THE EVOLUTION OF TECHNOLOGY DIFFUSION AND THE GREAT DIVERGENCE

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EXECUTIVE SUMMARY

New technologies disseminate increasingly rapidly from rich to poor countries but poor countries struggle to employ these technologies with the same degree of intensity and versatility. This suggests that the potential for technological leap-frogging is over-hyped. The challenge for poor countries is to invest in the right kinds of knowledge so that imported technologies can be more effectively harnessed and adapted for productive use.

INTRODUCTION

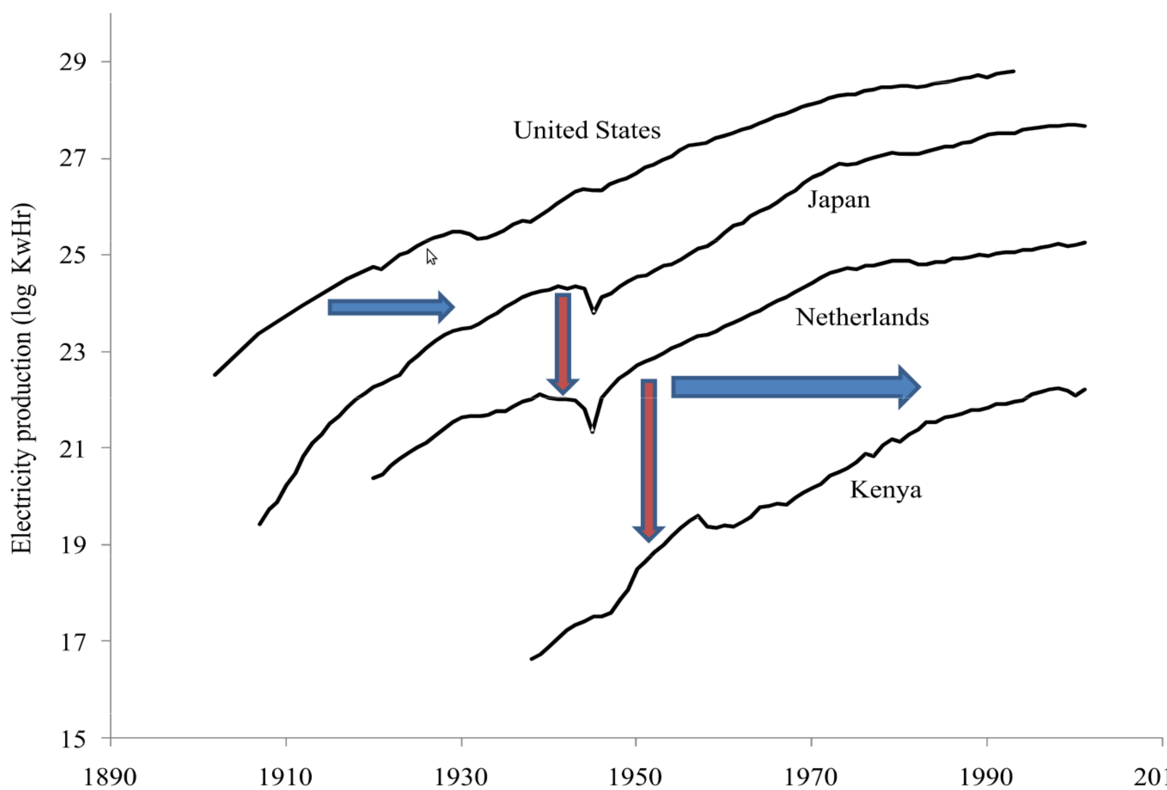
Two-hundred years ago, cross-country differences in income were relatively small. European countries and Western offshoots, so-called Western countries, were on average 90 percent richer than the rest.[1] By 2000, this income gap had grown to 750 percent. This cross-country divergence in income is the so-called **Great Divergence**. Most economic studies of long-run development have tried to relate current income differences to pre-determined factors, such as genetic endowments, cultural differences, climate and institutions.[2] Typically, these studies regress current income per capita on the proposed pre-determined drivers, finding high correlations. However, these exercises are not very informative about the mechanisms by which the dramatic cross-country differences in income have emerged or about the timing of the divergence. In particular, since their explanatory factors were largely determined in 1800, they cannot account for the fact that income differences were small in 1800 but large today.

