Advanced Macroeconomics
10. Determinants of Total Factor Productivity

Karl Whelan

School of Economics, UCD

Spring 2021

Part I

The Romer Model and New Technologies

TFP Growth as Invention of New Inputs

- Solow model identified total factor productivity (TFP) as the key determinant of growth in the long run.
- What determines the technology term A?
- Paul Romer (1990) provided a specific view with aggregate production as

$$Y = L_Y^{1-\alpha}\left(x_1^\alpha + x_2^\alpha + ... + x_A^\alpha\right) = L_Y^{1-\alpha}\sum_{i=1}^{A} x_i^\alpha$$

  where L_Y is the number of workers and the x_i's are different capital goods.
- Crucial feature is diminishing marginal returns applies, not to capital as a whole, but separately to each of the individual capital goods (because $0 < \alpha < 1$).
- If A was fixed, the pattern of diminishing returns would mean that growth would eventually taper off. But in the Romer model, A is not fixed.

Labour and Capital

- There are L_A workers engaged in Research and Development leading to the invention of new capital goods and an increase in A each period.
- The total labour force is

$$L = L_A + L_Y$$

- Workers either produce goods or do research to invent new goods.
- To simplify the production function, we can define the aggregate capital stock as the sum of all the different capital inputs

$$K = \sum_{i=1}^{A} x_i$$

- We can assume that the demand from producers for each of these capital goods is the same and that this demand $\bar{x}$ is

$$x_i = \bar{x} \qquad i = 1, 2, ...A$$

- This means that the production function can be written as

$$Y = AL_Y^{1-\alpha}\bar{x}^{\alpha}$$

Growth in the Romer Model

- Note now that
$$K = A\bar{x} \Rightarrow \bar{x} = \frac{K}{A}$$
- So output can be re-expressed as
$$Y = AL_Y^{1-\alpha}\left(\frac{K}{A}\right)^{\alpha} = (AL_Y)^{1-\alpha} K^{\alpha}$$
- This looks just like the Solow model's production function.
- The TFP term is written as $A^{1-\alpha}$ as opposed to just A but this does not affect the substance of the model.
- In this model, TFP growth comes from the invention of new technologies.
- Without new technologies, additional capital accumulation would be subject to diminishing marginal returns and growth would grind to a halt.
- New technologies means that additional capital accumulated can be spread across a wider amount of inputs and there is continuous ongoing growth.

Production of Inventions

- Romer's model of economic growth driven by new technologies.
- Full paper looks at why new technologies are invented:
  - Researchers work at trying to invent new technologies so that, when successful, they can make monopoly profits on their new inventions.
- Process of invention has a sort of "production function for ideas":

$$\frac{dA}{dt} = \gamma L_A^{\lambda} A^{\phi}$$

- Change in the number of capital goods depends positively on the number of researchers and on the prevailing value of A itself.
- λ is an index of diminishing marginal productivity for researchers.
- The effect of current A stems from the "giants shoulders" effect.
  - For instance, the invention of a new piece of software will have relied on the previous invention of the relevant computer hardware, which itself relied on the previous invention of semiconductor chips, and so on.

Assumptions about Workers

- Assumes workers can move freely between the output and research sectors.
- There is a common wage across both sectors.
- This means the marginal return to a worker in the research sector ends up being the same as the marginal return to a worker in the output sector.
- Because of diminishing marginal returns to labour, this implies a downward-sloping demand curve for labour.
- The equal marginal returns across sectors determines how may workers are employed in each sector.
    - If something raises the productivity of workers in the research sector, this sector will hire more workers until diminishing marginal productivity of these workers brings their marginal product back in line with the marginal product in the output sector.

Trade-offs in the Romer Model

1. **Present versus Future**:
   - Governments could incentivise people to go into education and research with the hope of inventing new technologies that will raise productivity over time.
   - However, these people will then not be producing goods and services, so it means lower output today.
2. **Competition versus Growth**:
   - In general, Romer's model points to outcomes in which there is too little R&D activity.
   - People who invent a great new product can influence future inventions but usually do not receive the full stream of profits from these future inventions.
   - Laws to strengthen patent protection may raise the incentives to conduct R&D.
   - This points to a potential conflict between policies aimed at raising macroeconomic growth and microeconomic policies aimed at reducing the inefficiencies due to monopoly power.

Past and Future of New Technologies

- Many of the facts about economic history back up Romer's model.
- Robert Gordon's paper (on the website) provides an excellent description of the various phases of technological invention.

1. **First Industrial Revolution (1750-1830)**
    - Inventions of the steam engine and cotton gin, lead to railroads and steamships. Took 150 years to have full impact.
2. **Second Industrial Revolution (1870-1900)**
    - Electric light, internal combustion engine, fresh running water to urban homes, sewers.
    - Telephone, radio, records, movies, electric machinery, consumer appliances, cars. The latter lead to suburbs, supermarkets, highways.
    - "Follow-up" inventions continued like television and air conditioning.
3. **Third Industrial Revolution (since 1960s)**
    - Electronic mainframe computers, 1960s.
    - Invention of the web and internet around 1995.

