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ABSTRACT

This chapter presents a tractable framework for the study of technology adoption and diffusion in the context of economic development. Firms in countries behind the world technology frontier can rapidly adopt new techniques from the world frontier. Lower absorptive capacity (because of weak education systems, poor management practices, or barriers to technology adoption), institutional distortions, mismatch between frontier technologies and the needs of firms in the country (i.e., “inappropriate technology”), and credit market frictions slow down technology adoption and cause the economy in question to have a greater distance to the frontier and thus lower income per capita—although the long-run growth rate of the country still remains equal to that of the frontier. This framework is extended to study the choice between innovation and imitation, as well as the role of selection for higher-productivity and higher-absorptive capacity firms during the process of economic development. We illustrate the main comparative statics of our framework with a number of correlations based on cross-country and firm-level data. The tractability of the framework makes it amenable to a range of additional extensions.

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1 Introduction

Studies of economic growth in industrialized economies single out advances in technology as the most important engine of change (see the discussion in Barro and Sala-i Martin, 2004; Acemoglu, 2009) and researchers have emphasized technology differences as a key driver of cross-country disparities in prosperity around the world today (Klenow and Rodríguez-Clare, 1997; Hall and Jones, 1999; Acemoglu and Zilibotti, 2001; Caselli, 2005; World Bank, 2024).

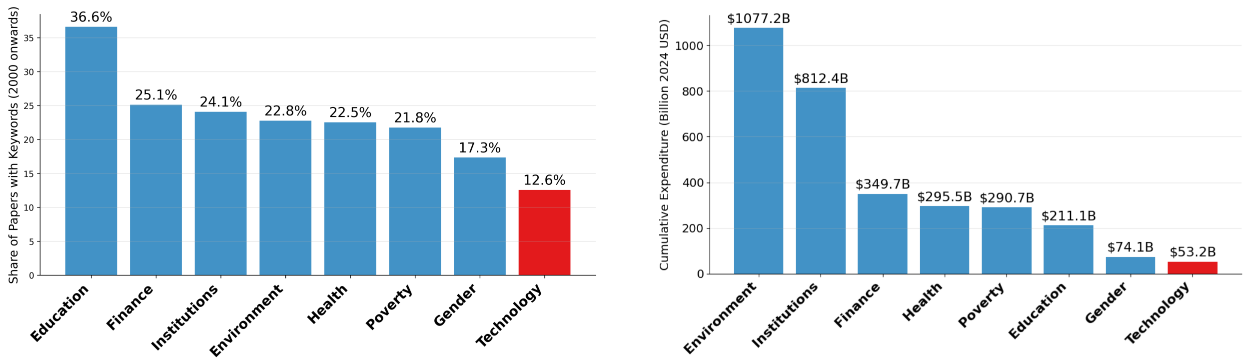
In contrast, much of the economic development literature focuses on other issues. Academic articles in the field give a glimpse of this emphasis. Among 4,716 papers published in the field of economic development since 2000, Figure 1a shows that less than 13 percent have a keyword related to “technology”, while 37 percent have one related to “education”, 25 percent related to “credit” or “finance”, 24 percent related to “institutions” or “political economy”, around 23 percent related to “environment” and another 23 percent related to “health”, 22 percent related to “poverty”, and finally 17.3 percent have keywords related to “gender.”

This focus appears to extend from research to policy. In terms of headline emphasis, Figure 1b shows that only about $53.2 billion worth of World Bank lending is identified by Bank staff to be dedicated directly to improving technology while, over the same time period, loans focused on the environment made up over $1 trillion, loans designed to improve institutions over $800 billion, loans in support of better health almost $300 billion, loans for the education system $211.1 billion, and loans focused on gender $74.1 billion.[1]

There are some good reasons for this difference in emphasis between studies of economic growth in today’s high-income countries and those of economic development in lower-income countries. Many problems in today’s less developed economies are related to market failures, as well as inefficient institutions and policies that induce countries to operate well within their “production possibilities frontier” (meaning that they produce less than they should be able to given their technology and factor endowments). Nevertheless, technology still plays a leading role in the problems of development—not least because the same market failures and institutional factors also adversely affect technology and thus the overall production possibilities frontier of an economy. More importantly, better technology directly improves the productive capacity of an economy, enabling more efficient use of its factors of production and resources.[2] This chapter argues for a greater

[1] The data sources and construction of these categories are described in the Appendix.

[2] Technological backwardness may also contribute to market failures—e.g., in education and health, but



(a) Keywords in Development Economics Publications

(b) World Bank Development Support by Focus Area

Figure 1: **Technology's Relative Emphasis in Development Research and Policy**
Note: The left panel shows the percentage of 4,716 articles published in top economics journals between 2000 and 2025, classified under JEL codes O1 (Economic Development) and O2 (Development Planning and Policy), that contain selected keywords in their abstracts. Keywords are grouped into eight themes. An article is classified under a given theme if its abstract contains at least one of the keywords of that theme, and, a paper can be classified into multiple themes. The right panel shows the total commitment amount in billions of US dollars for World Bank development assistance projects from 2001 to 2025, categorized by the same 8 themes and the same set of keywords as the left panel. Data is from the World Bank Projects & Operations database. The total commitment amount over this period is $2.38 trillion (in 2024 US dollars), allocated across 13,761 projects. See the Appendix for more details.

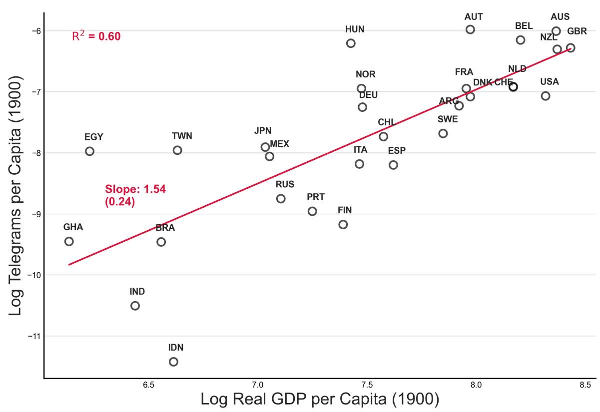
focus on technology-related questions within development economics.