In what follows I first describe research I have conducted with Marti Mestieri that shows that the cross-country evolution of income over the last 200 years can be explained by differences in the evolution of the processes of technology diffusion across countries. In the second part of this article, I use this evidence to conjecture what factors may have induced the changes in the process of technology diffusion and whether there is any evidence that technology leap-frogging can narrow the income differences between developed and developing economies.

THE EVOLUTION OF TECHNOLOGY DIFFUSION

Before exploring how technology diffusion has changed, we should reflect on what dimensions of the process of diffusion of technologies are important for productivity growth. I argue that there are at least two components of the diffusion process that are relevant. A first component is related to the range of technologies used, or equivalently to the lag with which new technologies are adopted. New technologies embody higher productivity. Therefore, an acceleration in the rate at which new technologies arrive in the country raises aggregate productivity growth. Productivity is also affected by the penetration rate of new technologies. After controlling for the effect of income on the demand for technologies, the more units of new technology a country uses, the higher the number of workers that can benefit from the productivity gains brought by the new technology. Thus, increases in the penetration rate of technology (or as we call it below, the intensive margin of adoption) also raise the growth rate of productivity.

Figure 1: The Diffusion of Electricity Production across Countries



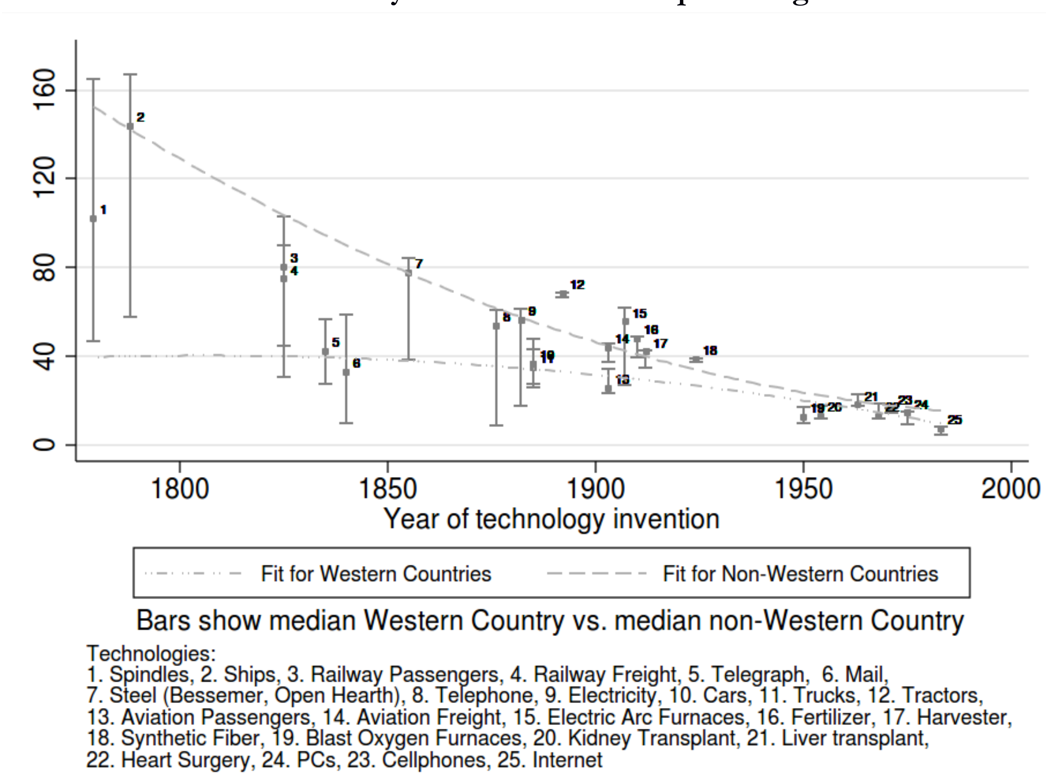
Adoption lags and long-run penetration rates of technologies can be measured through the vertical and horizontal distances of the diffusion curves (See Figure 1.)[3] Intuitively, the horizontal shifter informs us about when the technology was introduced in the country. The vertical shifter captures the penetration rate the technology will attain when it has fully diffused.