Gordon on the Second Industrial Revolution

- Gordon believes that the inventions of the "second industrial revolution" made the biggest differences to standards of living.
- He describes life in 1870 as follows

  "*most aspects of life in 1870 (except for the rich) were dark, dangerous, and involved backbreaking work. There was no electricity in 1870. The insides of dwelling units were not only dark but also smoky, due to residue and air pollution from candles and oil lamps. The enclosed iron stove had only recently been invented and much cooking was still done on the open hearth. Only the proximity of the hearth or stove was warm; bedrooms were unheated and family members carried warm bricks with them to bed.*"

  But the biggest inconvenience was the lack of running water. Every drop of water for laundry, cooking, and indoor chamber pots had to be hauled in by the housewife, and wastewater hauled out. The average North Carolina housewife in 1885 had to walk 148 miles per year while carrying 35 tonnes of water."

Gordon's Thought Experiment

- To illustrate why he believes modern inventions don't match up with past improvements in terms of their ability to generate genuine improvements in living standards, Gordon offers the following thought experiment.

  "*You are required to make a choice between option A and option B. With option A you are allowed to keep 2002 electronic technology, including your Windows 98 laptop accessing Amazon, and you can keep running water and indoor toilets; but you can't use anything invented since 2002.*"

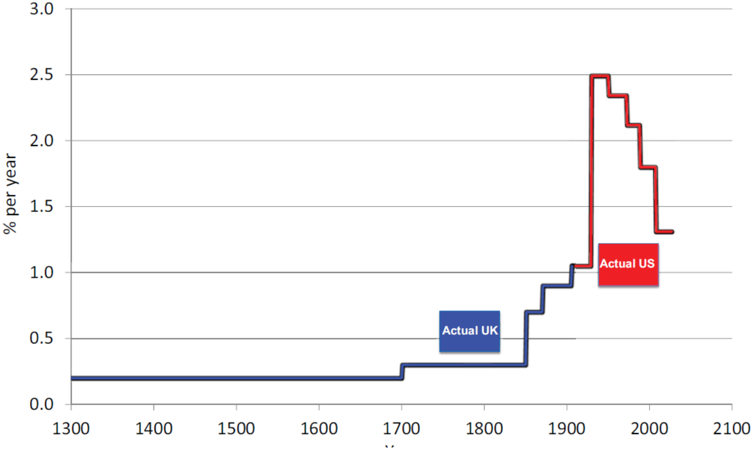
  "*Option B is that you get everything invented in the past decade right up to Facebook, Twitter, and the iPad, but you have to give up running water and indoor toilets. You have to haul the water into your dwelling and carry out the waste. Even at 3am on a rainy night, your only toilet option is a wet and perhaps muddy walk to the outhouse. Which option do you choose?*"

- You probably won't be surprised to find out that most people pick option A.
- As a fan of iPads and Twitter (not Facebook ...) I'm thankful we don't have to make the choice!

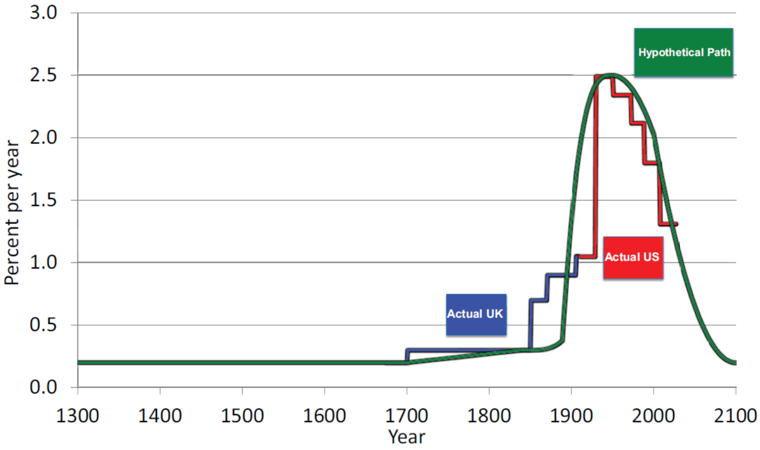
Gordon on Future Growth

- Gordon believes that the technological innovations associated with computer technologies are far less important than those associated with the "second industrial revolution" and that growth may sputter out over time.
- The next slide repeats a chart from Gordon's paper showing the growth rate of per capita GDP for the world's leading economies (first the UK, then the US). It shows growth accelerating until 1950 and declining thereafter.
- The slide after shows a hypothetical chart in which Gordon projects a continuing fall-off in growth.
- Gordon also discusses other factors likely to holdback growth in leading countries - leveling off of educational achievement, an aging population and energy-related constraints.
- We should note, however, that economists are not very good at forecasting the invention of new technologies or their impact!
- Joel Mokyr's article "Is technological progress a thing of the past?" (linked to on the website) is a good counterpart to Gordon's scepticism.

