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Catching up or lagging behind: The role of technology diffusion[†]

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Whether there is a per capita income convergence or divergence among countries has been a major area of dispute in economics. Many poor countries, particularly those in Sub-Saharan Africa, not only fail to grow faster than the rich countries, they, in fact, experience negative per capita growth. Therefore the gap between these countries and the rich ones widens more. Nevertheless, there has been some evidence of a higher convergence within relatively advanced OECD countries during the postwar period and a catching-up of especially East Asian countries in recent decades. This research note will try to shed some light on this dispute from the perspective of technology diffusion models.

The role of technology in growth models

The notion related to the link between growth and technology dates back to early twentieth century. Kondratieff found the existence of long-wave business cycles with a period of about 40-60 years. Technological innovations, such as steam engine, steel railway, electricity, and the subsequent structural changes in the whole economy were considered to be the main driving forces of these cycles. However, not until 1990s did technology enter as an endogenous variable in growth models.

In the neoclassical growth theory, technological progress is considered as an exogenous process. In the original model laid out by Solow at the beginning of 1950s, economic growth results from increases in the amount of capital that each worker is set to operate. As capital per worker increases through time, the marginal productivity of capital declines. Ultimately, the output per worker approaches a constant and the growth ceases. In order to allow for long-run growth in GDP per capita, Solow (1956) added an exogenous term to the production function and labeled it as “technological progress”. Therefore the long-run growth rate depends only on exogenously determined technological advances, reflecting the progress in science. In this setting, technology is assumed to be a public good, i.e. something available to everyone everywhere free of charge.

However, it is well-known by 1960s that significant quantities of resources are being expended on research and development not only by governments but also by profit-making institutions (Arrow, 1969). Arrow also pointed out that the analysis of production functions revealed that a major proportion of the increase in per capita income couldn’t be explained by increases in the capital-labor ratio as neoclassicals argue, and that production functions differ strongly among nations. Since production is defined relative to a given body of technological knowledge, the former finding implies that technological knowledge has been growing

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over time, while the latter implies that technological knowledge varies over countries. So, the body of technological knowledge should be regarded as the result as well as the cause of economic changes. The theoretical work on growth, therefore, has already suggested by late 1960s that technology should enter as an endogenous variable in growth models. But it is realized almost twenty years later, only after macroeconomists returned to growth issues encouraged by the availability of Summers-Heston data set, which allowed to make cross-country growth comparisons.

The developments in the theory of economic growth pioneered by Romer (1986, 1990) and Lucas (1988) end up with the new or endogenous growth models; "endogenous" in the sense that technological progress is determined within the model. These models thus provide a more convincing conceptual framework for the analysis of the role of technology in growth. The studies on the new growth theory view commercially oriented innovation efforts that respond to economic incentives as the major engine of technological progress and growth. In this view, innovation feeds on knowledge that results from cumulative R&D experience on the one hand, and it contributes to this stock of knowledge on the other. Consequently an economy's growth depends on its cumulative R&D effort and on its effective stock of knowledge, with the two being interrelated. Therefore, unlike the neoclassical theory of growth, which treats technological progress as an exogenous process and focuses instead on capital accumulation, the new growth theory focuses on technological progress as the main source of output expansion. However -taken either as exogenous or endogenous- technology is the main driving force behind the long-run economic growth in both theories.

Convergence implications of growth models

The convergence implications of growth models can be deducted from how they treat technology. On one side, neoclassical models based on Solow (1956), hold that technology is available everywhere to everyone at no cost, while at the other extreme, the endogenous growth theory, as it is first put forward by Romer (1990), relates a country's technical advances only to its own innovations. Therefore, the former implies convergence of per capita incomes worldwide, while the latter has no convergence implications at all.

