9 Technology Adoption

"…it is a matter not of individual inventiveness but of the receptivity of whole societies to innovation". [Jared Diamond].

Learning Goals

- Understand the critical role of economic openness in determining a country' exposure to world-wide technological progress
- Acknowledge how country' characteristics may influence the pace of adoption of new technologies
- Understand why the adoption of foreign technologies may require deliberate efforts to improve a country' absorptive capacity

9.1 Introduction

How to improve the state of technology is a policy question that confronts all modern societies. For technological leaders, keeping the lead requires a continuous effort to invent new products and processes. For most countries, however, the issue is not as much of pushing forward the world technological frontier, but mostly to benefit from technological achievements occurred abroad: since the inventing process does not have to be repeated, there is a potential advantage for those who adopt successful technologies without the need to learn from the beginning. The view that poor countries may improve their living standards by imitating the best practices in rich countries backs from David Hume, but it was popularized by Alexander Gershenkron, who coined the term "advantage of backwardness"[169].

In practice we do not see new technologies flowing automatically from rich countries to poor countries. New technologies have the *potential* to be transferred across agents and

[169] Hume, D., 1758. Essays and Treaties' on Several Subjects. London: A. Millar. Gershenkron, A. , 1952. "Economic backwardness in historical perspective". In Bert F. Hoselitz (ed.) The progress of underdeveloped Areas, Chicago: The University of Chicago Press, 3-29.

country borders, but whether they are adopted or not in each environment depends on incentives. These incentives, in turn, differ across space, depending on local economic, political, cultural and geographical circumstances. For an emerging economy, taking advantage of the potential generated by technological diffusion is basically a matter of shaping the country's set of capabilities so that it becomes in the interest of individuals to invest in new technologies.

This chapter addresses the question of why available technologies do not flow uniformly across the space, and what policymakers can do about it. In Section 9.2, we stress the role of economic openness in determining the exposure of a country to worldwide technological diffusion. In Section 9.3, we discuss how the recipient country' characteristics may determine its permeability to technological diffusion. Section 9.4 turns to the question of heterogeneity in technology, to discuss the costs involved in the selection of the technologies that better match each country' set of capabilities, and on the eventual need to adapt foreign technologies. Section 9.5 presents a simple model to think an economy faced with the challenge of catching up to the frontier technology. In this model, the World technological frontier expands at an exogenous rate, like in the Solow model, and the country's characteristics and policies determine how close it gets to that frontier. Section 9.6 summarizes the main ideas.

Box 9.1: four breakthrough invention of the humankind

In the neoclassical model, it is assumed that technology spills over instantaneously across firms and countries borders at no cost. In the real life, however, technology does not spread instantaneously across the space, people and societies. It instead flows asymmetrically, through specific mechanisms of human interaction. To illustrate this statement, we exemplify with four breakthrough inventions of the Humankind.

The wheel: the wheel was first used for pottery in Mesopotamia by 3.500 B.C, and was adapted three centuries later for transportation on chariots. You may think this invention as almost a public good: once a potential user becomes aware of the concept, it will be very easy for him to imitate the invention and use it for his own benefit. Nevertheless, it took many centuries for this simple idea to spread across the Middle East, Western Europe, and Asia. In the New World, people had to wait until the 15th century to take advantage of the wheel in transportation. This example suggests that *geographical distance* plays a role in determining the pace of technological diffusion.

Making fire: arguably, this technology is easier to hide from imitators than the wheel. Eventually, the hominids who first discovered how to make a campfire, around 1.4 million years ago, tried to keep it secret, to have an advantage over their competitors. But whether through diffusion of independent discoveries, the fact is that the ability to make fire became universally known a long ago in the human history. This example suggests the *passage of time* has a role in eroding the barriers to technological diffusion.

Writing: this technology was developed independently in Mesopotamia and in Egypt around the third millennial BC, in China around 2000 BC, and in Central America around 600 BC. Writing is a powerful tool that fuels human interactions, but it is a complex technology: it requires considerable individual efforts to transmit. It is not surprising that after the invention of writing, it spread rapidly throughout mercantile societies, where the need to record transactions was latent, but failed to penetrate agricultural-based societies, where *economic incentives* to adopt it were absent. Today, although governments spend huge amounts of resources to make this technology universally available, many people do not adopt it. When assimilating knowledge is costly, people will only adopt it if they consider it worth it.

Democracy: democracy was first implemented in the ancient Greece, in the city-state of Athens, around the year 508 BC. At that time, democracy was introduced to provide peasants with the opportunity to engage in highly productive long-term investments (preparation of the fields for the cultivation of olive trees), a political system that minimised the risk of expropriation[170]. Nowadays, democracy is still difficult to implement and maintain in many environments. The construction of a democracy depends on collective actions and the existence of complementary ingredients, such as the rule of law and freedom of the press. There are often conditions to implement democracy, but this is not the interest of those who have the power to decide. This example highlights the fact that lack of *complementary factors* and *vested interests* can delay the pace of technological diffusion.

[170] Fleck, R., Hansen, A., 2006. The Origins of Democracy: A Model with Application to Ancient Greece The Journal of Law and Economics, 49, 115–146.

Taken together, these examples remind us that, although technology has the potential to spread across societies, in practice its diffusion is far from automatic. Because of various combinations of geographic distance, secrecy, complementarities, and incentives, technology tends to be differently assimilated across people and societies.

9.2 The key role of openness

9.2.1 A necessary condition

In isolation, it would be impossible for a region to import foreign technologies. Consider, for instance, the Aboriginal Tasmanians before the European discoveries: since they had no contact with other civilizations for more than 10,000 years, they could not acquire any new technology other than what they invented themselves. A necessary condition for a country to learn from abroad is to maintain a minimum contact with the outside world.

In our days, no country in the world is completely isolated. With the arrival of telecommunications and the internet, people in remote areas are given the opportunity to learn and share ideas with fellows located in the centre. Today, knowledge has the potential to circulate across distant people and societies at a speed without parallel in human history. And yet, technology still differs considerably across countries and country-regions. Openness and access to information are necessary for technology to diffuse, but certainly they are not sufficient.

9.2.2 The critical role of international trade

A primary channel of economic interdependence is international trade. There are different mechanisms through which international trade increases an economy' permeability to the world technological diffusion. First, importing equipment from more advanced countries is a direct way of using *embodied* technology*,* without the need to replicate the research effort. Second, opening the domestic market to the *competition* of foreign firms bringing newer and more sophisticated products compels domestic firms to improve their products and to seek for more efficient ways of producing them. Third, competition in foreign markets provides exporting firms with the discipline of interacting with demanding customers, inducing them to meet high quality standards (*learning by exporting*). Fourth, access to external markets may favour the establishment of new exporting industries, eventually pushed by *foreign direct investment*, that otherwise would not spring in the country. Fifth, a society more exposed to foreign ideas tends to be more demanding in respect to the quality of domestic *policies* and institutions.

Protectionism, in contrast, creates economic rents and therefore the conditions for agents to become organized in interest groups, and to spend resources in pressing the government for more protection, instead of devoting their talents in the search for better technologies. All in all, trade openness plays a key role in shaping the agents' incentives so that it becomes their interest to take opportunity of the world technological progress.

Some authors argued that one reason why the United States of America emerged economically in the 1865-1929 period and surpassed England as the world technological leader is that it became a "free trade club"[171]. In this club, members states were not allowed to impose restrictions on imports from (or on technology developed by) other member states. In Europe, in contrast, sovereign states had the legal power to impose barriers to mutual imports, restricting the exposure of countries to each other innovations. It was only after the launch of the European Economic Community, in 1957, that Europe started its move towards a "free trade club".

Empirically, many studies have supported the claim that openness to international trade speeds up the pace of technological diffusion and helps improves the quality of domestic policies (an example in Box 9.3). Some authors have found that it is not only trade openness that matters, but also the *identity* of the trading partner: that is countries trading primarily with

[171] Parente, S. and Prescott, P., 2004. "Barriers to technology adoption and Development", Journal of Political Economy 102(2), 298-321.

technological leaders are more likely to adopt new technologies than countries trading primarily with laggard countries[172].