Gordon on the Growth Rate of Leading Economies



Gordon's Hypothetical Path for Growth



Part II

Cross-Country Patterns

Cross-Country Differences in Output Per Worker

- The Romer model shows how the invention of new technologies promotes economic growth.
- However, only a very few countries in the world are "on the technological frontier".
- One way to illustrate this is to estimate the level of TFP for different countries.
- An important paper that did these calculations is by Hall and Jones (1999).
- The basis of the study is a "levels accounting" exercise starting from a production function

$$Y_i = K_i^{\alpha} \left(h_i A_i L_i \right)^{1-\alpha}$$

- Hall and Jones account for the effect of education on labour productivity.
- They construct measures of *human capital* based on estimates of the return to education—this is the h_i in the above equation.

Hall and Jones

- Hall and Jones show that their production function can be re-formulated as

$$\frac{Y_i}{L_i} = \left(\frac{K_i}{Y_i}\right)^{\frac{\alpha}{1-\alpha}} h_i A_i$$

- h_i estimated using evidence on educational levels and they set $\alpha = 1/3$.
- This allowed them to express all cross-country differences in output per worker in terms of three multiplicative terms: capital intensity (i.e. $\frac{K_i}{Y_i}$), human capital per worker, and technology or total factor productivity.
- They found that output per worker in the richest five countries was 31.7 times that in the poorest five countries.
- This was explained as follows:
    - Differences in capital intensity contributed a factor of 1.8.
    - Differences in human capital contributed a factor of 2.2
    - The remainder—a factor of 8.3—was due to differences in TFP.

Table from Hall-Jones Paper

TABLE I
PRODUCTIVITY CALCULATIONS: RATIOS TO U. S. VALUES

Country	Y/L	Contribution from $(K/Y)^{\alpha/(1-\alpha)}$	H/L	A
United States	1.000	1.000	1.000	1.000
Canada	0.941	1.002	0.908	1.034
Italy	0.834	1.063	0.650	1.207
West Germany	0.818	1.118	0.802	0.912
France	0.818	1.091	0.666	1.126
United Kingdom	0.727	0.891	0.808	1.011
Hong Kong	0.608	0.741	0.735	1.115
Singapore	0.606	1.031	0.545	1.078
Japan	0.587	1.119	0.797	0.658
Mexico	0.433	0.868	0.538	0.926
Argentina	0.418	0.953	0.676	0.648
U.S.S.R.	0.417	1.231	0.724	0.468
India	0.086	0.709	0.454	0.267
China	0.060	0.891	0.632	0.106
Kenya	0.056	0.747	0.457	0.165
Zaire	0.033	0.499	0.408	0.160
Average, 127 countries:	0.296	0.853	0.565	0.516
Standard deviation:	0.268	0.234	0.168	0.325
Correlation with Y/L (logs)	1.000	0.624	0.798	0.889
Correlation with A (logs)	0.889	0.248	0.522	1.000

The elements of this table are the empirical counterparts to the components of equation (3), all measured as ratios to the U. S. values. That is, the first column of data is the product of the other three columns.

Leaders and Followers

- Romer model mainly relevant to most advanced economies.
- Most technologies get used all around the world, not just where invented.
- Suggests a model in which ability to learn about the usage of new technologies should play a key role in determining output per worker.
- Assume that there is a "lead" country with technology, A_t at time t growing at rate g every period
$$\frac{dA_t}{dt} = gA_t$$
- All other countries in the world, indexed by j, have technology levels given by $A_{jt} < A_t$.
- The growth rate of technology in country j is determined by
$$\frac{dA_{jt}}{dt} = \lambda_j A_{jt} + \sigma_j \left(A_t - A_{jt} \right)$$
where $\lambda_j < g$ and $\sigma_j > 0$.

Growth in Follower Countries

Technology growth in the follower country is

$$\frac{dA_{jt}}{dt} = \lambda_j A_{jt} + \sigma_j \left(A_t - A_{jt} \right)$$

where $\lambda_j < g$ and $\sigma_j > 0$.Technology growth in follower countries is determined by two factors

- - **Learning**: technology level will grow faster the bigger the percentage gap between its level of technology, A_{jt} and the level of the leader, A_t. Larger σ_j means the better the country is at learning from the the lead country.
  - **Invention**: The first term, λ_j indicates the country's capacity for increasing its level of technology without learning from the leader.
- We assume $\lambda_j < g$. This means that country j can't grow faster than the lead country without the learning that comes from having lower technology than the frontier.

The Model's Solution

- Characterising how A_{jt} behaves over time requires solving differential equations which are not part of this course.
- The solution to this model shows that A_{jt} gradually converges over time to

$$A_{jt} = \left(\frac{\sigma_j}{\sigma_j + g - \lambda_j} \right) A_t$$

- So each country never actually catches up to the leader but instead converges to some fraction of the lead country's technology level.
- Because they are slower at developing technologies ($\lambda_j < g$), the follower countries can't over-take the leader country.
- However, they can grow faster than their own rate of technological invention as long as there is a gap between them and the leader.
- They converge towards growing at the same rate g as the leader but maintain GDP that is a constant percentage lower than that of the leader.