The research based on the neoclassical perspective assumed technology as being of about the same size in all countries. The only factor left within this framework that can explain differences in per capita growth across countries is transitional dynamics. Since initial conditions generally differ, countries may grow at different rates in the process towards the long-run equilibrium. Specifically, countries where capital is scarce compared to labor are expected to have a higher rate of profit on capital, a higher rate of capital accumulation, and higher per capita growth. To the extent that capital is internationally mobile and moves to the countries where returns to capital are higher, the gap in income levels between rich and poor countries are expected to narrow and ultimately disappear. Therefore, neoclassical growth model predicts absolute income convergence among countries, i.e. poorer countries grow faster than richer ones due to the diminishing returns to capital, whatever their respective characteristics are. In the long run, the neoclassical model of economic growth predicts that, GDP per capita in all countries will grow at the same exogenously determined rate of technological progress.

The endogenous growth theory, as it is first put forward by Romer (1990), relates a country's technical advances only to its own innovations, leaving no room for convergence of per capita incomes among countries. Indeed, if technology diffusion were national in character, there would be no possibility for convergence; each country would grow at a rate determined by its own research effort. But in reality, research in one country benefits from knowledge created in others, providing a mechanism by which a laggard country would tend to catch up, formulated by the diffusion of technology models of endogenous growth theory.

In technology diffusion models, technological knowledge is the design of a new intermediate product and technology diffuses internationally through intermediate goods. The idea is that employing the foreign intermediate good involves the implicit usage of the design knowledge that was created with the R&D investment of the foreign inventor. Therefore, the technological knowledge of the design is embodied in the intermediate good. A typical model of indirect technology diffusion is the leader-follower model of Barro and Sala-i-Martin (1995). The convergence mechanism behind this model is that as technology diffusion occurs, the follower countries tend to catch up to the leaders because imitation and implementation of discoveries are cheaper than innovation. Besides implying a form of convergence, this model of technology diffusion restates neoclassical affirmation that economies with comparatively lower per capita income grow faster. Because the greater the gap between the leader and the follower, the larger the set of innovations that the follower can choose from, thus the higher the return from the most promising project that is available for imitation. This idea is represented by the assumption that follower country's cost of imitation increases as the gap between the two country decreases. Therefore, the growth rate of the follower decreases over time.

To sum up, the technology diffusion model suggests that technological advance is the main source of economic growth and diffusion of technology is the basic mechanism of per capita income convergence among countries. Therefore, the growth rate of a country depends on the state of domestic technology relative to that of the rest of the world. In a typical model of technology diffusion, the rate of economic growth of a backward country depends on the extent of the adoption and implementation of new technologies that are already in use in leading countries. Strong diffusion is the only force towards convergence, because it equalizes differences in technology across countries (Keller, 2001). The reason is that -with the exception of China- almost all of the R&D activity in the world economy is concentrated[§] in a small handful of industrial countries and, yet, not all of the other countries stagnate relative to these frontier countries. The new growth theory underlines international economic relations, such as importing, exporting, and FDI as technology transmission mechanisms that link a country's growth rate to economic developments in its partners (Grossman and Helpman, 1994). Therefore, unlike the pioneering works on endogenous growth theory, which relates a country's technical advances only to its own innovations, the diffusion of technology models imply convergence of per capita incomes among countries. Nevertheless, there is an important difference from the neoclassical suggestion of absolute income convergence among countries: Various aspects of government policy that facilitate technology diffusion – such as openness,

[§] In 2012, for example, 9 industrial countries plus China accounted for over 80% of world's formal R&D expenditures according to Global R&D Funding Forecasts.

taxation, provision of public services, and maintenance of property rights – in the follower country matter in order to catch-up to the leader.