9.2.3 Foreign Direct Investment

Like international trade, FDI is a vehicle for cross-country technological diffusion. Specific mechanisms through which FDI promotes the transfer of technology include: bringing new machinery and production techniques to the host country; demonstration effects that induce imitation by local firms; increased competition in the domestic market; creation of a demand for high-quality or specific intermediate inputs.

To this, one shall add an important role of foreign investors in promoting face-to-face contacts between workers in the headquarters and in the subsidiaries. These face-to-face contacts are essential to diffuse the so-called *tacit knowledge*, which by nature is not easy to communicate at distance (see Box 6.2).

The empirical evidence has not been, however, very supportive to the idea that FDI by its own generates faster productivity growth. Studies have found an important potential role for FDI, but the extent to which this potential materializes in each country, depends on country characteristics[173]. Countries have different characteristics, and these characteristics play a critical role in determining the permeability to the potential diffusion resulting from FDI. In the next section, we turn precisely to the role of country characteristics.

[172] Bayoumi, T., Coe., D. and Helpman, E., 1999. R&D spillovers and global growth. Journal of International Economics 47, 399-428. Savvides, A., Zachariadis, M., 2005. International technology diffusion and the growth of TFP in the manufacturing sector of developing economies. Review of Development Economics 9 (4). Lichtenberg, F., de La Potterie, B., 1998. International R&D spillovers: a comment. European Economic Review 42, 1483-1491.

[173] Borenztein, E., De Gregorio, J., Lee, J., 1998. How does foreign direct investment affect economic growth? Journal of International Economics 45, 115-35. Xu, B., 2000. Multinational enterprises, technology diffusion and host country productivity growth. Journal of development economics, 62 (2), 477-93.

Box 9.3 Trade openness and convergence

The question as to whether trade openness is good or bad for growth has been subject to intensive debate by economists of all times. The general case in models with a widely accepted set of assumptions is that international trade is good for growth. Still, one may find models stressing less common but equally realistic assumptions showing that trade can be detrimental to growth. Models with learning by doing are typically in the second category.

Empirically, most evidence points to the case that trade openness is indeed good for growth. Jeffrey Sachs and Andrew Warner[174] constructed an "index of trade openness" according to which a country was classified as "open" if it satisfied 5 requirements at the same time[175]. Controlling for other explanatory variables, the authors found that, on average, open economies grew by 2-2.5 p.p. faster along the period 1970-1989 than closed economies. The authors also found that within the group of "developing countries", those that were considered as "open economies" expanded at 4.49% per year, while "closed economies" expanded at 0.69%, only. Among "developed economies", those that are open economies expanded at 2.29%, while closed economies expanded at 0.74%. The authors then concluded that poor countries tend to grow faster than richer countries as long as they are *linked together* by international trade.

More generally, the authors also found that closed economies tended to experience severe macroeconomic crisis more frequently than open economies. This is in line with the view that international trade is important channel for *international technological diffusion* ,

[174] Sachs, J. D. and Warner, A. M., 1995. "Economic reform and the process of economic integration", Brookings Papers of Economic Activity 1, 1-95. Sachs, J. D. and Warner, A. M., 1997. "Fundamental sources of long-run growth". American Economic Review, Papers and Proceedings, May.

[175] These are: average tariff rates below 40 percent; average quota and licensing coverage of imports of less than 40 percent; a black-market exchange rate premium that averaged less than 20 percent during the decade of the 1970s and 1980s; a non-socialist economic system; no extreme controls (taxes, quotas, state monopolies) on exports.

improving the permeability of economies to new technologies and best practices in other countries, leading to better governance in general.

9.3 Permeability to technological diffusion

Although backwardness carries with it the potential for a country to catch up, the degree to which this potential materializes in each specific environment depends on economic, political and social circumstances. Factors such as the availability of human skills, infrastructures and the quality of domestic institutions, by shaping the economic incentives to implement new technologies, may accelerate or retard technology adoption. This section briefly reviews the role of country characteristics in determining the permeability of a country to worldwide technological change. We also discuss the challenges posed by the fact that new technologies come along with the destruction of existing rents, giving rise to negative reactions by those who have more to lose with the change.

9.3.1 Complementarities

The productivity of a new equipment does not depend only on its intrinsic efficiency but also on the abundance/adequacy of *complementary inputs* in the hosting economy. The more a new technology matches with a given country' endowments, the higher the likelihood of it to be profitable and therefore adopted in that country.

An obvious complementary input to new technologies is human capital. Poor and unequal countries with low levels of literacy will find it more difficult to adopt sophisticated technologies than countries with high levels of human capital. Some authors have argued that the human capital needed to absorb new technologies is not independent of a country' development stage. For a laggard country, where most growth opportunities involve the imitation and adoption of foreign technologies, the critical ingredient will be a good coverage of primary and secondary education. For a country closer to the technological frontier, however, because much of the growth opportunities involve the adoption of more sophisticated technologies and the development of new ones, it is important to invest in higher education and in high-quality research centres[176].

This means that human capital not only has a direct effect on production as an input in the production function (as captured by the MRW model), but also an indirect effect, in shaping the permeability of a country to the World technological progress. Conventional growth accounting assessing the contribution of human capital by the elasticity in production only, tends to understate the true impact of human capital on growth.

Complementary inputs other than human capital include physical infrastructure (roads, ports, telecommunication networks, power supply), business services (accountancy, machinery repairs), financial services (banks, insurance, stock markets), government services (property rights protection, regulation), and so on.

The fact that technology requires complementary inputs suggests that the slow adoption of new technologies in developing countries may be an optimal response to differences in endowments, which translate into differences in the efficiency with which new technologies can be used. The implication is that governments have a role in shaping a country' absorptive capability: by promoting the education of people, building infrastructure and promoting a balanced development of the different capabilities, government policies influence decisively the pace at which new technologies are adopted. That said, improving a country' absorptive

[176] Theoretical models where technological diffusion is mediated through human capital include Nelson and Phelps (1996), Acemoglu et al (2006), Aghion and Howitt (2005). [Nelson,, R., Phelps, E., 1966. Investment in humans, technological diffusion and economic growth. American economic review 61, 69-75. Acemoglu, D., Aghion, P., Zilibotti, F., 2006. Distance to frontier, selection and economic growth, Journal of the European Economic Association, March 2006, Vol. 4, No. 1, Pages 37-74. Aghion, P., Howitt, P. 2005. Growth with quality improving innovations: an integrated approach. In Aghion, P., and Durlauf, S. (eds), Handbook of Economic Growth, North Holland, Amsterdam, Chapter 2, 67-110.]. On the empirical front, the relationship between human capital and technological adoption was investigated by Griliches (1957), Benhabib and Spiegel (1994), Eaton and Kortum (1996), Doms, Dunn and Troske (1997) and Borentzein et al. (1998), Caselli and Coleman (2001), Caselli and Wilson (2004). [Griliches, Z., 1957. Hybrid corn: an exploration in the economics of technological change. Econometrica, 25, pp. 501-522. Benhabib, W., Spiegel, M., 1994. "The role of human capital in economic development: evidence from aggregate cross-country data". Journal of monetary economics 34, 143-173. Caselli, F., Wilson, D., 2004. Importing technology. Journal of monetary economics 51, 1-32].

capability is not an easy task: infrastructures are expensive, human capital can only change slowly and geographical conditions like the climate cannot be changed at all. Hence, the process of turning the country more permeable to the adoption of new technologies involves choices and is necessarily a slow one.

9.3.2 The vintage capital theory

New technologies replace old technologies that become obsolete. That being the case, one would expect investors to buy the state-of-the-art technology only, and the share of old technologies in the capital stock to gradually decline over time (this view is known and the "vintage capital theory")[177].

In the real world, however, there are many examples in which investment in frontier technologies only becomes dominant after a period of time during which investment in non-frontier technologies continues to dominate. A historical example occurred in Germany after WWII[178]: with the war, Germany lost a significant part of its merchant fleet. If Germany had rebuilt its merchant fleet with state-of-the-art ships, only, it should have acquired a higher proportion of motor-ships (relative to sail-ships and steamships) than other European countries. However, that was not the case.

The persistent behaviour of investment in old technologies looks a paradox. Why should entrepreneurs insist in buying technologies that are less efficient, instead of investing in state-of-the-art technologies?