Implications

- Because $g - \lambda_j > 0$, this means that

$$\frac{d}{d\sigma_j}\left(\frac{\sigma_j}{\sigma_j + g - \lambda_j}\right) > 0$$

- The long-run ratio of the country's technology to the leader's depends positively on the "learning parameter" σ_j. higher this parameter, the closer the ratio gets to one and the higher up the "pecking order" the country gets.
- In addition, the more growth the country can generate each period independent of learning, the higher will be its equilibrium ratio of technology relative to the leader.

$$\frac{d}{d\lambda_j}\left(\frac{\sigma_j}{\sigma_j + g - \lambda_j}\right) > 0$$

- This model can account for "growth miracles': If a country can increase σ_j (e.g. by education policy), the economy may grow rapidly as its position in the steady-state distribution of income moves upwards substantially.

Transition Paths

- To be more precise, we can show that the solution behaves according to

$$\frac{A_{jt}}{A_t} = \frac{\sigma_j}{\sigma_j + g - \lambda_j} + \frac{D_{j0}}{A_t} e^{-(\sigma_j + g - \lambda_j)t}$$

  where e is the exponential number 2.718...

- This second term tends to disappear to zero over time but that doesn't mean it's unimportant. How a country behaves along its "transition path" depends on the value of an arbitrary parameter D_{j0} that determines the economy's initial position.
- If $D_{j0} < 0$, then the term that is disappearing over time is a negative term that is a drag on the level of technology. This means that the country starts out below its equilibrium technology ratio and grows faster than the leader for some period of time.
- If $D_{j0} > 0$, then the term that is disappearing over time is a positive term that is boosting the level of technology. This means that the country starts out above its equilibrium technology ratio and grows slower than the leader for some period of time.

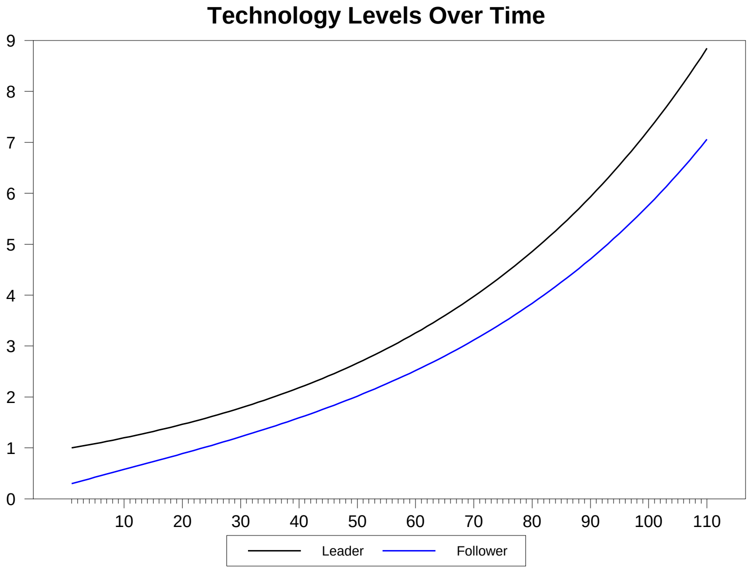
Illustrating Transition Dynamics

- The charts on the next six pages illustrate how these dynamics work.
- They charts show model simulations for a leader economy with $g = 0.02$ and a follower economy with $\lambda_j = 0.01$ and $\sigma_j = 0.04$. These values mean

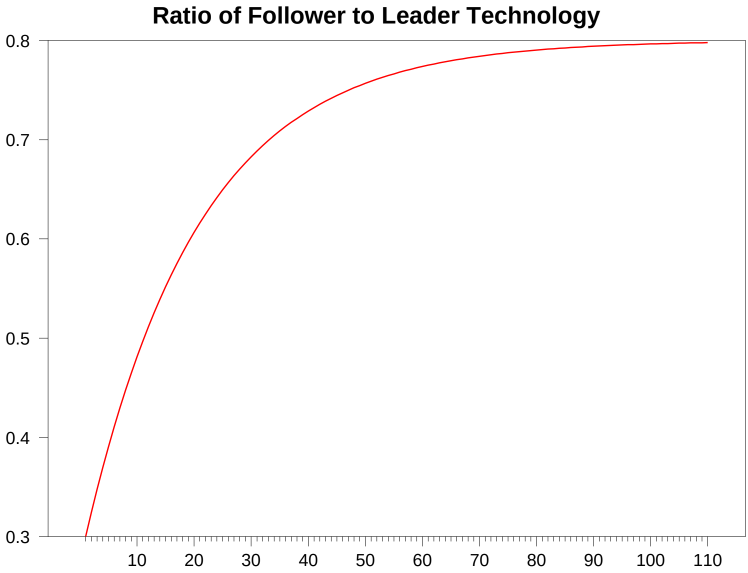
$$\frac{\sigma_j}{\sigma_j + g - \lambda_j} = \frac{0.04}{0.04 + 0.02 - 0.01} = 0.8$$

  so the follower economy converges to a level of technology that is 20 percent below that of the leader.
- The first three charts show what happens when this economy has a value of $D_{j0} = -0.5$, so that it starts out with a technology level only 30 percent that of the leader.
- The second three charts show what happens when this economy has a value of $D_{j0} = 0.5$, so that it starts out with a technology level 30 percent above that of the leader, even though the equilibrium value is 20 percent below.