There is plenty of evidence that technology is correlated with economic development. Countries that are economically less developed lag behind in various measures of technology.[3] Figure 2 uses data from Comin and Hobijn (2010), Acemoglu (2025), and the World Bank to give a glimpse of this relationship, focusing on some of the leading technologies from different eras. The first panel depicts the correlation between gross domestic product (GDP) per capita and telegram usage per capita in the early 1900s. The second panel shows that in the 1950s there was a similar relationship between GDP per capita and an important advanced technology of that era, the telephone. The third panel turns to a more modern example of a frontier technology, the Internet, and shows the same pattern in the 2000s. The last panel focuses on how "advanced technology-intensive" each country's exports are, as an omnibus measure of technological development, which exhibits a similar

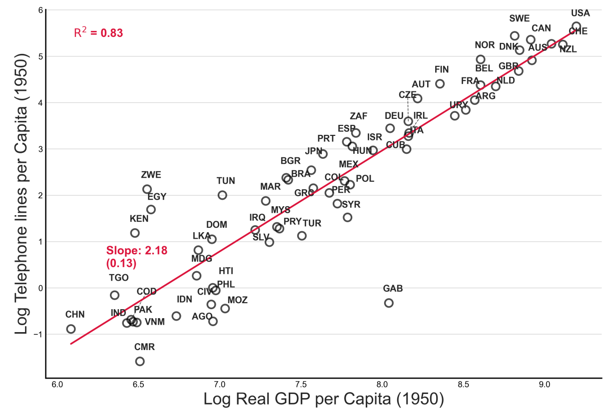
also in the context of monopoly and market structure—though this is beyond the focus in this chapter.

[3]As in much of the economic development literature, we use GDP per capita or GDP per worker as a proxy for economic development. Even though the process of development is multifaceted, there is a strong association between GDP per capita and other aspects of economic development such as lower poverty, urbanization, share of industry and services in national income, education, health, and a more integrated market.

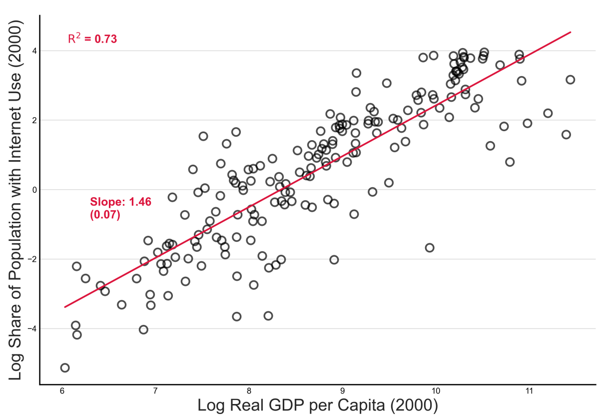
relationship.[4] All four panels in Figure 2 indicate that technology—more specifically the adoption of already well-established advanced technology—in lower income economies has consistently lagged behind best practice. Although these correlations by no means establish a causal role of technology in economic development, this pattern indicates that any macroeconomic account of economic development must grapple with the covariation between technology and GDP per capita.



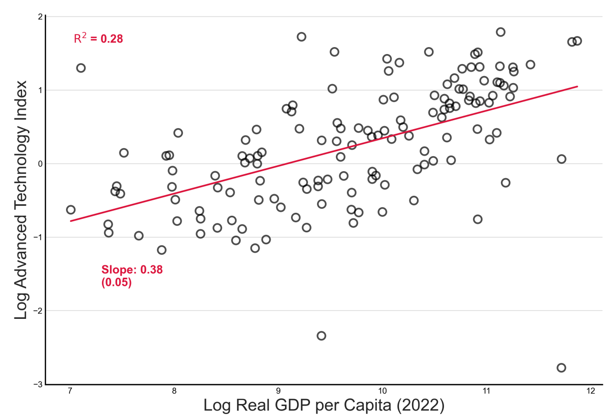
(a) GDP per capita and telegram usage, 1900.



(b) GDP per capita and telephone lines, 1950.



(c) GDP per capita and internet use, 2000.



(d) GDP per capita and Adv. Tech. Ind., 2022.

Figure 2: **Technology diffusion and economic performance**

Note: The figure shows the correlation between log GDP per capita (PPP-adjusted) and four different measures of technology adoption across different time periods. The top-left panel uses telegrams per capita in 1900 and the top-right panel uses telephone lines per capita in 1950, both computed from Comin and Hobijn (2010). The bottom-left panel uses the share of internet users in 2000, computed by the World Bank. The bottom-right panel uses the Advanced Technology Index in 2022. Country labels are shown in top panels. The red line in each panel represents the linear fit. See the Appendix for further details.

This chapter develops a simple framework for the analysis of technology adoption and its relationship to economic development. Our purpose is to provide a workhorse

[4]The sources and construction of the variables in this figure are described in the Appendix.

model for researchers to use in subsequent in-depth analysis of how technology affects development by impacting the productive capacity of an economy. This objective motivates our choice of a tractable framework that features firm-level technology decisions—so that the framework is useful for studies that rely on firm-level data. Given our focus on technology in less developed economies, the key choices we model concern technological upgrading (adoption of new and advanced techniques from the world frontier and other improvements in technology), rather than innovation at the frontier.

Our model has two building blocks:

- We build on ideas first articulated in Gerschenkron (1962) and modeled in Acemoglu et al. (2006) and Acemoglu (2009, Chapter 18), whereby there is a "technological advantage to being backward", in that economies that are behind the world frontier can improve their technology faster by adopting technologies from the frontier than those at the frontier, which typically have to advance through new inventions and innovations. This is the main consideration that makes our approach be about technology adoption rather than frontier innovation (for which there would presumably be no advantage to being backward).
- We use a variant of the framework first proposed by Klette and Kortum (2004), which extends the macro models of Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992) to firm-level technology choices and dynamics—with the main difference that instead of labor reallocation due to "creative destruction" at the firm level, our model features an expansion in the set of intermediate inputs used in production, driven by firm-level technology adoption decisions, which in equilibrium induces a reallocation of labor from existing intermediates to new ones.

In the long-run equilibrium of this framework, all countries settle into the same growth rate as the world technology frontier. Hence, the long-run equilibrium determines the *relative technology* and *relative income per capita position* of each country. The reason for this configuration is that, given the "technological advantages to being backward", countries are always pulled to the same growth rate as the frontier. In particular, if a country were to grow permanently at a lower rate, it would fall so far behind the world frontier that adopting ideas and technologies from the frontier would be easier and faster, and hence its growth rate would ultimately increase. With the same logic, a country could not grow faster than the frontier either—for it would lose the advantage of being backward and technological improvements would become harder and harder over time. Institutional, human capital, and scientific characteristics of countries determine their relative position. Consequently, with a given distribution of country characteristics, the long-run equilibrium of this model determines a stable world income distribution.[5] We also show that starting from any distribution of initial technology levels, there is a unique dynamic equilibrium which converges to this long-run equilibrium.