9.3.3 Switching costs

[177] Johansen, L., 1959. "Substitution versus fixed production coefficients in the theory of economic growth: a synthesis". Econometrica 27, 157-176. Solow, R., 1960. "Investment in technical progress", in Arrow, K (ed.), Mathematical methods in the social sciences, Standford University Press.]

[178] Comin, D., and Hobijn, B. , 2004. "Cross-country technology adoption: making the theories, facing the facts". Journal of Monetary Economics 51, 39-83.

One reason for the persistence of old, dominated technologies, when newer and more efficient technologies are available is the existence of "switching costs": costs related to the move from one technology to another.

A first type of switching costs is related to complementary specific investments in physical capital or in infrastructure that are specific to the old technology: when the DVD player replaced the old vinyl record player, consumers had to set aside their collections of vinyl records and start buying new CD records. Naturally, those consumers with bigger collections of vinyl had more to lose with the technological change, and eventually resisted the adoption of the new technology.

A similar reasoning holds for the *value of experience* acquired in dealing with the old technology. Learning how to operate a technology and taking opportunity of its full potential takes time, materializing a "sunk cost" that cannot be recovered once the technology is abandoned. Hence, after this technology-specific investment in human capital is made, the worker has great incentives to stick with the old technology. For a worker, switching to a new technology will imply a decline in the value of his accumulated experience, as well as the need to incur in new learning costs. With no surprise, when technology-specific skills are important, workers tend to resist the adoption of new technologies, irrespectively of how efficient they are (a classical example in Box 9.4).

Switching costs may also result from "network externalities". A network externality arises when the benefit of using a given technology increases with the number of users of that technology. For instance, consider the telephone: the more people use telephones, the more valuable the telephone is to each user. Thus, when many users are hang-on to an existing technology, it becomes difficult for a newer, superior, technology to emerge.

A special case of network effects arises in the form of "social learning". Suppose, for instance, that you considered buying a computer with an exotic operating system. Even if this operating system was more efficient than the MS Windows, you would need to balance the costs of obtaining assistance in case no one else was adopting the same software. In contrast, people using MS Windows face lower user costs, because they have a higher chance of interacting with other people using the same software. The more people are using a technology, the higher the likelihood of each new user to interact with a potential teacher and hence the lower the learning cost. When this is so, the conditions exist for a widely used technology to block a new one, even if more efficient.

Box 9.4. Locked to QWERTY

The QWERTY keyword, that you probably find in your laptop, is a rather inefficient one. As you may easily check, the commonest letters are scattered over all rows and concentrated on the left side of the keyboard, so that right-handed people have to use their weaker hand to reach them.

Why was this keyboard designed with such unhelpful and unproductive features? The reason is that, by 1873, when this layout was created, mechanical typewriters jammed easily if two keys were struck in a very quick succession. The QWERTY key layout was therefore a technological response to a problem of jamming. It was purposefully designed with the aim to slow down typists and reduce the frequency of jams.

What makes this case interesting is that the QWERTY keyboard is still used today, having survived the elimination of the problem of jamming that motivated its creation in the first place. The reason is that, at the time the problem of jamming was fixed, the QWERTY keyboard was already established as a “lingua franca”: users were accustomed to it, and constructers of typing machines and computers kept providing this layout in new equipments, because this was what the market demanded. Attempts to launch new and more efficient keyboards were tried, but without success, because people were already locked-in to the less efficient technology and refused the change[179].

9.3.4 Leapfrogging

Lock-in effects related to switching costs should, at the first sight, favour economic convergence: countries that are intensive users of the old technology should be the countries that have more to lose by adopting the new technology. Less developed economies in contrast, because they are not heavily committed to any technology, could in principle jump to the

[179] David, P. 1985. Clio and the Economics of Qwerty. American Economic Review 75, 332-337.

frontier by investing in state-of-the-art technologies. The opportunity that laggard countries have to jump ahead of the leaders is dubbed as "leapfrogging".

In the real world, examples of leapfrogging abound. For instance, many developing countries in the past decade have adopted cellular phones faster than developed countries, because operators were not locked-in to the technology of conventional telephones. Leapfrogging is not, however, a general case: there is significant evidence suggesting that more advanced economies are not only those that invent new technologies, they are also those who adopt newer technologies first[180].

A possible explanation for this pattern is that part of experience acquired with the old technology is not exactly a sunk cost, being instead *transferable* to the new technology. For instance, it is probably easier for someone with experience in mechanic typewriting to become a computer typist, than someone with no experience at all. The time and effort the mechanic typewriter invested in learning with old technology is not completely lost, because it can be adapter to work with a computer.

This means that the accumulated experience in dealing with an old technology not only has the potential to reduce the user costs in that technology (giving rise to lock-in effects), it may also help reducing the costs of adopting a new and more efficient technology. When the second effect is significant, users of the old technology will have an advantage instead of a

[180] Examining the diffusion of 25 technologies across 23 industrial countries for the period from 1788 until 2001, Comin and Hobijn (op.cit) found that most technologies are first adopted in advanced economies and then they trickle down to countries that lag economically. The authors also found that leaders in the adoption of a predecessor technology tend to be the leaders in the adoption of the successive technology.

disadvantage relative to workers who have no relevant experience in the field[181]. Box 9.5 presents an argument in this avenue.

Box 9.5. The Haussman - Klinger forest

The ability of a country to start producing more sophisticated goods depends on a country' set of capabilities. Much of these capabilities, in turn, were acquired, developed and accumulated in response to earlier production needs. For instance, engineers might have been trained to support an existing textile industry. These engineers, in turn, could be adapted to work in a clothing factory. This means the ability of a country to attract new technologies may be conditional on the usefulness of the industry-specific experience and infrastructure that was generated by the country current specialization pattern.

To illustrate this idea, Hausmann and Klinger (2007) proposed a metaphor with a forest, where each tree represents a product[182]. In that forest, each tree is placed at some distance to the other trees, the distance capturing the degree to which the skills acquired in one productive experience can be used in other productive experience. Because some industries use skills that are common to a large number of industries, some parts of the forest are *denser* than others.

In this metaphor, firms are monkeys that live in the trees, and the process of structural transformation involves the monkeys jumping around from tree to tree. Moving to trees at larger distances involves the need for productive capabilities that have not been previously accumulated. Because some trees generate more income than others, each monkey would like

[181] Jovanovic and Nyarko (1996) build a model of individual decisions, whereby learning by doing provides an agent with information that improves its productivity in the old technology (vertical shifts). In this model, agents may also switch to new technologies (horizontal shifts). The degree of similarity of the new technology to the old one determines how transferable the accumulated knowledge is. The lower the possibility of transferring the accumulated knowledge to use with the new technology, the larger will be the productivity loss faced by workers being asked to move to the new technology. When the technological leap is too large, the expertise loss may be such that a highly skilled agent prefers not to switch, becoming therefore locked in the old technology [Jovanovic, B., Nyarko, Y., 1996, Learning by doing and the choice of technology, Econometrica 64, 1299-1310].

[182] Hausmann, R. and B. Klinger, (2007), "The structure of the product space and the evolution of comparative advantage", CID Working Paper no. 146, April.

to move to high productivity trees. However, because smaller jumps are less costly than larger jumps, the ability of the “tribe” to engage in superior technologies depends on having a path to nearby trees that are increasingly of higher productivity. If the move towards high productivity trees require larger jumps, the tribe may find itself in a poverty trap, jumping around lower income trees.

With this paradigm, the authors argued that the process of technological change is path-dependent: when a country’ accumulated experience is less valuable, comparative advantages will determine a specialization in industries with low potential to generate new knowledge and spur economic development. If however the country has accumulated experience that is highly transferable to new technologies, it will find it easier to start producing more sophisticated products. This interpretation is consistent with a broad notion of acquired “experience” or “capabilities”, including infrastructure, labour skills, country-specific technical knowledge, specific regulations, and so on.

9.3.5 Barriers to technological adoption

Innovations not only have the potential to generate rents, they also have the potential to destroy existing rents. To the extent that technological progress brings about more efficient machinery and production methods, owners of the old machinery will lose. Technological change often comes along with redistributive effects that challenge the balance of political powers.