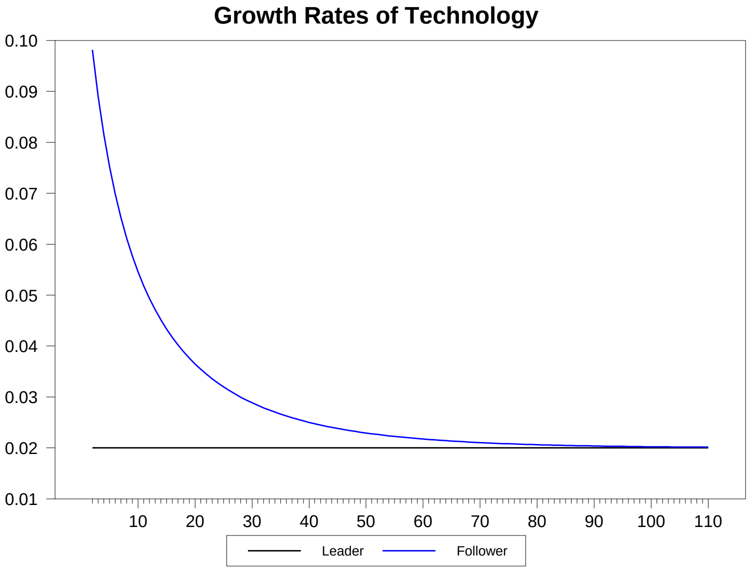
Follower Starts Out Below Equilibrium Technology Ratio



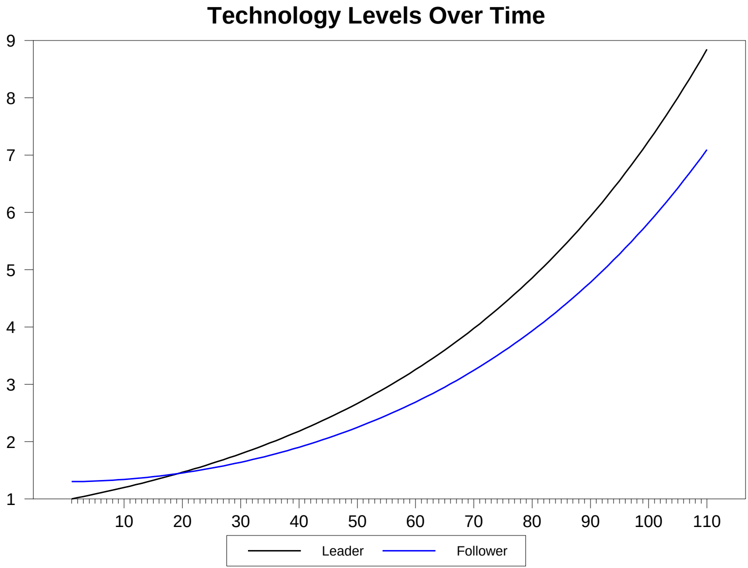
Follower Starts Out Below Equilibrium Technology Ratio



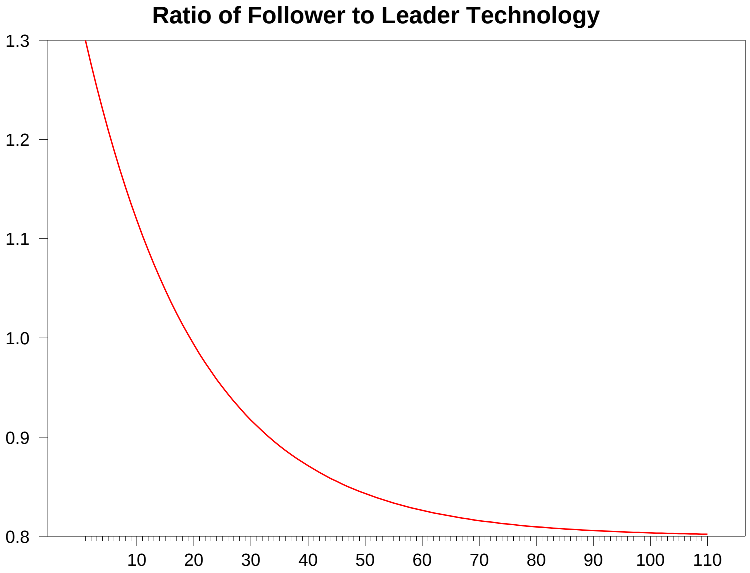
Follower Starts Out Below Equilibrium Technology Ratio