Absorptive Capacity and Investment Capacity

Government policies that are expected to facilitate technology diffusion coincide to a large extent with the determinants of growth highlighted by the empirical research as affecting the growth rate of a country. These country-specific factors can be mapped into two broad categories: The first category, which is made up of human capital and R&D, is called the *absorptive capacity*, in the sense that countries themselves must have a certain level of human capital stock and engage in R&D activities in order to be able to absorb foreign technology. The rest of the determinants highlighted by the empirical research as affecting the rate of growth, namely the rule-of-law index, the government consumption, the price stability as well as the political stability comprise the second category that can be called *investment capacity*, in the sense that they determine the general investment environment of a country. Investment capacity can be thought to affect the growth rate of a country by affecting the physical capital accumulation through either domestic or foreign investment.

The absorptive capacity hypothesis expects weaker technology diffusion towards countries with lower R&D expenditures and lower human capital stocks. The empirical studies on diffusion of technology confirm the absorption hypothesis that the flow of advanced technology can increase the growth rate of the host economy only by interacting with that country's absorptive capability such as the following cross-country work:

- FDI is an important vehicle for the transfer of technology, contributing to growth in larger measure than domestic investment in developing countries only when the host country has a minimum threshold stock of human capital (Borensztein, de Gregorio, and Lee, 1995).

- R&D spillovers from developed to 77 developing countries from Africa, Asia, Latin America, and the Middle East are substantial. However, the results imply that the increase in a developing country's total factor productivity is higher the larger is its foreign R&D capital stock (i.e. its trade is biased towards countries with higher R&D); the more open it is to machinery and equipment imports from the industrial countries; and the more educated is its labor force (Coe, Helpman and Hoffmaister, 1997).

- There is strong evidence of technology diffusion towards developed, but weak evidence towards developing countries from U.S. multinational companies due to deficiency of human capital in most developing countries to benefit from the technology transfer (Xu, 2000).

- Bijsterbosch and Kolasa (2009) affirm the importance of human capital on the effect of FDI on convergence of productivity in the Central and Eastern Europe towards that of the euro area.

- Neto and Veiga (2013) find a positive effect of FDI on productivity growth and on the GDP growth once the initial level of human capital is taken into account.

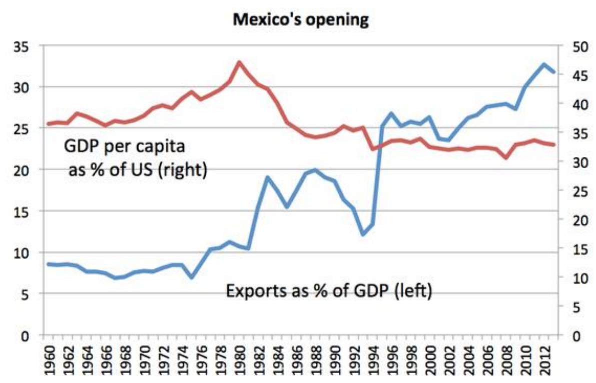
In general, country specific studies on countries with poor absorptive capacity fail to find evidence of technological spillovers, such as Haddad and Harrison (1993) on Morocco and Aitken and Harrison (1999) on

Venezuela. In contrast, there is evidence of international spillovers from US to countries with high absorptive-capacity, such as European countries, Japan, and Canada (Bernstein and Mohnen, 1998; Eaton and Kortum, 1999; Branstetter, 2000; Gera, Gu, and Lee, 2003). The absorptive capacity hypothesis explains this ambiguity in the empirical evidence related to indirect technology diffusion.

In sum, empirical evidence supports the idea that there are strong complementary effects between technology transfer and absorptive capacity on the growth rate of income. Own R&D activities and stocks of a human capital seem to play an important role in order for a country benefit from foreign spillovers. The most common proxies used for the absorptive capacity are R&D expenditures as percentage of GDP and the percentage of students at the tertiary level in the population.