Not surprisingly, history is full of examples of powerful elites and organized groups seeing their economic, political and social interests threatened by the adoption of new technologies placing obstacles to its diffusion. For instance, in the nineteen century Austria-

Hungary, the elites acted to block industrialization and even the introduction of railways, just because they realized industrialization would reduce their power and privileges[183].

Obstacles put in the path of innovators by established interests are labelled *barriers to technology adoption*[184]. An obvious form of barrier is bribery: whenever the use of old technologies generates economic rents, the opportunity exists for established elites to persuade the political power to block innovations by imposing regulatory and legal constraints. More generally, barriers to technology adoption may include violence or threat of violence, worker strikes, etc.

Barriers to technology adoption may also arise in the form of social norms: the implementation of new technologies often requires organizational changes and complementary reforms that challenge beliefs and traditions within a country. Those with a stake in the old technology may find it profitable to support these traditions and beliefs in an attempt to block the adoption of new technologies. Leaders in laggard countries often lack the political power or the political will to confront these traditions.

All in all, the arrival of new technologies may face the resistance of groups who have a stake in the preservation of the status quo. Because of this, many authors content a most decisive element influencing the pace of technological diffusion is the quality of political institutions: the less influenceable they are by privileged elites, the easier it will be to find policymakers committed with reforms and able to accept the underlying changes that the new technologies are likely to bring about.

[183] Acemoglu, D. 2003. "Root causes: a historical approach to assessing the role of institutions in economic development". Finance and Development, 27-30, June.

[184] Parente, S. and Prescott, P., 1994, op. cit.

9.4 Matching specific needs

9.4.1 Self-discovery

Because economies differ in terms of endowments, infrastructure, climate and culture, they should optimally adopt different technologies. If information was perfect, investors would always pick up the technology that better matched the target environment. In a world with uncertainty, however, finding out which of the many potential technologies better fits a country's specific circumstances is a process of trial and failure. This process is known as "self-discovery"[185].

The process of "Self-discovery" involves externalities from the innovator to the followers. First, the entrepreneur that adopts a new technology provides valuable information to its competitors: if the entrepreneur succeeds, other entrepreneurs who opted to wait and see will imitate it, eroding the innovator' rents; if it fails, the innovator will bear the costs alone. Because the entrepreneur that first adopts the new technology provides valuable information to other potential entrepreneurs without being compensated for that, an information externality arises. Second, innovators often need to train workers in the use of the new technology. Once the innovator incurs the training costs, the risk exists of competitors to free ride on workers mobility, and of beating the innovator with lower training costs.

These externalities clearly reduce the incentives to innovate. If the expected gain from moving first is not large enough to compensate the innovating firm for its risk taking, the firm will optimally prefer to wait and see, postponing the adoption of the new technology, even if that was socially valuable. This discussion adds to the general case that private returns to innovation tend to fall short the social returns, calling for government intervention.

[185] Hausmann R., Rodrick D. 2003 "Economic Development as Self-Discovery" Journal of Development Economics 72(2) 603-633.

9.4.2 Mastering foreign technologies

A difficulty in the adoption of foreign technologies by developing countries is that many technologies are invented targeting the conditions of advanced countries. The reason is that researchers must recover the fixed costs involved in R&D, and this will be easier to achieve is the innovation targets a large economy with many wealthy consumers, than if the innovation is directed to a small, idiosyncratic, poor economy. This reasoning explains why many inventors around the world are trying to develop ideas that are useful in the United States, to sell the patent there, rather trying to develop ideas that are specific to their own narrow contexts. This bias, coined as *directed technological change*, implies that many of the available technologies may not be suitable for the needs of poorer countries, with different climate and factor endowments[186]. In agriculture, for instance, most innovations relate to cultures of temperate zones – where rich countries are – thus not being suitable to be implemented in developing countries located in the tropics. In manufactures, many innovations in machinery tend to economize labour and are specially designed to improve the productivity of skilled labour, thus not matching the abundance of unskilled labour that is typical in poor countries.

To the extent that innovations do not fit well with the characteristics of developing countries, their adoption "tout-court" would result in productivity gaps that could not be eliminated along time[187]. Hence, an effective technology transfer may involve some investment by the recipient country, in order to master the foreign technology and adapt it to the local environment, preferences and believes.

Mastering a foreign technology involves however a fixed cost for the innovator. An entrepreneur will engage in such an effort only if he is able to make profits during a period of time. This may presume a minimum protection from eventual imitators. A problem with many

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[186] Acemoglu, D., 2002. Directed Technical Change, The Review of Economic Studies 69 (4) 781–809.

[187] Atkinson, A., and J. Stiglitz, 1969. A new view of technological change, Economic Journal, pp. 573-578. Basu, S., Weil, D., 1998. Appropriate technology and growth, Quarterly Journal of Economics, 113(4), pp. 1025-1054.

developing countries is that the enforcement of property rights there is so weak that it doesn't pay for innovators to spend resources in adapting foreign technologies, because imitators will free ride on that effort. Instead, talented inventors in developing countries may find it more profitable to design new products targeting the needs of industrial countries, where patented inventions can be sold to reward the R&D costs. A corollary is that the enforcement of intellectual property rights in developing countries is an essential pre-requisite to expand the size of their markets and, by then, to induce investments in technology more directed to the South[188].

9.4.3 Institutions do not travel well

The idea that foreign technologies may not match the conditions of the recipient country does not apply to technology in the engineering sense only. It holds for technology in broad terms, including policies and institutions. Just like the effectiveness of a given machine in a particular location depends on the availability of labour skills, the effectiveness of a given policy or institution may depend on how this new policy or institution interacts with existing policies and institutions, culture, and beliefs. For instance, financial liberalization may help improve the allocation of resources, but it may also be a source of macroeconomic instability if effective supervision is lacking; privatization of utilities can deliver higher efficiency in management, but it can also be welfare reducing if there is no competition authority protecting the consumers from price abuses; protecting property rights is in general favourable to long term investment, but it will fail to do so if it lacks an effective judiciary.

The implication is that the simple copy of institutions that perform well in a given context does not necessarily deliver the highest possible economic performance in a different

[188] Acemoglu, D., Zilibotti, F., 2001. Productivity differences. Quarterly Journal of Economics 116, 563-606.

context[189]. A suggestive example of how the replacement of old traditions by apparently more efficient policies resulted in welfare loss happened in Bombay Deccan, in the nineteenth century colonial India. The reform consisted in the introduction of civil courts, to improve the effectiveness of contracts in general. These courts however interacted adversely with the credit market for agriculture: before courts were introduced, a traditional practice of risk-sharing existed, whereby lenders subsidized farmers during bad harvests. The newly established civil courts were able to enforce simple debt contracts, but not the complex risk-sharing informal arrangements such as those that proved effective in the past. The reform end up turning farmers more vulnerable to bad harvests[190].

The recognition that the effectiveness of economic reforms is largely conditional on their interaction with existing policies and institutions had lead policymakers and international institutions to search for an appropriate sequence of reforms[191]. Along this reasoning, it has been argued that the optimal policy often involves adapting the institutional arrangements to fit a country set of characteristics[192]. An example of this is in Box 9.6.

[189] Douglass North (1994, p.8): "(…) transferring the formal political and economic rules of successful western market economies to third world and Eastern European economies is not a sufficient condition for good economic performance". [North, D., 1994. Economic performance through time". The American economic review 84(3), 359-368].

[190] Kranton, R., Swamy, A., 1999. The hazards of piecemeal reform: British civil courts and the credit market in colonial India. Journal of Development Economics 58, 1-24.

[191] Along this reasoning, it has been argued that laggard countries, which are expected to rely more on adoption of foreign technologies than on own innovation efforts, should focus first on institutions to support investments, such as long-term banking finance. In a later stage, when innovation becomes more important, free entry, open competition, trade openness, and flexible labour markets become critical ingredients to provide a selection mechanism to weed out unprofitable projects [Acemoglu, D., Daron Acemoglu & Philippe Aghion & Fabrizio Zilibotti, 2006. "Distance to Frontier, Selection, and Economic Growth," Journal of the European Economic Association, vol. 4(1), pages 37-74, 03.].