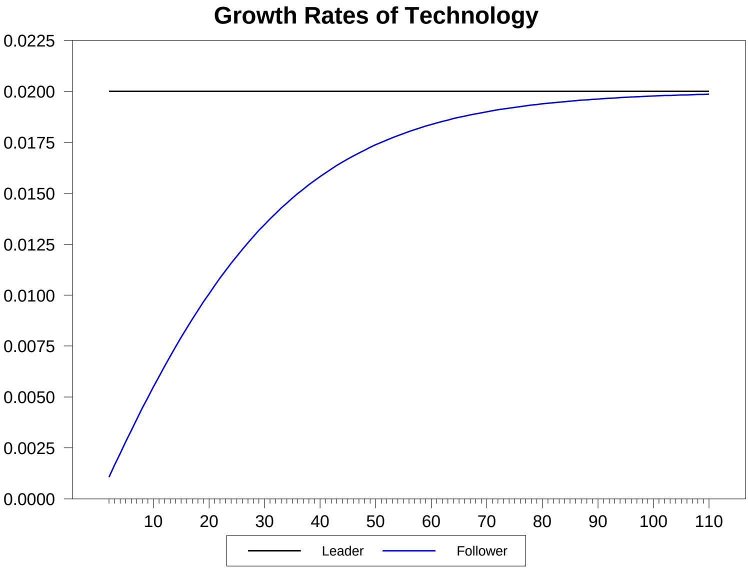
Follower Starts Out Above Equilibrium Technology Ratio



Follower Starts Out Above Equilibrium Technology Ratio



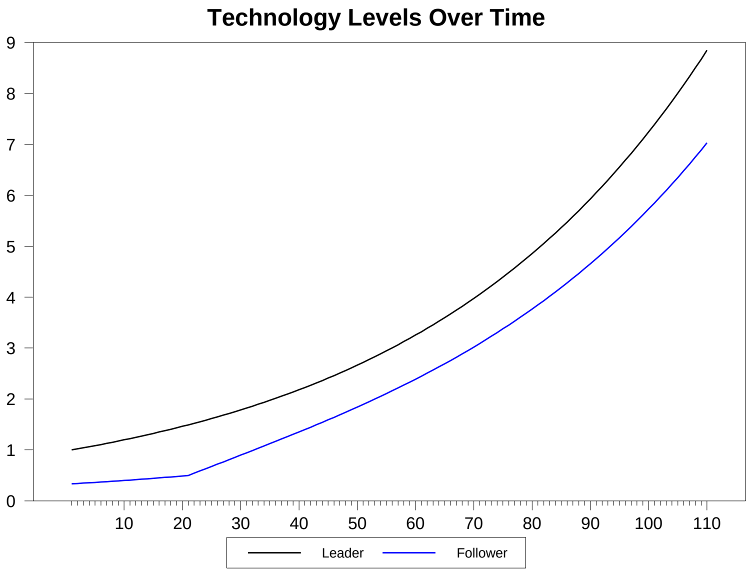
Follower Starts Out Above Equilibrium Technology Ratio



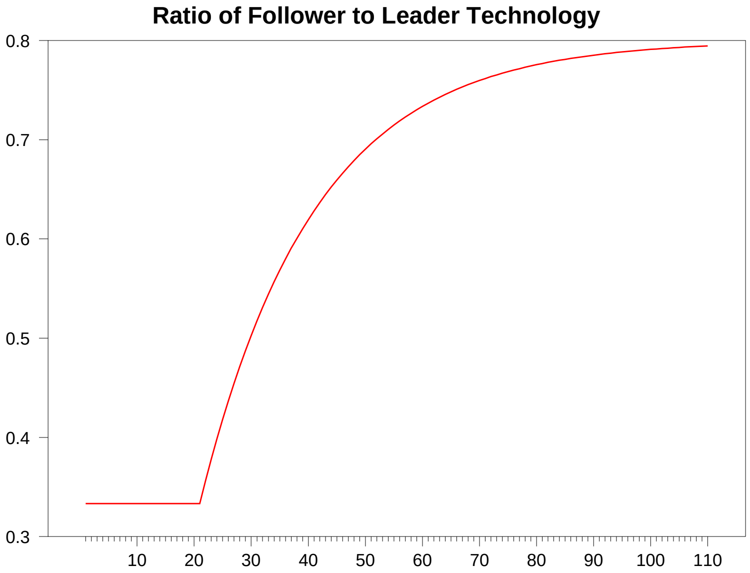
Growth Miracles

- Finally, we show how the model may also be able to account for the sort of "growth miracles" that are occasionally observed when countries suddenly start experiencing rapid growth.
- If a country can increase its value of σ_j via education or science-related policies, its position in the steady-state distribution of income may move upwards substantially, with the economy then going through a phase of rapid growth.
- The next three charts show what happens when, in period 21, an economy changes from having $\sigma_j = 0.005$ to $\sigma_j = 0.04$. The equilibrium technology ratio changes from one-third to 0.8 and the economy experiences a long transitional period of rapid growth.
- An important message from this model is that for most countries, it is not their ability to invent new capital goods that is key to high living standards, but rather their ability to learn from those countries that are more technologically advanced.