After developing this framework, we use it to illustrate the natural linkages between institutions, credit market conditions, and market structure, on the one hand, and overall economic development, on the other. With this framework, we also discuss the issue of "inappropriate technology", whereby frontier techniques are not well suited to the conditions of developing countries, thus making the diffusion of technology slower and less productivity-enhancing for poorer economies. We then extend the framework to illustrate how informality, along with various market and policy distortions, working through the "selection" process that shapes the composition of firms in terms of different productivities and technological capacity. Finally, in the last part of the paper we present a number of correlations in cross-country and firm-level data that illustrate the key comparative statics from our framework. We start in the next section with a brief overview of the literature on technology in economic development.

2 Literature on Technology in Economic Development

The framework presented in this chapter blends various elements from the (endogenous) growth and economic development literatures. We start by overviewing key relevant contributions from the growth side.

Gerschenkron (1962) provided the original insight that less developed countries could "catch up" relative to more developed economies through employing a variety of strategies, including imitation of frontier technologies and alternative financial arrangements. Nelson and Phelps (1966) proposed a seminal model of technology diffusion with some elements of Gerschenkron's emphasis. Building on these insights, a complementary perspective emphasizes that catch-up depends on a country's "social capability" and its ability to absorb and implement frontier knowledge (e.g., Abramovitz, 1986; Benhabib and Spiegel, 1994; and Cohen and Levinthal, 1990). Some of these ideas are also discussed in the context of technological leapfrogging—whereby countries that are behind can jump ahead of others, because they can be faster in adopting new technologies. A

[5] While there are large variations in country growth rates from decade to decade and major changes in institutions and other important characteristics, the world income distribution since the 1950s has been largely stable—with only a small increase in the cross-country variance of GDP per capita. See Acemoglu (2009, Chapters 1 and 3) for further discussion.

model of economic growth with leapfrogging was developed in Brezis et al. (1993), while Hornbeck et al. (2024) explore leapfrogging in the context of transitioning from water to steam power and Ames and Rosenberg (1963) discuss historical changes in technological leadership more broadly. More recently, Akcigit et al. (2026) analyze how globalization and trade policy affect the evolution of cross-country technological leadership, including the scope for catch-up and leadership turnover.

The formal modeling of endogenous growth through the adoption and spread of existing technologies begins with Romer (1986, 1990), and runs through Grossman and Helpman (1991), Aghion and Howitt (1992), and Howitt (2000), although the primary emphasis in this literature is on innovation and frontier technologies. Acemoglu et al. (2006, AAZ) presents a framework where firms have a choice between innovation and imitation, with imitation benefiting from the existence of frontier technologies as suggested by Gerschenkron. This paper also discusses the role of alternative financial and institutional arrangements at different stages of technological development. Gancia and Zilibotti (2009) further extend this framework to discuss the diffusion of technology from advanced to less-developed economies. Acemoglu (2009, Chapter 18) presents a model similar to the one we study here but without the firm-level structure. In that work, as in this chapter, there is a single technology adoption effort which has elements of innovation/imitation/adaptation, and this benefits from a flow of ideas emanating from the world technology frontier.

Our chapter is also related to a small but growing macroeconomic literature on the adoption and diffusion of technology. Parente and Prescott (1994), Andolfatto and MacDonald (1998), Jovanovic and Stolyarov (2000), Manuelli and Seshadri (2014), and Comin and Mestieri (2018), among others, consider neoclassical (competitive) models of technology adoption and diffusion. Acemoglu et al. (2012) present an endogenous growth model, where "standardization" can be an engine of growth through technology adoption but can alternately be a barrier to long-run innovation. On the empirical side, Comin and Hobijn (2010) build a new data set of diffusion of a large number of technologies and document their slow diffusion (see the data cited in the Introduction). Related work emphasizes international knowledge spillovers as well as the role of trade and geography in shaping technology diffusion (e.g., Coe and Helpman, 1995; Eaton and Kortum, 2002; and Keller, 2004). Complementing this diffusion perspective with a micro-founded firm-dynamics approach, Akcigit and Ates (2021) link the slowdown in business dynamism and rising concentration to a decline in knowledge diffusion from frontier firms to laggards. Recent reviews of technology adoption in the development context can be found in Cirera et al. (2022) and Kruger and Steyn (2025).

Technology adoption is also closely related to the question of misallocation of resources. Hsieh and Klenow (2009) assessed how misallocation reduces aggregate productivity using micro firm-level data, finding significantly more misallocation in less developed economies than in the United States. A complementary, model-based literature emphasizes how frictions and policy distortions can generate persistent dispersion in firm size and productivity and thereby lower total factor productivity, TFP (e.g., Hopenhayn and Rogerson, 1993; Restuccia and Rogerson, 2008; and Guner et al., 2008). Using a similar approach, Restuccia (2025) also finds more dispersed firm-level productivity and greater misallocation in lower-income countries.

Technology adoption and its implications have been analyzed in a number of subliteratures in economic development.

First, the role of technology in economic development is often intertwined with institutions. Knack and Keefer (1995, 1997), Hall and Jones (1999), Acemoglu et al. (2001, 2002), Acemoglu and Johnson (2005) and Besley and Persson (2011) have provided cross-country evidence supporting the hypothesis that strong institutions impact long-term prosperity, and have suggested that technology choices are one of the primary channels via which this effect operates. Similar evidence on the long-lasting influence of institutions, exploiting subnational variation, is presented in Banerjee and Iyer (2005), Iyer (2010), Dell (2010), Dell et al. (2018), Dell and Olken (2020), and Iyer and Weir (2025). This literature is surveyed in Johnson (2025), while Acemoglu (2025) offers a framework integrating political economy with the choice of technology.

The interplay of institutions and technology choices is relevant, too, in the context of "middle-income trap" discussions, which pertain to the potential inability of developing countries to continue to grow after they reach a certain level of income, well below that of the more developed economies (see, e.g., Gill et al., 2007; Gill and Kharas, 2015; and World Bank, 2024). Acemoglu et al. (2006) propose one explanation for such traps based on the idea that the power of large incumbent firms may prevent a switch from imitation-based growth to the requisite innovation-based growth once a country is no longer too far behind the world frontier.

There is also a small literature examining micro data to estimate how institutions and technology interact in the process of development. Besley (1995) provides an early study showing an impact of property rights on agricultural technology and productivity in Ghana. Akcigit et al. (2023) point to one channel via which institutions affect technology: larger firms are more likely to be politically connected and to survive, but are less likely to be innovative. Relatedly, Akcigit and Goldschlag (2023) study the allocation of inventors across firms and show that inventors have increasingly sorted into large incumbents; moreover, inventors hired by incumbents earn more but exhibit lower subsequent innovative output, consistent with incumbents dampening the implementation of frontier ideas. In a complementary vein, Akcigit and Kerr (2018) document systematic heterogeneity in innovation across the firm-size distribution, showing that smaller firms contribute disproportionately to major breakthroughs, while larger firms tilt toward more incremental innovation.