[192] Rodrik (2006). Rodrik, D., 2006. Goodbye Washington Consensus, Hello Washington Confusion?, Journal of Economic Literature 44 (4), 973-987.

Box 9.6. Islamic Finance

The Islamic laws (*Sharia*), which rule the social, political and economic aspects of Islamic societies, encourage hard work, fair dealing, property rights, and the honour of contracts. The law also approves the earning of profits, because profits reward successful entrepreneurship and reflect the creation of additional wealth.

The Sharia prohibits however interest payments. The reason is that interest is a predetermined cost that is due irrespectively of the business outcome[193]. Banishing interest payments, the *Sharia* precludes the use of bonds and the development of banking, at least as designed for industrial economies. This, in turn, leads to insufficient savings, low investment and low growth.

Fortunately, a window was open to adapt the concept of banking so as to make it acceptable by the Islamic rules. This window is labelled *Murabaha*: this consists on a purchase and resale contract, in which the bank purchases goods from the producer with the promise to re-sell them at an agreed-upon date at an agreed-upon inflated price. Although it looks like a debt-instrument, the *Murabaha* is viewed as legitimate by the Islamic laws, because the financier bears risk during the period he owns the goods.

The principles of Islamic Finance were already practiced in Muslim societies throughout the middle ages, but it was after its inception in Egypt, in 1963, in Dubay, in 1975, and the opening of the first Islam bank subsidiary of a Western Bank (the Citibank) in Barhain in 1996 that Islamic Finance flourished around the world. Today, there are more than three hundred Islamic financial institutions operating in more than 75 countries, including in Europe and the United States. These institutions offer a wide set of instruments targeting the needs of providers and users of funds: *murabaha* (trade with mar-kup financing), *bay' salam* (forward

[193] Because the Islamic doctrine advocates profit sharing (*qirad*), it foresees instead a kind of "venture capital" called *Mudarabah*: under this scheme, one party provides the capital for a project and the other party provides labour effort. The principle is that providers of funds become partners instead of creditors: if the enterprise succeeds, they share profits; if it fails, they lose the capital and the working time invested. Such a contract reflects the ideal cooperative spirit of Islam: borrowers and lenders share losses as well as rewards.

sale), bay’ mu’ ajjal (deferred payment sale), *ijara* (leasing), *mudarabah* (profit-sharing), *musharaka* (partnership). These instruments can then be combined to build a wider range of complex financial instruments.

The emergence of Islamic banking is creating big challenges to policymakers. This includes developing a framework to implement monetary policy and adapting the Western institutions of supervision and regulation. But with no question, Islamic Finance has proved to be a successful form of providing funds to entrepreneurs in compliance to a specific culture. It offers a good example of the principle that sometimes it is better to have a well-adapted institution than trying to imitate the original one without taking into account the specific circumstances[194].

9.5 A simple model of technology adoption

This section presents a two-sector model to illustrate the challenges of an economy aiming to catch up with the technological frontier. In this model, the cumulative nature of knowledge is accounted for assuming that technological improvements in the domestic economy depend both on the domestic stock of knowledge and on developments at the frontier technology. In this model, country characteristics and the research effort determine how far the country gets from the world technological frontier, while its long run growth is linked to the world-wide rate of technological progress[195].

9.5.1 The trade-off between production and R&D

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[194] For a brief description of Islamic finance, see El Qorchi (2005). [El Qorchi, M., Islamic Finance Gears Up, Finance and Development December 2005].

[195] Models along this line include, for instance, Barro and Sala-i-Martin (1997) and Klenow and Rodriguez-Clare (2005). [Barro,, R, Sala-i-Martion, X., 1997. “Technological diffusion, convergence, and Growth”. Quarterly Journal of Economics 113, 1025-1054. Klenow, P. and Rodriguez-Clare, A., 2005. “Externalities and Growth”. In Aghion, P., and Durlauf, S. (eds), Handbook of Economic Growth, North Holland, Amsterdam, Chapter 11, 817-866].

The economy has two sectors, the production sector and the research sector. The production sector employs capital and labour to produce final goods and services, which are used for consumption and investment in physical capital. The research sector employs labour, to expand the stock of knowledge, that can be employed in both sectors. Formally, the total labour force in the economy (N) is split in two groups: those workers engaged in the production of final goods (N_Y) and those workers engaged in the research sector ($N-N_Y$). Denoting by μ the fraction of the total labour force (N) devoted to R&D, we have:

$$N_Y = (1-\mu)N \qquad (9.1)$$

In the final goods sector, output consists in a homogenous good, *Y*, produced under the Cobb-Douglas technology:

$$Y = AK^{\beta}\left(\lambda N_Y\right)^{1-\beta} \quad , \qquad (9.2)$$

where *K* includes both Human and Physical capital, N_Y is the fraction of the labour force involved in the production of goods and services, A stands for the influence of local idiosyncrasies, such as climate and natural resources, and λ measures the efficiency of labour.

Together, equations (9.1) and (9.2) illustrates the trade-off underlying the allocation of working time to the research sector versus production of final goods: if the economy commits a larger share of the labour force to R&D (μ rises), there will be a negative impact on per capita output, because less working time is devoted to final good production. Eventually, however, a higher research effort will allow output to expand faster over time, via faster technological change.

Output can be spent in consumption (*C*) or Investment (*I*=*sY*). The capital stock evolves as in the basic Solow model with and exogenous saving rate:

$$\dot{K}_t = sY_t - \delta K_t \qquad (9.3)$$

Also, in line with the Solow model, it is assumed that population expands at a constant rate, n.

9.5.2 The research technology

We now need to specify a relationship between resources employed in the research sector and technological change. To avoid scale effects, we postulate a functional form whereby the change in technology is proportional to the *fraction* of labour allocated to the research sector. Specifically, the production function of knowledge takes the following form:

$$\dot{\lambda} = b\mu\left[\bar{\lambda}^{\sigma}\lambda^{1-\sigma}\right] \qquad \lambda \leq \bar{\lambda}\,,\ \ 0<\sigma<1 \qquad (9.4)$$

Where b is a positive parameter measuring the "productivity in the research sector", $\bar{\lambda}$ represents the world "technological frontier" and σ is an exogenous parameter measuring the strength of technological diffusion into the country.

The knowledge production function captures the cumulative nature of knowledge ("standing on shoulders effect") postulating that the creation of new knowledge depends linearly on the existing stock of knowledge (term in brackets). The existing stock of knowledge is however an average of domestic and foreign knowledge. Implicitly, it is assumed the researcher combine domestic technology with frontier technology to produce new knowledge.

Parameter μ captures the research effort. It accounts for the spending of resources to discover or to adapt the technologies that better match the country needs. In a broad interpretation, you may also interpret μ as including government spending in the provision of public infrastructure, research institutes and agencies to promote technological change. According to (9.4). technological change requires a deliberate effort to invent new technologies or to adapt existing technologies. When no resources are spent, the country will not be able to benefit from world technological progress and will not grow.

In this formulation, the impact of the research effort is mediated by *productivity in the research sector*, b. In a narrow interpretation, this term may be interpreted as capturing the skills of engineers and scientists. In a broader interpretation, parameter b may be seen as capturing the influence of barriers to technological adoption, such as licensing, legal restrictions and low enforcement of property rights. These barriers increase the costs of adopting new technologies, implying that more resources μ are needed to achieve a given improvement in technology.

Dividing both terms of (9.4) by λ, we obtain the growth rate of technology in our economy as a function of the remaining parameters:

$$\gamma = \frac{\dot{\lambda}}{\dot{\lambda}} = b\mu\left(\frac{\bar{\lambda}}{\lambda}\right)^{\sigma} \qquad (9.5)$$

The second term in (9.5) may be interpreted as the “benefits of backwardness”: other things equal, the more knowledge remains to be absorbed by the country ($\bar{\lambda}/\lambda$), the higher it will be its rate of technological change. The rationale is that, as the country approaches the frontier, less and more complex ideas will be available for copying, so the cost of achieving a given improvement in technology increases. Countries that are backward relative to the technological frontier will enjoy greater improvements in technology for each unit of output spent in technology adoption. The parameter σ <1 imposes diminishing returns on the “advantage of backwardness”.