It is important to make two technical remarks about our estimates. First, the trend in the intensive margin is not a reflection of the fact that developed economies have richer consumers that demand more goods and services since our measurement of the intensive margin of adoption filters this effect out. Second, to estimate the long-run penetration rate we do not need to have observed the complete diffusion process.

Using the CHAT data set,[4] we identify the extensive and intensive adoption margins for 25 significant technologies invented over the last 200 years in an (unbalanced) sample that covers 132 countries. Then, we use our estimates to study the cross-country evolution of these two adoption margins.

We uncover two empirical patterns which are presented in Figures 2 and 3. To present these patterns, Figure 2 plots, for each of the 25 technologies, the median adoption lags for the developed and for the developing countries against the year of invention of the technology. The figure shows that adoption lags for old technologies such as spindles or the steam and motor ships were very long everywhere, but they were much longer in non-Western than in Western countries.

Figure 2: Evolution of Cross-Country Distribution of Adoption Lags



Over the last 200 years, the gap in the adoption lags between developed and developing countries has narrowed continuously. This convergence in adoption lags has been so dramatic that recent technologies such as cell-phone or internet have arrived within very few years to developed and developing countries.

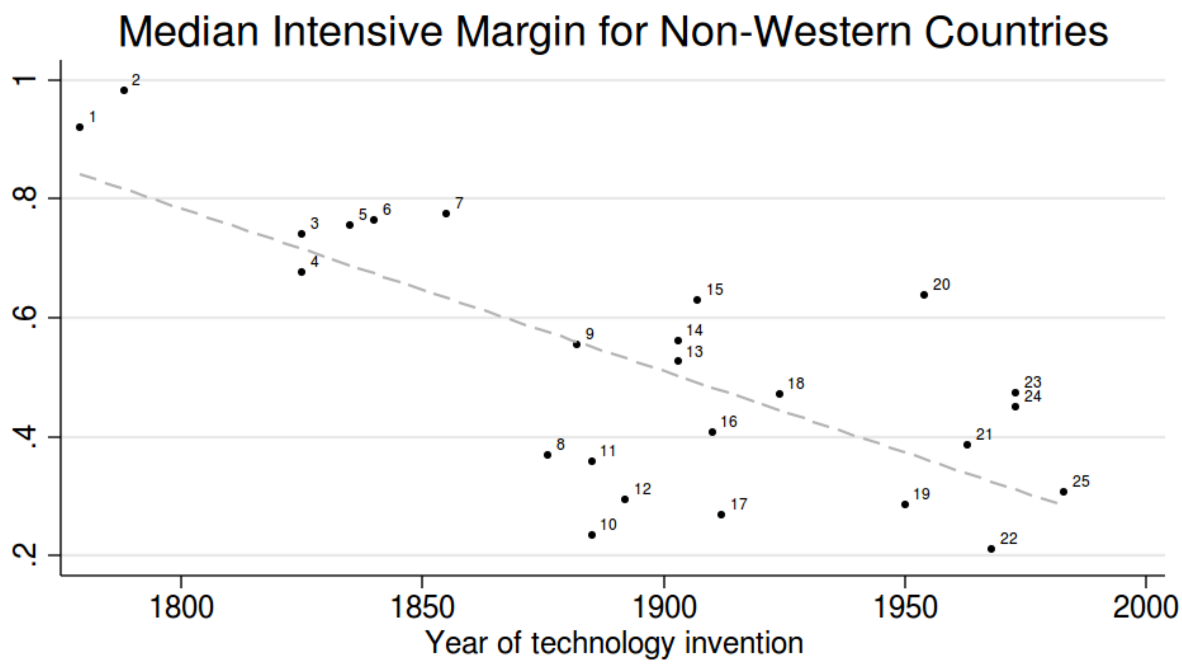
Figure 3 shows, for each of the 25 technologies, the median intensity of use for the non-Western countries relative to the Western countries. Technologies invented at the beginning of the Industrial Revolution, such as spindles and steam and motor ships, were utilized in the median non-Western country similarly as in Western countries. Since then, the relative intensity of use has diverged. That is, newer technologies have been utilized relatively less in developing countries. The magnitudes of this divergence are very significant. For example, the penetration rate of the internet in the median non-Western country has been approximately three times smaller than Western countries.