Second, there is long-standing emphasis on technology adoption and its interplay with national-level knowledge in the context of particular sectors. Much of this work is focused on agriculture and starts with Schultz's seminal contribution (Schultz, 1964), which stressed the role of human capital in technology adoption. Important work building on this approach includes Foster and Rosenzweig (1996), who provided evidence that technological changes associated with the Green Revolution increased returns to schooling, while Foster and Rosenzweig (1995) showed that the adoption of high-yielding seeds was impeded by a lack of knowledge, but this could be overcome through experience and by learning from neighbors. Munshi (2004) finds that learning across neighbors is harder in more heterogeneous societies. Conley and Udry (2010) provide evidence on social learning and the diffusion of profitable agricultural practices. Besley and Case (1993) discuss alternative approaches to modeling the adoption of new agricultural technology in low-income settings. More recent work has used randomized controlled trials (RCTs) to shed light on whether and why productive agricultural technologies may not be adopted rapidly. In particular, Duflo et al. (2008, 2011) found that farmers in Western Kenya "fail to take advantage of apparently profitable fertilizer investments, but they do invest in response to small, time-limited discounts on the cost of acquiring fertilizer (free delivery) just after harvest." Chandrasekhar et al. (2022) argue that farmers (correctly) believe that not all information is reliable and they are concerned about passing along incorrect facts, as this will damage their reputation. The role of learning from experience and from social networks has also received some attention, and the relevant literature is discussed in Munshi (2004, 2007).

Issues of technology adoption are arguably even more important for manufacturing, which are often at the forefront of modern technology adoption in developing countries. Kaldor (1967) placed early emphasis on the importance of manufacturing for economic growth, and this theme has been developed by Rodrik (2016). Other works that studied the adoption of new technologies in the manufacturing sector of developing countries include, among others, Su and Yao (2017) and Lavopa and Szirmai (2018).

There is also a large literature on public health-related technologies, much of which focuses on big public health campaigns or the adoption and spread of specific technologies. For example, Miguel and Kremer (2004) and Bleakley (2007) show large effects from hookworm eradication in Kenya and the US South, respectively, while Hoddinott et al. (2008) study the long-term effects of providing a nutritious supplement to children, and Charpak et al. (2024) document that the effects of improved perinatal care for vulnerable newborns last into adulthood. Bouguen et al. (2019) review what RCTs have revealed about what works in terms of improving health care (and related technologies) in low income settings. Kremer and Miguel (2007) additionally suggest a note of caution, again in the context of deworming, showing that one-time interventions may not be sufficient for the widespread adoption of an attractive technology. At the macroeconomic level, Acemoglu and Johnson (2007) document very large improvements in mortality and life expectancy in developing countries from the adoption of antibiotics and better public health measures from the 1950 onward, though they do not find corresponding positive effects on economic growth.

More recently, there is a growing literature on the adoption of digital technologies in developing countries. Jensen (2007) has pioneered the study of adoption of telecommunication technologies in developing countries, documenting the positive effects of mobile phones in terms of bringing buyers and sellers together in the fishing industry in Kerala, India. Mbiti and Weil (2011) show how mobile money facilitates welfare-enhancing financial transfers among people with few resources, while Suri and Jack (2016) document that the adoption of mobile money in Kenya increased consumption and reduced extreme poverty. Ugur and Mitra (2017) discuss technology adoption and its employment impact in low-income countries, while Sakyi et al. (2023) focus on problems of technology adoption in Africa. Cirera et al. (2022) survey the adoption of digital technologies in smaller firms across developing countries, more broadly. Fu et al. (2025) also use an RCT to establish how access to digital technology can help income resilience for marginalized communities in Bangladesh. See also Peters et al. (2026) in this Handbook on the role of digital technologies in service-led growth and structural transformation in developing economies.

Third, the issue of "appropriate" technology in economic development has received considerable attention. The idea of appropriate versus inappropriate technology, especially in terms of the capital intensity requirements of modern technologies, was proposed in Salter (1960) and David (1975), and refined further in Stewart (1978). More recently, Basu and Weil (1998) study a model of technology adoption in which frontier technologies are more capital-intensive than what would be ideal for developing countries and this reduces productivity growth in developing economies. Acemoglu and Zilibotti (2001) build a model of directed technological change where technologies developed in high income countries make optimal use of the skills available in those countries. When adopted in lower income countries, where the skill mix is different, there is a technology-skill mismatch that helps to explain the large cross-country differences in output per worker. In a similar vein, Caselli and Coleman (2006) find evidence in support of the idea that skilled labor-abundant richer countries choose technologies better suited to skilled workers, and these technologies are not ideal for places that are more abundant in unskilled workers. Moscona and Sastry (Moscona and Sastry) explore these issues using high-quality micro data on the transfer of modern seed technologies across countries and information on the types of pathogens affecting different crops in different areas. They find that inappropriate technology can still explain up to 20 percent of differences in agricultural productivity across countries. See also Moscona et al. (2026) in this Handbook on the importance of local context and appropriate technology issues in economic development. Another related literature focuses on international technology transfer via licensing agreements and trade linkages. This literature is discussed in Goldberg and Ruta (2026) in this Handbook.

In addition to those three thematic literatures, a number of papers relate to the comparative static results that emerge from our framework. At the macro level, Saint-Paul (1992), Acemoglu and Zilibotti (1997), and Greenwood and Smith (1997) explore the theoretical linkages between credit markets, technology choices and growth, while King and Levine (1993a,b) provide extensive evidence on the association between credit and growth. Levine (2005) surveys this literature, while more recently Comin and Nanda (2019) track the importance of financial development for technology adoption across long periods of time. At the microeconomic end, several papers, including Banerjee et al. (2015) and Banerjee et al. (2024), use RCTs to study the effects of credit on entrepreneurship and broader investments (though given the scale of the interventions, the effects on technology choice are often harder to detect).

A growing body of work explores the impacts of management practices on firm productivity and technology choices, though mostly focusing on industrialized economies. A pioneering study here is Bloom and Van Reenen's work on how management practices vary across firms and across countries—with institutions, human capital, and market structure being potential influences on management (Bloom and Van Reenen, 2007). Bloom et al. (2013) run a small-scale RCT in India and estimate that better management practices boost productivity through improved quality and reduced inventory holdings. Using the more model-based approach, Akcigit et al. (2021) find that inefficiencies in managerial delegation—and the preference for family members—account for 11 percent of the difference in income per capita between the US and India. There are additionally a few studies pointing to the relationship between informality and technology. La Porta and Shleifer (2014) argue that informal firms have low productivity and do not compete against formal sector firms, while Sodokin et al. (2023) suggest that firms in the informal sector may actually have the most to gain from the use of information technology.