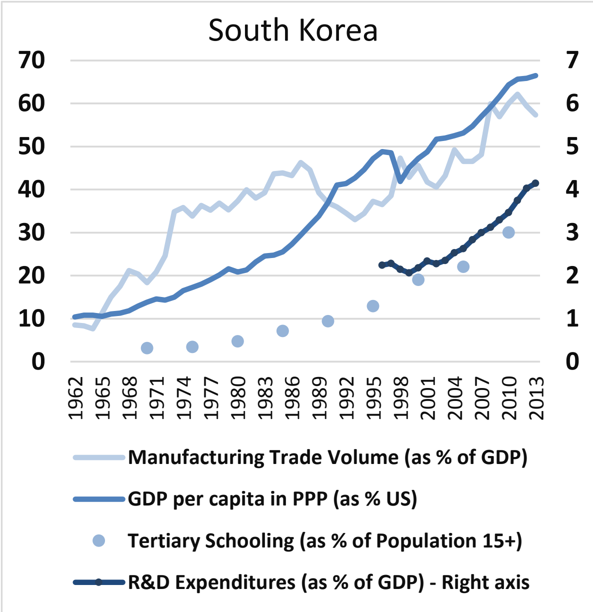
Some graphical evidence

The central prediction of neoclassical growth theory that all countries would converge towards the same level of productivity proved to be an illusion. Then the hope for economically less developed countries becomes the implications of the new growth theory. If diffusion of technology is the basic mechanism of per capita income convergence among countries, one way for the developing countries to catch up is benefiting as much as possible from technology diffusion. This requires "outward-looking" development policies, i.e. enhancing trade and FDI. However, there are still doubts on the benefits of openness directly or indirectly through technology diffusion among economists. For example, Krugman (2016) indicates that economists need to be upfront about the limitations of benefits of openness, basing his argument on the experience of Mexico. Following the widespread belief that import-substitution was the key to economic takeoff, based on loose, as Krugman comments, historical reasoning due to the experiences of the US and Germany, many developing countries including Mexico tried it until 80s. But the results were not as great as the rapid growth experience of some East Asian economies, which had followed an export-oriented path rather than the import substitution. So, since 1980s, "outward-looking" development policies have been considered as more favorable to growth than "inward-looking" policies.



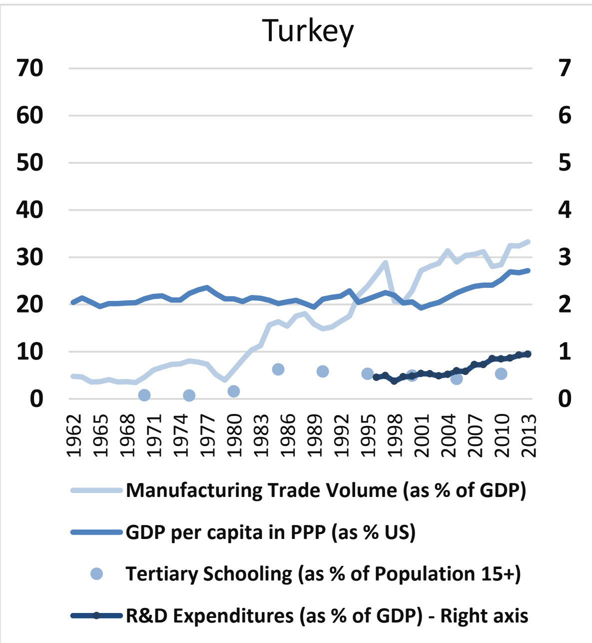
Krugman points out that growth has not accelerated in other regions as much as in East Asian countries when policy shifted away from inward focus, e.g., Mexico did radical trade liberalization in 1985-88, and transformed from an economy that didn't export much besides oil and tourism to a major manufacturing export power. However, the effect on growth has been underwhelming, i.e. there has been no evidence of convergence to the technological leader, the US, as shown in the figure that Krugman provided, where GDP per capita as % of that of US and exports as % of GDP are depicted for Mexico.

