South.
- In general: an increase in $N_H(t)$ relative to $N_L(t)$ will benefit the skill-abundant North more than the skill-scarce South.
- Conversely, an increase in $N_L(t)$ will tend to benefit Southern economies relatively more.

Endogenous Technological Change and Appropriate Technology X

- Since new technologies are developed in the North and there are no intellectual property rights for Northern R&D in the South, new technologies will be developed—*designed*—for the North.
- Suppose the simplest version of the directed technical change model (with the lab equipment specification) and:

$$\dot{N}_L(t) = \eta Z_L(t) \text{ and } \dot{N}_H(t) = \eta Z_H(t), \quad (18)$$

where η_L and η_H have been set equal to each other.

Summary of Endogenous Technological Change and Appropriate Technology

Proposition The unique steady-state equilibrium involves:

$$\frac{P_H^n}{P_L^n} = \left(\frac{\omega H^n}{L^n} \right)^{-\beta}$$

$$\frac{N_H^*}{N_L^*} = \frac{\omega H^n}{L^n}. \quad (19)$$

Moreover, in the North the threshold sector satisfies

$$\frac{1 - I^{n*}}{I^{n*}} = \frac{\omega H^n}{L^n}$$

and the skill premium is

$$\frac{w_H^{n*}}{w_L^{n*}} = \omega.$$

This steady-state equilibrium is globally saddle path stable.

Directed Technical Change I

- To understand the implications of directed technical change for equilibrium relative technologies N_L and N_H , define:

- *Net output* in country j :

$$NY_j \equiv Y_j - X_j,$$

- *Income per capita* and *income per effective unit of labor* in different countries:

$$y_j \equiv \frac{Y_j}{L_j + H_j} \text{ and } y_j^{\text{eff}} \equiv \frac{Y_j}{L_j + \omega H_j}.$$

- All of these quantities are functions of labor supplies and of relative technologies, N_H / N_L .

Directed Technical Change II

Proposition Consider the above-described model. Then:

The steady-state equilibrium technology ratio N_H^*/N_L^* is such that, given a constant level of for given $N_H + N_L$, it achieves the unique maximum of net output in the North, NY^n , as a function of relative technology N_H/N_L .

At the steady-state equilibrium technology ratio N_H^*/N_L^* , we have $y_n > y_s$ and $y_n^{eff} > y_s^{eff}$.

Directed Technical Change III

- ① The steady-state equilibrium technology is appropriate for the needs of the North; research firms are targeting Northern markets. Moreover, since there is a unique maximum of NY_n (given $N_H + N_L$), NY_s will *not* be maximized by N_H^* / N_L^* .
- ② Technologies are inappropriate for the needs of the South. Hence, income per capita and income per effective units of labor in the North will be higher than in the South.
- ③ The process of directed technical change, combined with import of frontier technologies to less-developed economies, creates an advantage for the more advanced economies and acts as a force towards greater cross-country inequality.
- ④ This source of cross-country income differences can be quite substantial in practice (Acemoglu and Zilibotti, 2001)

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.

Main Lessons II

- 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.
- 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.

Conclusions (continued) I

- ① Once we allow a relatively rapid diffusion of technologies, does there remain any reason for technology or productivity differences across countries (beyond differences in physical and human capital)? Yes: “appropriateness” of technologies and barriers to technological change.
- ② There are reasons to suspect that technology-skill mismatch may be more important, because of the organization of the world technology market. Two features are important:
 - ① The majority of frontier technologies are developed in a few rich countries.
 - ② The lack of effective intellectual property rights enforcement implies that technology firms in rich countries target the needs of their own domestic market.

Conclusions (continued) II

- ③ Thus new technologies will be “too skill-biased” and this source of inappropriateness of technologies can create a large endogenous technology and income gap among nations.
- ④ Productivity differences also stem because production is organized differently around the world: a key reason for is institutions and policies in place in different parts of the world.
- ⑤ What types of contracts firms can write with their suppliers, can have an important effect on their technology adoption decisions and thus on cross-country differences on productivity.
- ⑥ But contracting institutions are only one of many potential organizational differences across countries that might impact upon equilibrium productivity.