There is also a growing literature on the process of selection, firm growth, and misallocation—relating to our discussion of selection and technology adoption. Hsieh and Klenow (2014) emphasize the differences in the extent to which more productive firms can grow in different developing economies and argue that this is a major cause of under-performance in some developing economies. Li and Lo (2023), using a variant of the AAZ framework, explore the same issues and find that "productivity growth falls with firm age in a country with well-developed financial market (e.g., the U.S.), but increases with firm age in a country with poor financial development (e.g., India)."

3 Theoretical Framework

Our purpose is to build a firm-level model of technology choice that provides insights on the role of technology in the process of economic development. Given this objective, we focus on technology adoption decisions of firms from a world frontier, modeled as in Acemoglu et al. (2006) and Acemoglu (2009). In particular, the distance to the technology frontier of an economy determines how easy it is for its firms to pick up technologies and ideas from that frontier. We take the evolution of the world technology frontier as exogenous, though that can be easily endogenized (as in standard endogenous technological change models or as in Acemoglu, 2009). Technology decisions are modeled as adoption effort at the firm level, which includes various activities associated with imitation and adaptation of existing technologies as well as research and development expenditure. The micro block of our model builds on Klette and Kortum (2004), except that instead of their quality ladder structure, we have a model of expanding input varieties.[6]

Throughout, we simplify the exposition by focusing on a single developing economy, though it is straightforward to conduct the analysis for several economies and determine the evolution of the world income distribution.

[6]Our baseline setup features only the extensive-margin acquisition of new product lines ("external" innovation). Akcigit and Kerr (2018) extend this framework by allowing incumbents to also innovate on their existing lines ("internal" innovation), generating within-line improvements in addition to adding new lines.

Production

The economy is infinite-horizon in continuous time and features a unique, competitively-produced final good. Specifically, the final good at each point in time is produced by combining the available set of intermediate inputs (or simply intermediates) with an elasticity of substitution $\sigma > 1$. Denoting the measure of available intermediates at time t by Q_t, this production function takes the form

$$Y_t = Q_t^{\frac{\sigma-2}{\sigma-1}} \cdot \left(\int_0^{Q_t} y_{jt}^{\frac{\sigma-1}{\sigma}} \cdot dj \right)^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where y_{jt} denotes the quantity of intermediate input j (and in what follows we suppress time indices whenever this will cause no confusion). The term $Q^{\frac{\sigma-2}{\sigma-1}}$ is included as a normalization. Since there is no international trade, only intermediates that are produced domestically can be used, and hence Q is both the range of intermediates produced and used in this economy.

We will see that Q is a measure of the technology of this economy—in fact, we will see below that Q is equal to TFP in this economy. Formally, because intermediates are complementary to each other, having more available intermediates increases productivity. Hence, technological upgrading in this model corresponds to introducing additional intermediates. For an economy at the world frontier, this would take the form of inventing a new intermediate, whereas for countries behind the frontier it would take the form of adopting intermediates from the frontier.

At any point in time, there is a set of active firms, denoted by F. Active firms are the ones that produce one or more intermediates. An active firm $f \in F$ has a linear production function for producing the intermediates it controls, given by

$$y_{fj} = \ell_{fj}, \tag{2}$$

where ℓ_{fj} is the quantity of labor used by this firm to produce intermediate j.

In addition to active firms, there are also entrants, which we describe below.

One advantage of our framework is that it distinguishes technology from capital. Technology is disembodied from capital (which does not exist in this model) and simply corresponds to the range of intermediates that are used in this economy, and these intermediates are produced using labor alone. In reality, of course, several important aspects of technology are embodied in capital goods, such as telephones, computers or machinery. Nevertheless, the general modeling approach here clarifies that technology is distinct from capital—having more of a certain type of machine is not the same as having multiple types of complementary machines.

Household Preferences

Since the household side does not play a major role in our framework, we model it by assuming that there is an infinitely-lived representative household that inelastically supplies one unit of labor (at the wage rate w_t at time t) and has logarithmic preferences given by

$$\mathbb{E}_t\left[\int_t^{\infty} e^{-\rho(s-t)} \cdot \log C_s \cdot ds\right], \tag{3}$$

where $\rho > 0$ is the rate of time preference and C_t denotes consumption at time t. The household's flow budget constraint is

$$\dot{A}_t + C_t \leq r_t \cdot A_t + w_t, \tag{4}$$

where A_t denotes its asset position, given by $A_t = \int_{f \in F} V_{ft} \cdot df$, where V_{ft} is the net present discounted value of active firm f at time t. The household also has to satisfy the standard no-Ponzi game condition:

$$\lim_{T \to \infty} A_T \cdot \exp\left(-\int_0^T r_s \cdot ds\right) \geq 0. \tag{5}$$

Technology Choices

In the background of the technology choices is the world technology frontier, represented by the world technology index $Q_W \geq Q$. We assume that the world technology index grows at a constant rate $\dot{Q}_W / Q_W = g_W > 0$. Domestic technology choices will benefit from frontier technologies represented by this index. We define the relative technology of the domestic economy to the world frontier by

$$q \equiv \frac{Q}{Q_W},$$

which is also an inverse measure of this economy's *distance to the world technology frontier.*

There are two sets of technology choices in this economy—by active firms to expand the set of intermediates they control, and by entrants trying to enter by introducing a new intermediate. Both decisions add new intermediates, and we will see that they also generate reallocation of labor across firms.

All firms (active ones and entrants) have access to the following menu for improving its technology. A firm can spend $\Gamma \cdot Z$ (in terms of the final good) in order to obtain a flow rate of technology advance (e.g., successful adaptation or imitation of the frontier technology) $B \cdot Z$, where the critical assumption is that

$$B = \theta \cdot b(q, \iota), \tag{6}$$

where θ is a measure of the absorptive capacity of the economy—meaning the ability of firms in this economy to absorb and build on the knowledge from the world technology frontier, which is in turn determined, for example, by its investments in science, tertiary education and technical training and instruction, as well as other barriers to technology adoption. In addition, b is a smooth function that is strictly decreasing in its first argument, and ι is a measure of the match between this country's needs and the world technology frontier, which we discuss in the next section. That the flow rate of technological improvement is decreasing in q is the key element inspired by Gerschenkron (1962): the further back a country is relative to the world technology frontier, the more ideas, products and techniques there are for it to imitate or adapt to its own conditions. In this section, we simplify the notation by suppressing ι and writing this as $\theta \cdot b(q)$. Moreover, in what follows, we also simplify the analysis by taking this function to be isoelastic

$$b\left(q\right) = q^{-\varepsilon}, \tag{7}$$

with $\varepsilon > 0$.