The expansion of the World technological frontier is the result of the cumulative R&D effort of all countries together. In this partial equilibrium model, we simply assume that the World technological frontier is expanding ate the exogenous rate $\bar{\gamma}$:

$$\bar{\lambda} = e^{\bar{\gamma}t} \qquad (9.6)$$

9.5.3 The Steady state

The benefit of backwardness implies that, all else equal, technological progress is faster when the country’ technological gap is larger. Thus, there is a force pulling the country towards the frontier. In the steady state, this force is powerful enough to ensure that its productivity level will grow at the same rate as the world technological frontier. Thus, in the steady state the condition $\dot{\lambda}/\lambda = \bar{\gamma}$ must hold. Using this in (9.5) implies:

$$\frac{\bar{\lambda}}{\lambda} = \left(\frac{\bar{\gamma}}{b\mu}\right)^{\frac{1}{\sigma}} \qquad (9.7)$$

Equation (9.7) states that the steady state technological gap is positively affected by the world rate of technological progress ($\bar{\gamma}$) and negatively affected by the country’ adoption effort (μ) and the productivity of the adoption effort (b).

The steady state level of per capita output in this model corresponds to the solution of the Usawa model (5.18), that we reproduce here:

$$y_t^* = (1-\mu) A^{\frac{1}{1-\beta}} \left(\frac{s}{n+\delta+\gamma}\right)^{\frac{\beta}{1-\beta}} \lambda_t . \qquad (9.8)$$

Solving together (9.7) and (9.8), using (9.6) and using the definition $\tilde{y} = y/\lambda$, one obtains the steady state level of per capita income in this extended version:

$$y_t^* = (1-\mu)A^{\frac{1}{1-\beta}}\left(\frac{s}{n+\delta+\bar{\gamma}}\right)^{\frac{\beta}{1-\beta}}\left(\frac{b\mu}{\bar{\gamma}}\right)^{\frac{1}{\sigma}}e^{\bar{\gamma}t}. \qquad (9.9)$$

As in the Solow model, country characteristics determine the level of income per capita, but not its steady state growth rate: the long run growth rate is exogenous and given by the world rate of technological progress. Also like the Solow model, this model does not predict absolute convergence of per capita incomes, but instead conditional convergence: differences parameters translate into cross-country differences in levels. In the long run, countries will evolve along parallel growth paths, an implication that is supported by the general evidence on conditional convergence.

There are however three main differences relative to the Solow model: First, the exogenous rate of technological progress now applies to the world, and the model determines how close the country gets to the world technological frontier. Second, the country's ability to approach the world technological frontier depends on the proportion of time allocated to research and technology adoption (innovation, adaptation), and the productivity of these efforts, b (that may be though as depending on political, social and economic factors). Third, the influence of the "old" parameters, namely aggregate efficiency (A), the propensity to invest in physical (human) capital (s), and the population growth rate (n), affects the position of per capita income given the level of technology

9.5.4 Transition dynamics

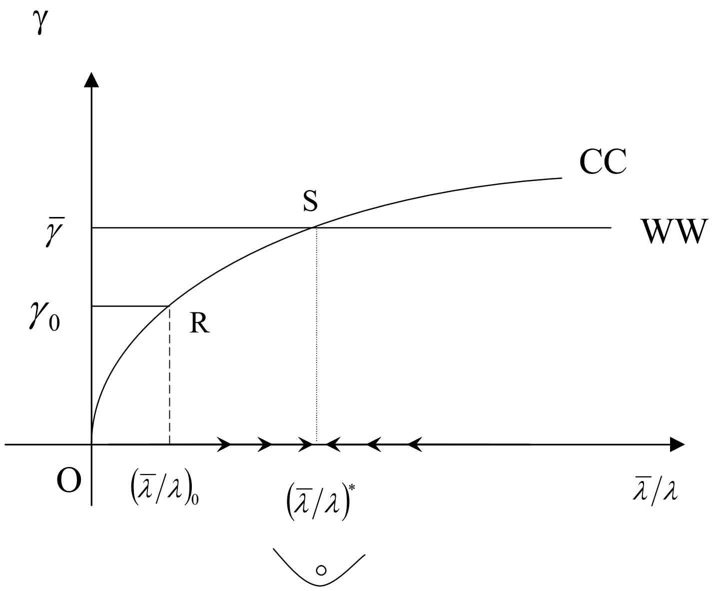
As in the basic Solow model, the principle of transition dynamics applies to changes in the exogenous parameters: a favourable change in a parameter will produce a *level effect* and a transitory period during which the country approaches the World technological frontier. During this period, the country will exhibit faster growth than the world average, but this will be temporary. In the long run, despite the differences in the behavioural parameters, the growth rate of per capita income in the country will be equal to that of the World frontier.

To see how the model works in the short run, we depict in Figure 9.1 the country rate of technological adoption, γ, as a function of its technological gap, $\bar{\lambda}/\lambda$ (Curve CC).

According to equation (9.5), this curve is upward sloped (a higher technological gap implies a faster rate of technology absorption) through the benefits of backwardness, but with diminishing returns. The figure also shows the growth rate of the World technological frontier, $\bar{\gamma}$, which is independent of the country technological gap (curve WW).

Now assume that the country is initially in point R, with a technological gap equal to $\left(\bar{\lambda}/\lambda\right)_0$. With such a gap, the rate of technological expansion in the economy is smaller than the world rate, that is $\gamma_0 < \bar{\gamma}$. This means that the economy will be diverging relative to the world economy. In the figure, the economy will move rightwards, from R to S (higher technological gap). As the technological gap increases, the advantage of backwardness manifests itself more strongly, so the rate of technological adoption (and, thereby, per capita output growth) increases. When point S is reached, the growth rate of the economy is exactly equal to the growth rate of the world technological frontier and the income gap stabilizes. By the same token, if the country starts out on the right-hand side of S, it will converge to S.

Figure 9.1: Transition *dynamics* and the steady state in the technology adoption model



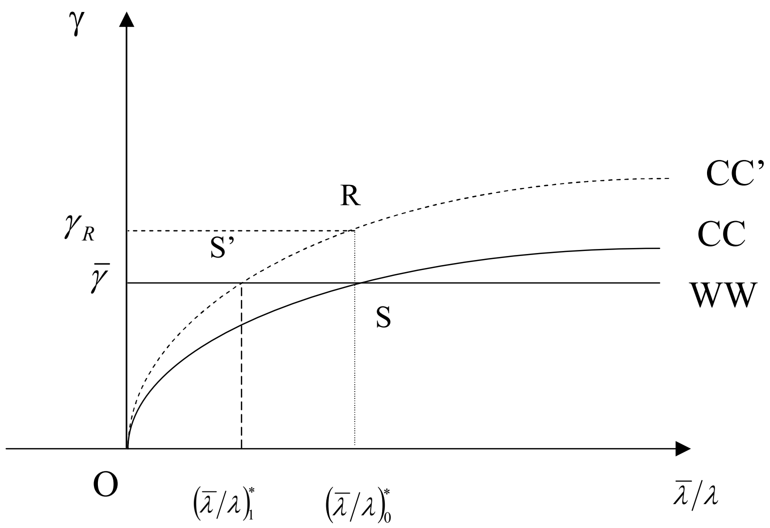
The curve CC describes the benefits of backwardness, for a given adoption effort. The curve WW describes the world rate of technological progress, which is exogenous. In point R, the country' technological gap vis-à-vis the world frontier is too small given its characteristics, implying that technology in this country will expand at a slower pace than at the frontier. In result, the technological gap will increase until the steady state S is reached.

9.5.5 *What happens if the technological adoption effort increases?*

Figure 9.2 describes the effect of a rise in the country' adoption effort. From (9.5), an increase in μ causes the CC locus to shift upwards. This means that the steady state moves to a different point (from S to S').

If the country is initially in the original steady state S, at the impact there will be an acceleration in the growth rate of technology adoption (from $\bar{\gamma}$ to γ_R - point R). Since the country technology is now expanding faster than the World frontier, the technological gap starts decreasing, meaning that the country moves leftwards, from R to S'. As the technological gap decreases, the benefit of backwardness decreases, implying a declining growth rate. In the new steady state (S'), the economy will again evolve in parallel relative to the rest of the world, but with a smaller technological gap disparity than initially.