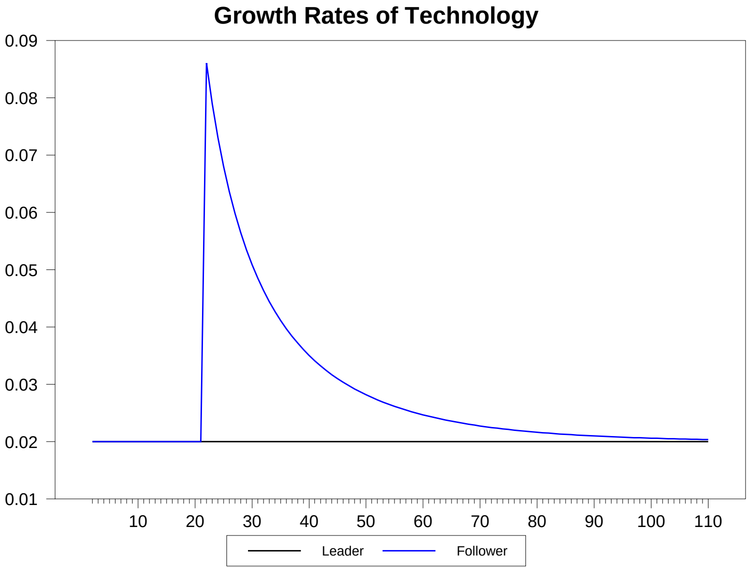
An Increasing in the Rate of Learning



An Increasing in the Rate of Learning



An Increasing in the Rate of Learning



Part III

Institutions

A Broader View of TFP

- The leaders-followers model views large differences as reflecting the extent to which countries have adopted the latest technologies.
- However, this is perhaps too mechanistic a view of what generates cross-country differences in efficiency.
- TFP measures how efficiently an economy use of its resources. There are a whole range of other factors that can affect this. For example:
    - **Bureaucratic Inefficiency and Corruption**: Red tape and bribing of officials can be important diversions of resources in poor economies.
    - **Crime**: Time spent on crime does not produce output. Neither do resources devoted to protecting inviduals and firms from crime.
    - **Restrictions on Market Mechanisms**: Protectionism, price controls, and central planning can all lead to resources being allocated in an inefficient manner.
- In addition, while technology adoption certainly has an impact on differences in TFP, this still leaves open the question of what drives the pace of technology adoption in poorer countries. Ultimately, the models so far don't answer the question of the *deeper determinants* of economic success.

Douglass North on Institutions

- There is now a large literature that focuses on the idea that differences in *institutions* provides the key to understanding TFP differences across countries.
- Economic activity does not take place in a vacuum. Firms need to take account of the legal and regulatory environment, the tax system, and the services provided by government as well as the political setting that determines these institutions.
- The work of economic historian Douglass North, winner of the 1993 Nobel prize for economics, was particularly influential in stressing the key importance of good institutions for economic growth.
- The historical approach adopted by North and other economic historians has been very valuable in highlighting cases where good institutions have facilitated economic growth and where bad institutions have prevented it.
- I have put a link on the webpage to a short paper by North "Institutional Change: A Framework of Analysis."

North on Institutions

- From the North paper on the website:
- *"A theory of institutional change is essential for further progress in the social sciences in general and economics in particular. Essential because neo-classical theory (and other theories in the social scientist's toolbag) at present cannot satisfactorily account for the very diverse performance of societies and economies both at a moment of time and over time. The explanations derived from neo-classical theory are not satisfactory because, while the models may account for most of the differences in performance between economies on the basis of differential investment in education, savings rates, etc., they do not account for why economies would fail to undertake the appropriate activities if they had a high payoff. Institutions determine the payoffs. While the fundamental neo-classical assumption of scarcity and hence competition has been robust (and is basic to this analysis), the assumption of a frictionless exchange process has led economic theory astray. Institutions are the structure that humans impose on human interaction and therefore define the incentives that (together with the other constraints (budget, technology, etc.) determine the choices that individuals make that shape the performance of societies and economies over time."*

North on Institutions

- *"Institutions consist of formal rules, informal constraints (norms of behavior, conventions, and self imposed codes of conduct) and the enforcement characteristics of both ... If institutions are the rules of the game, organizations are the players. They are groups of individuals engaged in purposive activity. The constraints imposed by the institutional framework (together with the other constraints) define the opportunity set and therefore the kind of organizations that will come into existence ... If the highest rates of return in a society are to be made from piracy, then organizations will invest in knowledge and skills that will make them better pirates; if organizations realize the highest payoffs by increasing productivity then they will invest in skills and knowledge to achieve that objective."*

An Example of the Importance of Institutions: Korea

- After World War II, Korea was split into a northern zone that became the Democratic People's Republic of Korea, a Soviet-style socialist republic, while South Korea became a capitalist economy.
- North Korea received external support from the USSR for many years but no longer receives external aid. It remains a centrally planned economy with only one political party. The economy has failed to prosper and there are reliable reports of large amounts of death from famine in the 1990s.
- In contrast, South Korea has been a huge economic success and is home to many globally successful corporations such as Samsung and Hyundai.
- The figure on the next page illustrates the gap between North and South Korea.
- While the two areas began with few substantive differences, sharing a common culture and identity, their different economic institutions mean that they are now completely different.
- Viewed from the sky, you can see development all over South Korea while North Korea is almost fully dark because of a lack of electricity.