If an active firm successfully adopts a new technology at time t, then it adds a new intermediate, j, to its portfolio of intermediates, and if an entrant does the same, then it becomes an active firm with one intermediate.

Market Structure, Institutions and Aggregate Output

Given the final good production function (1), the demand function for each intermediate is isoelastic, with elasticity σ, which implies that each intermediate has a profit-maximizing monopoly price of

$$p_j = p = \frac{\sigma}{\sigma - 1} \cdot w \tag{8}$$

for all $j \in [0, Q]$, where recall that w denotes the equilibrium wage rate. Because each intermediate enters the final good production function (1) symmetrically, cost minimization together with (8) implies that there will be equal supplies of all intermediates in equilibrium:

$$\ell_j = \ell = \frac{1}{Q} \tag{9}$$

for all $j \in [0, Q]$. Since the total labor supply is equal to one, labor market clearing implies

$$\int_0^Q \ell_j \cdot dj = 1, \tag{10}$$

where we impose the labor market clearing condition as an equality, since labor will always have positive marginal product. Combining (1) and (9), we obtain

$$Y = Q, \tag{11}$$

confirming that Q is indeed a measure of the economy's technology—the higher is Q, the greater is aggregate output (and its "total factor productivity" or TFP).

Let us next compute the per intermediate profit. This can be written as $\pi = (p - w)/Q$, where the numerator is the markup and $1/Q$ is the output of this intermediate from equations (2) and (9). Hence, $\pi = w/[(\sigma - 1) \cdot Q]$.

Since the labor market is competitive, the wage is equal to the (value of the) marginal product of labor. We can compute the wage from the fact that total profits plus wage must equal total output, and hence $Q \cdot \pi + w = Y$, which using (11) yields:

$$w = \frac{\sigma - 1}{\sigma} \cdot Q. \tag{12}$$

Consequently,

$$\pi = \frac{1}{\sigma}, \tag{13}$$

which is independent of Q, implying that profit per intermediate remains constant as the economy grows.

In addition, we assume that after production takes place and profits are realized, there is a probability $1 - \beta$ (independent across intermediates and over time) that those profits are expropriated or are wasted due to corruption or other institutional problems. Hence, the effective (expected) profit per intermediate is $\beta \cdot \pi$.

Household Maximization

The intertemporal maximization of the household yields the standard Euler equation $\dot{C}/C = r - \rho$, where r is the market interest rate (plus the transversality condition, which simply sets (5) equal to zero). In what follows, we will work with normalized consumption, $c \equiv C/Q$. Using this variable, we express the Euler equation as

$$\frac{\dot{c}}{c} = r - \rho - g, \tag{14}$$

where, recall that, g is the growth rate of output and thus $g \equiv \dot{Q}/Q$.

Value Functions and Output Growth

The key decisions in this model concern technology choices. To determine these, we proceed to compute the value functions of firms. In doing this, we will exploit the fact that what matters for a firm is the number of intermediates. Then, the value of an active firm with a portfolio of n intermediates, $V(n)$, can be written in the form of a standard Hamilton-Jacobi-Bellman (HJB) equation:

$$rV(n) - \dot{V}(n) = \max_{Z \geq 0} \left\{ n \cdot \beta \cdot \pi - \Gamma \cdot Z + \theta \cdot b(q) \cdot Z \cdot [V(n+1) - V(n)] \right\}. \tag{15}$$

The left-hand side, $rV(n) - \dot{V}(n)$, is the return on the firm's value. It is equal to the right-hand side, made up of its profit stream, which is given by n times expected profits of each intermediate, $\beta \cdot \pi$, minus cost for technology adoption, $\Gamma \cdot Z$, plus changes in this value because of additional intermediates being added to the firm's portfolio. At the flow rate $B \cdot Z$, optimally chosen by the firm, a new intermediate is added to the firm's portfolio and thus the firm's value jumps to $V(n+1)$, from its current value, $V(n)$.

We will introduce firm exit decisions as an extension, but for now note that a firm that has a fixed number of intermediates n, while the economy is growing, will shrink as it will have lower employment (recall equation (9)).

Since firm profits are scaled by the number of intermediates this firm operates, n, and costs are linear, we can conjecture that

$$V(n) = n \cdot v,$$

where v is the *normalized per-intermediate value function*. Time differentiating both sides of this equation and noting that this is for n constant, we obtain $\dot{V}(n)/V(n) = \dot{v}/v$.

Substituting this into (15),

$$rv - \dot{v} = \max_{z \geq 0} \{\beta \cdot \pi - \Gamma \cdot z + \theta \cdot b(q) \cdot z \cdot v\}. \tag{16}$$

where $z \equiv Z/n$. The first-order condition of this problem immediately pins down the value function v as

$$v = \frac{\Gamma}{\theta \cdot b(q)}. \tag{17}$$

Another key equation is the evolution of output or the technology index Q. From (6), this can be written as

$$\dot{Q} = \theta \cdot b(q) \cdot Z^T,$$

where Z^T is total technology adoption effort in the domestic economy. Since all output must be either consumed or invested for technology adoption, we have $Y = C + \Gamma \cdot Z^T$, and hence $\dot{Q} = \theta \cdot b(q) \cdot (Q - C)/\Gamma$ and thus

$$g = \frac{\dot{Q}}{Q} = \frac{\theta \cdot b(q) \cdot (1 - c)}{\Gamma}. \tag{18}$$

Therefore, using the definition of $c \equiv C/Q$ and $q \equiv Q/Q_W$ and the fact that Q_W always grows at the rate $g_W > 0$, we obtain our first key differential equation that will characterize the dynamics in this economy:

$$\frac{\dot{q}}{q} = \frac{\theta \cdot b(q) \cdot (1 - c)}{\Gamma} - g_W. \tag{19}$$

Equilibrium Definition

An equilibrium is therefore defined as a dynamic allocation represented by $\langle C, Y, Q, v, \ell, r, w, Z \rangle$ (each of which determines a mapping from time to a real-valued variable) such that:

- C maximizes household utility (3) subject to (4) and (5)—and hence $c \equiv C/Q$ satisfies Euler equation (14) and the transversality condition given by (5) holding as equality;
- aggregate output Y is equal to the number of intermediates Q, as in (11) and its law of motion is given by (18);
- the per intermediate value function v satisfies the HJB equation (16);
- the labor market clears—and thus the labor allocation ℓ is given by (9);
- the wage rate w is given by (12);

- the interest rate r satisfies (16);
- technology adoption effort Z is consistent with profit maximization, i.e., (17) holds.