Figure 9.2: The effect of an increase in adoption effort or of a decrease in barriers to technology adoption



Departing from S, an increase in research effort or an improvement in the country's permeability to global technological progress will increase its rate of technological change above the world average (point R). As the technological gap decreases, the benefit of backwardness diminishes, until the technological gap stabilizes (S').

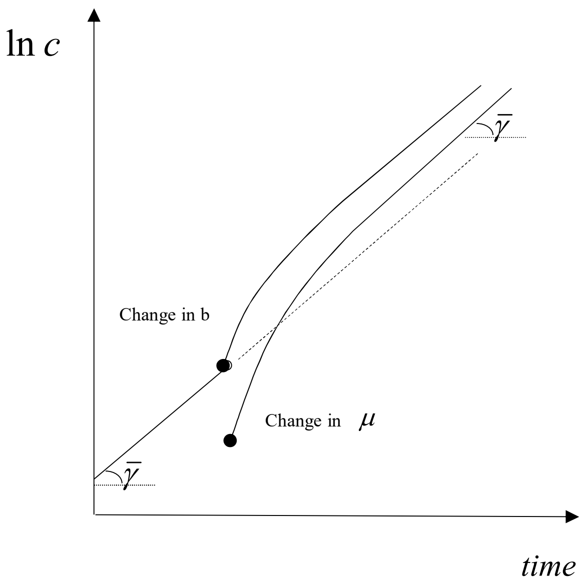
9.5.6 What happens when barriers to technology adoption decline?

Assume now that the economy opened to international trade, enabling the economy to draw more on foreign technologies than before, for each level of adoption effort. In our model, this is captured by an increase in parameter σ. Alternatively, assume that competition laws become more effective, allowing the productivity of researchers *b* to increase. In terms of

Figure 9.2, the elimination of barriers to technological adoption causes the locus CC to shift up, like when the intensity of research increases. The adjustment mechanism is also similar to the one before: the economy will grow temporarily faster than the rest of the world, but as the productivity gap declines, the growth rate approaches the world rate of technological progress (point S').

The main difference between the two cases is that an increase in the adoption effort involves the reallocation of resources away from production, while the elimination of barriers to technological adoption is in principle cheaper. Hence, although effects are similar in terms of Figure 9.2, the path of per capita consumption differs in the two cases. Figure 9.3 shows the difference: in the case of an increase in μ, there is an initial fall in per capita consumption that may or not deliver a higher consumption path in the new steady state. In case the improvements comes through elimination of barriers, a free cake is likely to be at reach.

Figure 9.3: The effect of an increase in adoption effort or productivity



The figures compares the impact on consumption of a technological improvement achieved with an increase with research effort with that achieved through the elimination of barriers to technological adoption.

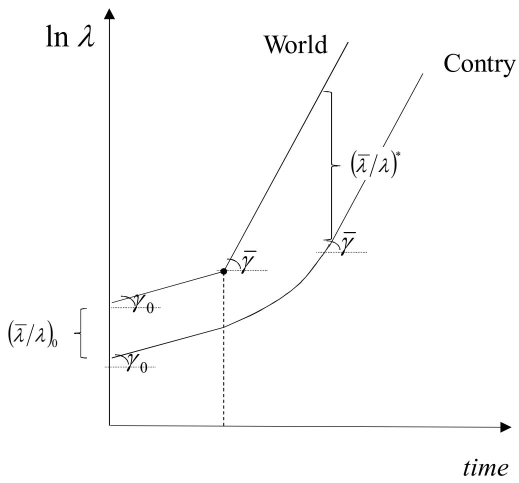
9.5.7 What happens when the world rate of technological progress increases?

We now analyse the impact of a shock that is out of control of an emerging country: a change in the world rate of technological progress.

To analyse this, let's refer again to Figure 9.1. Assume that initially the world technological frontier was expanding at rate γ_0 and that our emerging economy was in the corresponding steady state, with a constant technological gap equal to $(\bar{\lambda}/\lambda)_0$. Then suppose that the world rate of technological progress accelerated once-and-for all to $\bar{\gamma}$.

This change implies a shift in the country' steady state, from point R to point S. As explained before, the adjustment to the new steady state is not instantaneous: the faster expansion of the world technology frontier leads to a widening of the country technological gap. This, in turn, impacts positively on the country' rate of technology adoption (due to the benefit of backwardness). When the technological gap is sufficiently large, the country rate of technological absorption becomes equal to the world rate of technological progress $\bar{\gamma}$ and the technological gap stabilizes in its new steady state level, $(\bar{\lambda}/\lambda)^*$.

Figure 9.4: the widening of income gaps



Departing from a steady state, if the world technological frontier begins to expand faster, there will be a period during which the laggard country productivity gap will widen. With a larger gap, the benefits of backwardness will increase, fostering the country rate of technological change, until it matches that of the world technological frontier. In the new steady state there will be a larger technological gap than before.

Figure 9.4 displays the path of technology in the catching up economy (in logs) compared to that of the frontier: before the shock, the two technologies were growing in parallel, with a gap equal to $(\bar{\lambda}/\lambda)_0$; after the shock, the two growth rates depart from each other, resulting in an episode of temporary divergence; in the new steady state, the two technologies evolve again in parallel, but the new technological gap $(\bar{\lambda}/\lambda)^*$ is larger than the initial one.

All in all, the implication of the increase in the rate of technological progress at the frontier is a widening of income disparities. In the long run, the emerging country will grow as quickly as the world economy, just because it has fallen sufficiently behind.

9.5.8 The great divergence revisited

The model just described offers an interpretation for the episode of the Great Divergence: when West Europe and the Western Offshoots entered in modern growth, the world technological frontier started growing faster than before. However, the rest of the world did not enter immediately in modern growth. Because of domestic idiosyncrasies, countries such as India and China entered in modern economic growth two centuries later, only.

According to the discussion above, the acceleration in the rate of technological progress in Western economies should have caused the technological gap of laggard countries to increase. In fact, per capita incomes relative to the leader in India and China fell from 44% and 48%, respectively in 1700 to only 7,9% and 7,2% in 1965. Then, as the income gaps got larger, these countries started benefiting from faster technological diffusion, implying that at some point in time (by the middle of the twentieth century) these countries stopped diverging (see Box 9.2).

Box 9.2 Miracles and Disasters

Figure 9.5 plots the evolution of per capita incomes in two leader economies, the United Kingdom and the United States, and six followers, Argentina, Portugal, China, India, Botswana and Chad.

The facts in the figure are as follows:

- The two leader countries, United Kingdom and the United States, have evolved mostly in parallel, with differences in levels that you may relate to differences in efficiency in which resources are used. You may think these two countries as driving the technological frontier and sharing equally the benefits of the world technological diffusion.

- China and India diverged relative to the leader countries from the beginning of the sample up to the mid-twentieth century. According to the model above, such divergence could be explained by an acceleration of technological progress in the leader countries.

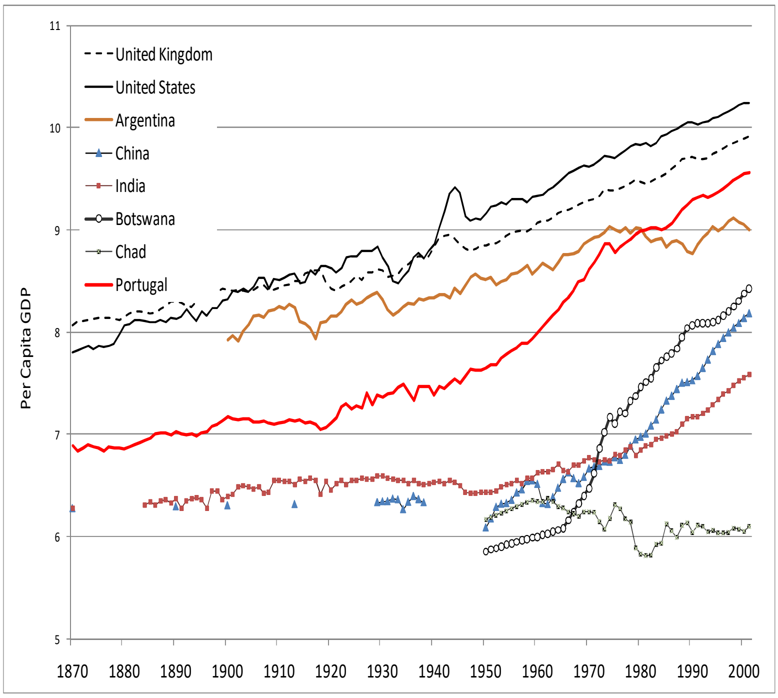
- By 1970, India is likely to have engaged in a parallel growth path without being able to catch up. This path is consistent to the idea that, when the laggard economy gets sufficiently behind, the benefits of backwardness prevent further divergence.