TECHNOLOGICAL LEAP-FROGGING?

These patterns of evolution for the adoption margins help us put in historical perspective the so-called technological leap-frogging. The most evident example of technological leap-frogging is the use of cellphones to overcome technological deficiencies in traditional communication and telecommunications services (e.g., landline telephone, TV and radio) or to facilitate the provision of other non-traditional services such as financial services. What do the general technology diffusion patterns I have just documented mean for the significance of these examples of technological leap-frogging? In particular, what do they imply about the likelihood of income convergence through technological leap-frogging?

The convergence in adoption lags proves right the common perception that new technologies are present everywhere. However, the divergence in the intensity of use shows that, contrary to common perceptions, new technologies are used much more intensively in developed than in developing economies. Below, I discuss why this may be the case. But regardless of what drives it, the divergence in the intensity of use of technologies suggests that despite all the great uses found in developing countries for some new technologies, in rich countries they have found even more uses. Hence their greater intensity of use—not only relative to poor countries, but also relative to the gap between the average gap in technology usage between rich and poor countries for other technologies.

Figure 3: Evolution of Median Intensive Margin in Non-Western Country Relative to Western



Technologies:
1. Spindles, 2. Ships, 3. Railway Passengers, 4. Railway Freight, 5. Telegraph, 6. Mail, 7. Steel (Bessemer, Open Hearth), 8. Telephone, 9. Electricity, 10. Cars, 11. Trucks, 12. Tractors, 13. Aviation Passengers, 14. Aviation Freight, 15. Electric Arc Furnaces, 16. Fertilizer, 17. Harvester, 18. Synthetic Fiber, 19. Blast Oxygen Furnaces, 20. Kidney Transplant, 21. Liver transplant, 22. Heart Surgery, 23. PCs, 24. Cellphones, 25. Internet

IMPLICATIONS FOR THE EVOLUTION OF THE WORLD INCOME DISTRIBUTION

How much does technology diffusion drive cross-country differences in income? More importantly, how have the changes in the process of technology diffusion shaped the evolution of the world income distribution?

Marti Mestieri and I have computed the effect of differences in technology on income. It turns out that the existing differences in adoption lags and in the intensive margin fully account for the differences we observed between Western and non-Western countries in 1820. We have also explored the role that the evolution of the diffusion process has had on the Great Divergence. The top panel of Table 1 shows the growth rates of productivity that we obtain for the median developed and developing economy after feeding in the observed evolutions of the adoption margins in each country. The bottom panel shows the actual growth rates we have observed in the data.

During the past two centuries, the annual growth rate of productivity in Western countries was 0.85 percentage points higher than in non-Western countries. The different evolution of technology diffusion generated an annual difference in growth of 0.75 percentage points. That is, it is responsible for 80 percent of the Great Divergence.

Table 1: Cross-Country Dynamics in Per-Capita Income, Model and Data

		Time Period		
		1820-2000	1820-1913	1913-2000
Simulation	Western Countries	1.47%	.84%	2.15%
	Rest of the World	.82%	.35%	1.31%
	Difference West-Rest	.65%	.49%	.84%
Maddison	Western Countries	1.61%	1.21%	1.95%
	Rest of the World	.86%	.63%	1.02%
	Difference West-Rest	.75%	.58%	.93%

A closer look at our simulations reveals that the large cross-country differences in adoption lags explain much of the income divergence during the 19th century between Western countries and the rest of the world. The Great Divergence continued during the 20th century because of the divergence in penetration rates (i.e., intensive margin of adoption) between Western countries and the rest of the world.