Balanced Growth Path

We start with a balanced growth path (BGP), defined as a dynamic equilibrium in which the developing country in question grows at the same (constant) rate as the world's technology frontier, $g = g_W$.[7]

In this case, the value function (16) simplifies since we have $\dot{v} = 0$, and also because the growth rate of the economy is constant, we must also have $\dot{c}/c = 0$, and thus we obtain a second equation in the value function:

$$v = \frac{\beta \cdot \pi}{r} = \frac{\beta \cdot \pi}{\rho + g_W}, \tag{20}$$

where the second equality uses (14) and $g = g_W$.

Combining (17) and (20) we arrive at a simple equation determining the relative technology and income level of a country (compared to the frontier):

$$q^* = b^{-1}\left(\frac{\Gamma \cdot (\rho + g_W)}{\theta \cdot \beta \cdot \pi}\right) = \left(\frac{\theta \cdot \beta \cdot \pi}{\Gamma \cdot (\rho + g_W)}\right)^{\frac{1}{\varepsilon}}, \tag{21}$$

where the second equality uses the isoelastic form given in (7). This equation uniquely pins down the relative position of a country's technology and as a decreasing function of the cost of technology adoption Γ and the discount rate ρ, and increasing function of absorptive capacity θ, profitability of innovation π, and security of property rights β (all which we discuss further below). The following proposition summarizes this discussion (proof in the text).[8]

Proposition 1. *There exists a unique BGP in which the country in question grows at the same rate as the world technology frontier, g_W, and its relative technology level is given by (21). This relative technology is increasing in the country's absorptive capacity θ, profitability of innovation π, and security of property rights β, and is decreasing in the cost of technology adoption Γ and the discount rate ρ.*

[7]We will see below that there exists a unique dynamic equilibrium converging to this BGP. For now, we can just note the intuition: given the form of the innovation possibilities frontier in (6) no country can grow faster than the world frontier, and if any country were to grow slower than the world frontier, this would translate into an infinite gap between itself and the frontier, making additional innovations infinitely cheap.

[8]The only additional step of the argument is to observe that the transversality condition of household maximization is always satisfied because $r > g$ due to logarithmic preferences in (3).

The main insight of this proposition is that, in the long run (in the BGP), the country in question grows at the same rate as the world technology frontier, but does not necessarily reach the frontier income level. In particular, if we impose that the frontier economy has GDP given by $Y_W = Q_W$ (as in the domestic economy), then the BGP pins down the relative income of the developing economy compared to the frontier economy. Note that the result that the country's growth rate is the same as the growth rate of the world frontier applies regardless of the absorptive capacity or the institutional distortions of the economy. The reason is that if the economy in question has weak institutions or other features that make technology adoption less easy or less profitable, then its technology level will be lower, but then the advantage of being backward mechanism becomes stronger and this still enables the economy to grow at the same rate as the world technology frontier. However, these characteristics related to absorptive capacity, institutions and preferences determine a country's *relative position* (or BGP distance from the frontier). This is the key economic mechanism that generates a (unique) BGP with a stable "world income distribution" in the model.

The proposition and equation (21) also show that the gap between the country in question and the frontier depends on the key parameters of the model (which will give us the comparative static results in the next section).

Note also that, although building on the idea of "technological advantage of being backward," Proposition 1 differs from the emphasis in Gerschenkron's work which was on how this force can generate rapid catch-up growth, while our model also features this catch-up mechanism (as we explain next) but additionally shows how this advantage undergirds a stable world income distribution in which countries with different characteristics all grow at the same rate but have different relative incomes.

Dynamic Equilibrium

The explicit dynamics of the equilibrium path, capturing the development process when a country starts below its long-run relative position are straightforward to characterize.

Combining equations (7) and (17) and differentiating with respect to time yields

$$\frac{\dot{v}}{v} = \varepsilon \frac{\dot{q}}{q} = \varepsilon \left(g - g_W\right).$$

Combining this with (16) and (17), we can solve out for the interest rate as

$$r = \frac{\beta \cdot \pi}{v} + \frac{\dot{v}}{v} = \frac{\beta \cdot \pi \cdot \theta \cdot b(q)}{\Gamma} + \varepsilon \cdot (g - g_W).$$

Combining this with (14) and using (18), we obtain our second key differential equation:

$$\frac{\dot{c}}{c} = \frac{\theta \cdot b(q)}{\Gamma} \cdot \Big(\beta\pi + (\varepsilon - 1) \cdot (1 - c)\Big) - \rho - \varepsilon \cdot g_W. \tag{22}$$

A dynamic equilibrium can be characterized by the solution of the differential equations (19) and (22), together with the initial condition $q = q_0$ and the transversality condition (given by (5) holding as equality).

Before providing the full characterization, we first explain why a dynamic equilibrium must converge to the BGP. To do this, let us go back to (19) and suppose that c is constant. Then it follows immediately that whenever $q > q^*$, we have $\dot{q} < 0$ and whenever $q < q^*$, $\dot{q} > 0$. Hence every country converges monotonically to their relative position in the world income distribution. Put differently, the long-run equilibrium of this framework (for given characteristics of all developing countries) determines a stable world income distribution in which all countries grow at the same rate.

The elasticity of the b function, ε, determines the speed of convergence. To gain intuition, consider the limit case where ε is very small, where dependence of technology adoption on the world frontier is very weak. In this case, the mechanism that pulls each country towards the world frontier becomes very weak and the model approaches the case where each country grows in its own right. This corresponds to a very slow convergence. Conversely, when ε is very high, there is strong dependence on the world technology frontier and those who are further behind benefit significantly more from the frontier. As a result, convergence to the world technology frontier is very fast. In the general case where c is not constant, the speed of convergence also depends on the discount rate.

This discussion motivates our general dynamic characterization, stated formally in the next proposition.

Proposition 2. *Starting from any $q_0 > 0$, there exists a unique dynamic equilibrium, and this equilibrium converges to the BGP characterized in Proposition 1. If the country starts with $q_0 < q^*$ (below its long-run position relative to the frontier), then it initially grows faster than the world until it converges to its relative position q^* given in (21).*

This proposition fully characterizes the macroeconomic development trajectory of a country. It also highlights how episodes of rapid growth can emerge as a country is further below relative to the world technology frontier than its long-run position warrants. In this case, the country initially grows faster than the world, and eventually converges to the world growth rate. An immediate corollary is that if a country's characteristics (institutions, absorptive capacity, etc.) improve starting from a BGP position, this will lead to an acceleration of technological and economic development, over time taking the country to a higher relative position.