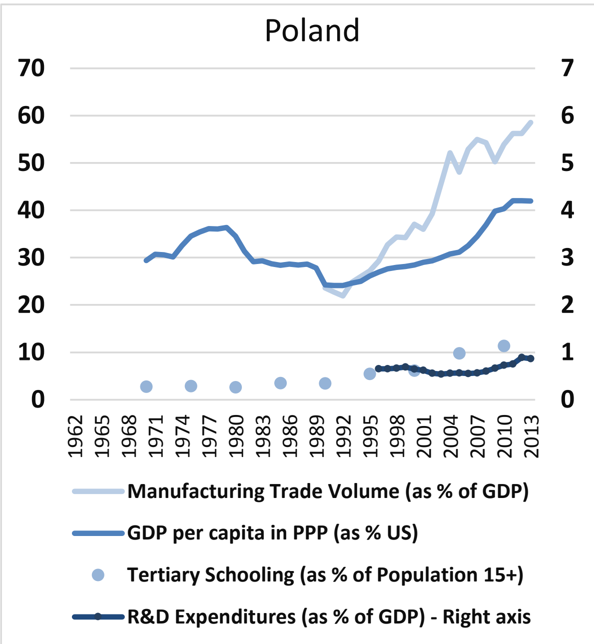
Although Krugman still argues that it's crucial to keep markets open and that benefits of globalization come mainly from technology diffusion, he indicates that the evidence is far from conclusive. The key point here seems to be the absorptive capacity. The following figures replicate that of Krugman by using trade volume in manufacturing (in line with theoretical considerations on diffusion of technology models) instead of total exports and adding proxies for absorptive capacity: Tertiary schooling (as % of population over 15) and R&D expenditures (as % of GDP).



Source: World Bank and Penn World Table Version 7.1 for 1962-2010, extended using World Bank Data till 2014

Comparing the figures for Mexico and South Korea, the two countries mentioned in Krugman's article as unsuccessful and successful examples of "outward-looking" development policies, respectively, reveals that absorptive capacity matters a lot. In case of S. Korea, the trade volume grows in parallel with the proxies for absorptive capacity and the per capita income of the country converges to that of the US.