WHAT FACTORS CAN EXPLAIN THE EVOLUTION OF THE DIFFUSION PROCESSES?

Research on the determinants of long-run development has typically emphasized factors such as genetic endowment, institutions, climate, and cultural traits. Because these factors were predetermined before 1800, they have a difficult time explaining why cross-country income differences were small in 1800 and large two centuries later.

One attempt to reconcile these hypotheses with the Great Divergence is to appeal to the acceleration of the rate of arrival of new technologies that brought the Industrial Revolution. Given the large differences in the lags with which new technologies are first adopted in rich and poor countries, such an acceleration may lead to significant income differences by 1900. In particular, it can account for approximately half of the income differences between developed and developing countries observed in 1900.

However, this argument ignores the convergence in adoption lags. As a result of this convergence, adoption lags led to convergence in income during the twentieth century. To fully account for the great divergence we need to understand why the intensity with which new technologies are used has diverged very significantly.

This is a difficult fact to explain by pre-determined factors since they have either remained fixed during the last two centuries or converged across countries. Take for example genetic endowments. The successive migration waves have reduced the (average) genetic distance between the inhabitants of the different countries. If genetic distance drives differences in economic development, we should have observed a Great Convergence instead of a Great Divergence over the last two centuries.

A similar argument can be made about political institutions. A century ago, most developed economies had good political institutions in place while most developing nations did not. Over the last century, institutions in developing countries have improved and now the distance between the quality of institutions in developed and developing countries is the smallest since the French Revolution.

So, what can account for the divergence in the intensity of use of technologies? To me, the most natural candidate is knowledge. Technological knowledge is a key ingredient for the adoption and use of new technologies. Often, companies need to know how to use a new technology before they can decide whether the technology will solve its needs. Familiarity with some predecessor technology is often an essential input towards finding an application to a technology.

Technological knowledge is acquired by using technology both at work and at school where the new technologies are introduced to the students. But since the possibility to train workers formally and informally depends on the prior experience in adopting technologies, a complementarity arises. In past work with William Easterly and Erik Gong, we have observed that there is a great degree of persistence in a country's advantage to adopt new technologies, both at the aggregate and in a sector relative to the other sectors in the economy. In recent work with Marti Mestieri we have tried to investigate why this is the case. We have observed that countries that had an advantage in adopting technologies in a given sector around 1500 AD, created formal schools where the skills to operate technologies in that sector were taught. Furthermore, the early creation of such schools fostered a subsequent advantage in the adoption of newer technologies in the sector.

How can this help us explain the Great Divergence? Once these considerations are taken into account, it is not difficult to see that the Industrial revolution not only brought an acceleration of the rate of arrival of new technologies, but also, an acceleration in the advantage to adopt and use new technologies that early adopters had.

As a result of this acceleration in the capacity to use new technologies, companies and individuals in developed economies increased the rate of use of new technologies faster than those in developing countries.

These dynamics of technology adoption may help us explain why technological leap-frogging is exceptional. There is always a predecessor technology that helps companies find a profitable application of a new technology. Jumping ahead of this curve is way too difficult for most companies and individuals in most countries.

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[1] These include Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom, Japan, Australia, New Zealand, Canada and the United States. See Maddison, A. (2004). Contours of the world economy and the art of macro-measurement 1500-2001. Ruggles Lecture.

[2] See, for example, Spolaore and Wacziarg, 2009, Ashraf and Galor, 2013, Acemoglu et al., 2005, Guiso, Sapienza and Zingales, 2003.

[3] This is the case because, by exploring the diffusion curves of many technologies and countries, Comin and Hobijn (2010) showed that the diffusion curves for different countries have similar shapes, but are displaced vertically and horizontally.

[4] See Comin, D. and Hobijn, B. (2009a). The CHAT Dataset. Working Paper 15319, National Bureau of Economic Research.