The Korean Peninsula at Night

An Econometric Approach

- There is a large literature on the link between institutions and economic performance using econometric methods.
- Hall and Jones (1999) estimate a cross-country regression of the form

$$\frac{Y_i}{L_i} = \alpha + \beta S_i + \epsilon_i$$

  where $\frac{Y}{L}$ is output per worker in country i and S_i is a variable that aims to measure the extent to which institutions in country i facilitate economic activity.
- HJ constructed S_i variable as an average of two different variables:
  1. An "index of government antidiversion policies". This is an average of five different variables relating to (i) law and order (ii) bureaucratic quality (iii) corruption (iv) risk of expropriation, and (v) government repudiation of contracts.
  2. An index that focuses on the openness of a country to trade with other countries

Two Econometric Problems

- **Endogeneity**: Do countries get rich because they have good institutions or do countries have good institutions because they are rich? If the latter is true, so that there is a relationship like

$$S_i = \gamma + \delta \frac{Y_i}{L_i} + \theta X_i + \eta_i$$

  then OLS regression of $\frac{Y_i}{L_i}$ on S_i gives a positive estimate of β even if the true value is zero.

- **Measurement Error**. The variables used as measures of institutional quality are only proxies for the true measure of institutional quality that actually affects economic output. This is effectively measurement error and this result in downward bias in coefficients, so OLS coefficient might be less than the true coefficient.

- So the presence of these econometric problems means OLS estimation will produce biased estimates, though whether the bias is upwards or downwards depends on the source of the bias.

A Solution? Instrumental Variables

- The usual solution to these econometric problems is estimation via instrumental variables.
- This means estimating β from

$$\frac{Y_i}{L_i} = \alpha + \beta \hat{S}_i + \epsilon_i$$

  where $\hat{S}_i$ is the fitted value from a regression of S on a set of instruments i.e. exogenous variables that may be correlated with the institutions variable but are not affected by the country's level of output per worker.
- By focusing on variations in institutions related to exogenous factors that are not determined by output per worker, the researcher can try to identify the true causal effect of institutions.
- But where to find good instruments?

History and Geography as a Source of Instruments

- Researchers focused on either *geography* or *history* as their inspiration for truly exogenous sources of variations in institutions.
  - **Geography** is certainly exogenous—it is not influenced by a country's level of prosperity. But certain types of geographical features may be correlated with whether a country has good institutions or not. Hall and Jones used the country's distance from the equator as an instrument.
  - **History**: Many countries around the world were colonised by various European countries and their current institutions are often determined, in a somewhat random fashion, by which countries colonised them. Hall and Jones used instruments measuring the fraction of people speaking English as a native language and a variable measuring the fraction of people speaking other Western European languages.
- HJ found a positive and significant effect of their "social infrastructure" variable when estimating using IV methods, with the coefficient being higher than the OLS estimate. They concluded that there is a causal effect from institutions to productivity and that the measurement error is a more important source of bias than is endogeneity.

Other Papers

- **Acemoglu, Johnson, and Robinson (2001)** develop a new instrument measuring settler mortality in different European colonies. Argue that countries where mortality for initial settlers was low were places where Europeans were more likely to settle and set up good institutions, with the reverse working when settler mortality was high. Using this instrument, they find a strong effect of "risk of expropriation" on output per capita.
- **Rodrik, Subramanian and Trebbi (2004)** assess the role of institutions (proxied by a variable measuring the strength of the rule of law), openness to trade and geography (as measured by distance from the equator). Use variables such as the AJR settler mortality variable and language-related variables, as instruments. Conclude that institutions, in the form of their rule of law variable, are the key determinant of economic success and do not find a significant role for trade or geography.
- **Gillanders and Whelan (2014)** compare the effect of the Rule of Law variable with a variable that measures the "ease of doing business". Apply IV methods using geographical variables as instruments. Conclude that ease of doing business that is the key determinant of output per capita rather than Rule of Law variable.

Things to Understand from this Topic

- The Romer model's production function.
- The Romer model's interpretation of total factor productivity.
- Policy trade-offs suggested by the Romer model.
- Robert Gordon on the history and future of technological innovation.
- The assumptions of the leader-follower model.
- The properties of the solution to the leader-follower model.
- How non-technological factors influence total factor productivity.
- Douglass North on institutions.
- How Korea illustrates the importance of institutions.
- Hall and Jones's approach to assessing the links between institutions and economic success.
- The econometric problems that Hall and Jones confronted and their findings.
- Findings of other papers in this literature.