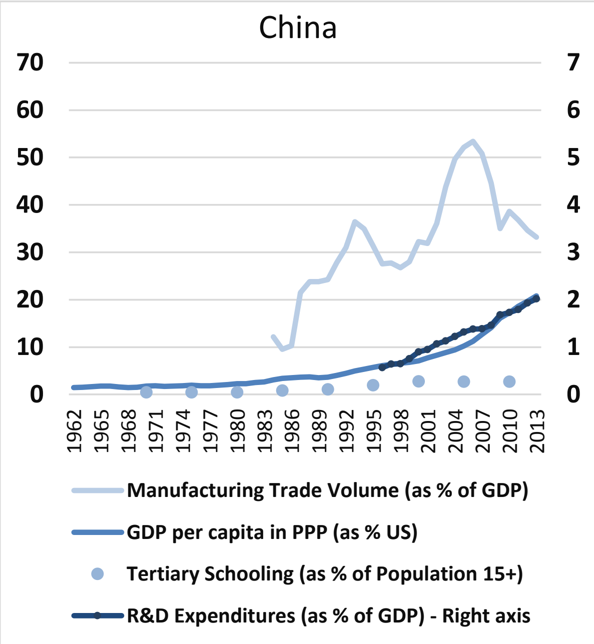


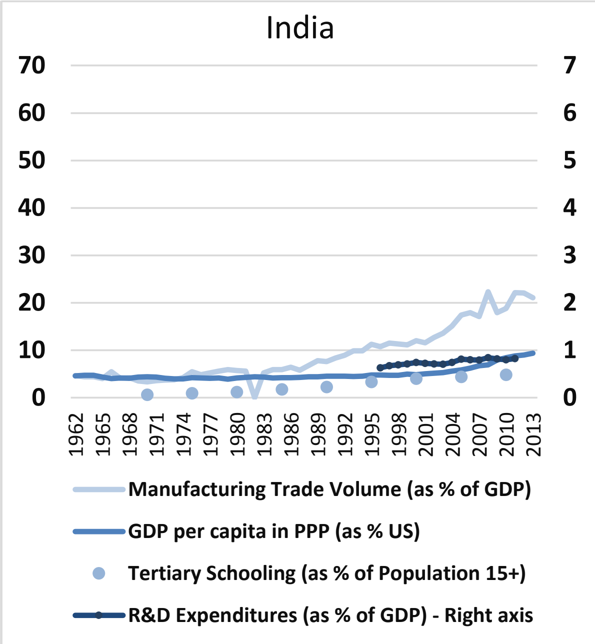


The figure for Turkey shows that the GDP per capita fluctuates around the average of 21% of that of the US between 1962 and 2004. A moderate catching up process from 1962-2004 average of 21% to 27% seems to be effective between 2004 and 2011, during which R&D expenditures rose to 0.9% of GDP from around 0.5%

of the previous 8 years for which data is available. The catching up process of Turkey stops in 2011, implying that the growth rate is around that of the US since then.

Comparing Turkey with Poland, an example from Europe, reveals that the catching up of Poland between 2004 and 2011 is higher than that of Turkey, up to 42% from the average of 30% of the previous years for which data is available. Considering that they have a similar increase in R&D expenditures to GDP ratio during this time period, the more rapid catching up of Poland seems to be related to the higher increase in manufacturing trade volume. The rapid catching up process started in 2004, when Poland became an EU member country. In case of Turkey, after 40 years of stagnancy, in the sense that the growth rate is more or less the same as that of the technological leader, i.e. the US, the catching up process begins when EU accession negotiations started in 2005 and ends in 2011 when negotiations practically stopped together with the willingness for economic reforms.





The graphical evidence for other countries, e.g. the BRIC, supports the absorption capacity hypothesis. The case of China resembles that of the South Korea as a later example of successful “outward-looking” development policies, where R&D expenditures rose from 0.6 to 2% of GDP in 15 years. There is some evidence for catching up in India since 2001 as well, whose manufacturing trade volume and to some extent R&D expenditures have been rising. It is difficult to talk about indirect technology diffusion via international trade in case of Brazil and Russia, since the increase in manufacturing trade volume in both countries is limited over the years covered in the figures. Therefore, Brazil and Russia have not benefited much from international technology diffusion and their growth performance depends on other factors, e.g. Russia experienced an enormous economic transformation 1990s resulted in a lagging behind and a rapid catching up in 2000s, on which the increase global oil prices until 2008 seems to have an important role.

Concluding remarks

In summary, theoretical models on growth show that improvements in technology have been the main source behind the long-run economic growth and diffusion of technology is a basic mechanism of per capita income convergence among countries. Indeed, in a world with international trade in goods and services, FDI, and other mechanisms of international dissemination of technology, a country’s productivity is affected by the R&D stock of its partners. Since developing countries spend relatively less on basic science and innovation, they rely even more on foreign sources of productivity growth. Therefore, the rate of economic growth of a backward country depends on the extent of the adoption and implementation of new technologies that are already in use in leading countries. This implies that it is essential to follow “outward-looking” policies to be able to catch-up.

However, both the empirical research based on new growth models and graphical evidence presented in this study show that the technology transfer brought about by trade and FDI; hence income convergence is not straightforward. A country benefits more from technology diffusion, the higher is its absorptive capacity. Human capital and domestic R&D comprise the absorptive capacity following the idea that a country needs to have a certain level of skill and needs to invest in R&D at least to some extent to understand and evaluate new technological trends and innovations in order to adopt foreign technological knowledge successfully. “Outward-looking” policies should go hand in hand with policies that enhance the countries’ absorptive capacity by conducting own R&D, facilitating technological implementation, and promoting human capital. The appropriate policies that allow technology diffusion together with the degree of success in adopting the foreign technology seem to determine whether per capita income of a country is catching up (convergence) or lagging behind (divergence) that of the technologically leader countries over time.

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