- In the second half of the twentieth century, some countries started approaching the leader countries: Portugal in the early 1950s, China in the early 1960s, Botswana in the mid-1960s. According to the model above, improvements in political, social and economic environments may have helped increase permeability of these countries to the world technological diffusion. These improvements translate into level effects in per capita income and hence to a temporary growth surge. In the long run, each country is expected to stabilize in a parallel growth path vis-à-vis the leader country.

- Along the period, Argentina has diverged relative to the technological frontier. This case is symmetrical to the earlier one: some change in fundamental has tilted the Argentinean economy in the wrong direction, causing its income gap relative to the frontier to increase.

- Per capita income in Chad has stagnated and even declined in some years. This economy failed to achieve conditional convergence. The performance of this country suggests that extremely adverse local conditions, prevented the country from taking opportunity of global technological diffusion.

Figure 9.5: Miracles and Disasters



The figure describes the evolution of per capita incomes in different countries, since 1870. In light if the model above, one could interpret the different patterns as describing: technological leaders that have drawn the frontier (US, UK); countries where policy changes determined changes in the respective steady state income gaps (Argentina, China, Portugal, and Botswana); countries that only started growing in parallel when the gap became high enough (India); and a non-converging country (Chad)

9.5.9 Proximate causes versus ultimate causes once again

The model stresses the role of exogenous parameters, such as the saving rate (s), the adoption effort (μ), and the productivity of adoption (b) in determining how close a country gets to the technological frontier.

It worth remembering, however, that these parameters can hardly be taken as independent from each other. For instance, an increase in the research effort may induce organizational and political changes in the country, paving the way to alleviate barriers to technological adoption: that would be a case of transpiration bringing more inspiration.

Similarly, in an economy closed to international trade, where property rights are not enforced and where privileged elites are able to block any attempt to introduce new technologies one will expect people to save less and to dedicate less resources to the adoption of new technologies (low transpiration because of low inspiration).

In a limiting case where property rights are not enforced at all, no agent in the economy will make any effort to innovate, and the economy will not be growing, despite the technological change at the frontier. This extreme case would capture the world poorest economies, that have not been able to achieve conditional convergence[196].

This discussion brings us again to the discussion of proximate causes versus the ultimate causes of economic growth. A reduced-form model such as the one described above is helpful to understand the mechanics of economic growth and to discuss links between critical behavioural parameters and economic performance. But if one really wants to deepen the question and ask why do some countries save more or invest more in R&D than others, we have to depart from the simple equations outlined above and ask what determines the fundamental parameters that we are taking as exogenous.

9.6 Key ideas of chapter 9

- The view that poor countries may catch up with rich countries by imitating successful technologies without the need to invent them again is labelled the "advantage of backwardness".
- In general, openness to trade and international factor mobility increase a country exposure to outside innovations, through demonstration effects, enhanced competition, and the transmission of tacit knowledge.
- The absorptive capability of a country depends on local characteristics, such as human capital endowments, infrastructure, institutions, and geography. Governments have a role in shaping a country set of capabilities in order to make it more attractive to technological change.
- Accumulated experience with an old technology may help or retard the adoption of the new technology, depending on how useful the inherited knowledge is to operate with the new technology.
- The arrival of new technologies may destroy existing rents. Vested interests with a stake in the old technology may use their political power to block the adoption of newer technologies.

[196] Howitt (2000) proposed a Schumpeterian model of economic growth, where the innovation effort is endogenously chosen by profit maximizing firms. The author shows that only in countries with a *minimum* level of protection of property rights firms will find it profitable to innovate. When these minimum conditions are not met, firms prefer not to innovate, and the economy stagnates. This case intends to capture the situation of the World poorest countries, which growth rates are mainly driven by internal factors. [Howitt, P., 2000. Endogenous growth and cross-country income differences", American Economic Review 90, 829-846].

- The fact that countries differ in terms of capabilities implies that the appropriate technology differs from country to country. The process of finding out which technology better suits a country set of capabilities is labelled "self-discovery". The process of self-discovery involves externalities that turn the adoption effort suboptimal in a laissez fare.
- Most innovations are targeted to match the characteristics of industrial countries. The transfer of these technologies to the development context may imply adaptation efforts. This is valid not only for technology in the engineering sense, but also to policies and institutions.
- The model of technological catching up analysed in the chapter distinguishes a world technological frontier and the technological level of an individual country.
- According to the model, international technological diffusion prevents countries from drifting indefinitely apart from each other. How close each country gests to the world frontier depends, however, on its absorptive capacity.
- In light of this model, an acceleration of the world rate of technological progress translates into faster growth in the laggard country too, but this will come up with a lag, implying that during the adjustment process the income gap vis-à-vis the frontier increases. This model offers an interpretation for the Great Divergence.

Problems and Exercises

Key concepts

- *Advantage of backwardness. Tacit knowledge. Vintage capital. Leapfrogging. Barriers to technology adoption. Learning costs . Value of experience . Self-discovery. Directed technological change.*

Essay questions:

- Explain how the adoption of a new technology may be retarded by complementarity effects relative to other factors and substitutability effects relative to older vintages.
- Comment: "Institutions do not travel well".
- Explain why in many poor countries the simple adoption of foreign technologies results in productivity gaps that cannot be eliminated along time.
- "The advantage of backwardness implies that laggard countries are doomed to grow faster than rich countries".

Exercises

9.1. In the "Alpha" economy, the typical company's production function is given by $Y_t = 0.5K_t^{1/2}(\lambda_t N_t)^{1/2}$, where K_t e N_t represent the physical capital and the number of workers in each production unit and λ is a term measuring the quality of the work factor. In this economy, the savings rate is 25%, population is expanding at 1%, and the depreciation rate is $\delta = 0.02$. (a) Assume for a moment that $\lambda_t = e^{0.02t}$. d1) Calculate the per capita product in efficiency units in the at steady state, $\tilde{y}$. d2) Describe the evolution of per capita income in steady state. d3) Graph and discuss the stability of the equilibrium. (b) Now take over that this economy did not produce its own technology, importing ideas from the rest of the world instead. In particular, assume that technology evolves according to $\dot{\lambda}/\lambda = b\mu(\bar{\lambda}/\lambda)^{0.5}$. f1) Interpret this equation. f2) Calculate the steady state technological gap assuming that $b = \mu = 0.01$. (g) Assume that the country managed to increase parameter b to b=0.125. (g1) Which type of reforms can be captured with this change? (g2) Describe in a graph the evolution of per capita income in that country until the new steady state is reached.

9.2. Consider a small emerging economy with the following production function: $Y = AK^{0.5}(\lambda N)^{0.5}$, where K includes both human and physical capital and λ measures the efficiency of labour. In this economy the population is constant, the saving rate is equal to s=0.2, the depreciation rate is equal to δ=0.03 and A=0.25. (a) Assume first that technology in this economy expands at 2% per year. Find the steady state in this economy and discuss the stability of the equilibrium. (b) Assume that technology in this economy evolves according to $\dot{\lambda}/\lambda = b\mu(\bar{\lambda}/\lambda)^{0.5}$. (b1) Find out the steady-state technological gap assuming that $\mu = 0.05$, b=0.1, and $\bar{\gamma} = 0.02$. (b2) Departing from (b1), assume that the rate of technological progress at the frontier decelerated to 0.01. Wat would be the implications for the technological gap and per capita income convergence?