Finally, we explain the proof of this proposition in two steps. First, we show local stability which provides intuition about the interplay of consumption and technological convergence (to the relative position of the country), and then we provide an argument for global stability which is similar to the saddle-path stability analysis of the neoclassical growth model. For local stability, summarize the two differential equations by the linearized 2 x 2 system:

$$\begin{pmatrix} \dot{c}/c \\ \dot{q}/q \end{pmatrix} = \Omega \times \begin{pmatrix} c \\ q \end{pmatrix}$$

where

$$\Omega = \begin{bmatrix} -\frac{\theta}{\Gamma} \cdot (\varepsilon - 1) \cdot b(q^*) & \frac{\theta}{\Gamma} \cdot b'(q^*) \cdot \Big(\beta \cdot \pi + (\varepsilon - 1) \cdot (1 - c^*)\Big) \\ -\frac{\theta}{\Gamma} \cdot b(q^*) & \frac{\theta}{\Gamma} \cdot b'(q^*) \cdot (1 - c^*) \end{bmatrix}.$$

The eigenvalues of this system, $\xi = (\xi_1, \xi_2)$, satisfy the equation $\det[\Omega - \xi \cdot I] = 0$, and by the standard solution to the quadratic equation, these two eigenvalues are real and have opposite signs since $\det(\Omega) < 0$.[9]

The global analysis follows from Figure 3 which shows the vector fields generated by (19) and (22) as in the analysis of dynamics in the standard neoclassical growth model. The fact that the locus for $\dot{c}/c = 0$ is steeper than that for $\dot{q}/q$ follows from the fact that $\left|\omega_{cq}/\omega_{cc}\right| > \left|\omega_{qq}/\omega_{qc}\right|$, and the directions of flows follow simply from the fact that both differential equations are decreasing in q.

Then, standard arguments establish that, given the initial condition for relative technology, q_0, there exists a unique dynamic equilibrium where initial (normalized) consumption jumps onto the unique stable arm, and all consumption levels that are away from the stable arm given the initial condition for q violate either the transversality condition or feasibil-

[9] A direct calculation yields

$$\det(\Omega) = \left(\frac{\theta}{\Gamma}\right)^2 \beta\pi\, b(q^*)\, b'(q^*).$$

Because $\beta\pi > 0$, $b(q^*) > 0$, and $b'(q^*) < 0$, we have $\det(\Omega) < 0$.

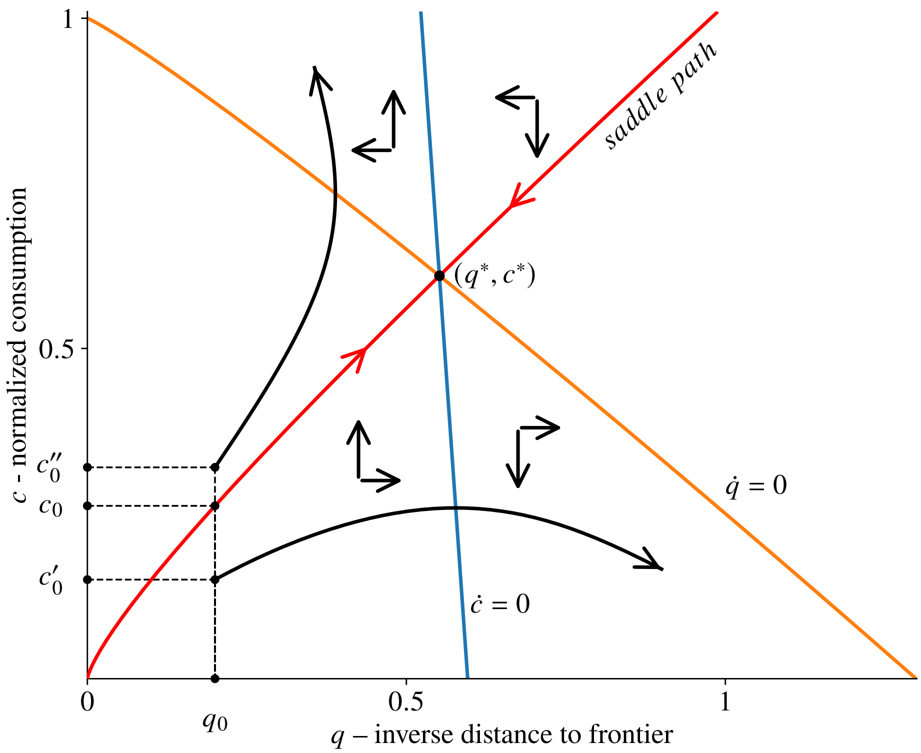


Figure 3: **Phase Diagram in (q, c)**

Note: The horizontal axis is relative technology $q \equiv Q/Q_W$ and the vertical axis is normalized consumption $c \equiv C/Q$, where the world frontier Q_W grows at rate g_W. The orange and blue curves correspond to $\dot{q} = 0$ and $\dot{c} = 0$, and are given by $\dot{q}/q = \frac{\theta \cdot b(q) \cdot (1-c)}{\Gamma} - g_W = 0$ and $\dot{c}/c = \frac{\theta \cdot b(q)}{\Gamma} \cdot \big(\beta \cdot \pi + (\varepsilon - 1) \cdot (1-c)\big) - \rho - \varepsilon \cdot g_W = 0$, with $b(q) = q^{-\varepsilon}$. Arrows depict the resulting vector field; the red curve is the local stable arm (saddle path) through the steady state (q^*, c^*). The plot uses $\theta = 0.02$, $\Gamma = 1$, $\rho = 0.01$, $g_W = 0.015$, $\varepsilon = 1.1$, and $\beta \cdot \pi = 0.65$.

ity. In particular, the $\dot{q} = 0$ locus (orange line) separates states in which innovation is fast enough to outpace the world frontier from those in which the economy falls behind the world frontier, while the $\dot{c} = 0$ locus (blue line) pins down combinations of (q, c) for which output and consumption growth rates are equal (and normalized consumption remains constant). Their intersection (q^*, c^*) gives the unique BGP. The red curve is the stable arm (saddle path): it is the unique set of initial conditions consistent with convergence to (q^*, c^*). For a given initial relative technology q_0, there exists a unique initial consumption level c_0 on the saddle path that ensures convergence. Starting at (q_0, c_0), consumption adjusts so that relative innovation gradually brings q toward q^* while c approaches c^*. In contrast, if the economy begins below the saddle path at (q_0, c_0') with $c_0' < c_0$, initial consumption is "too low": resources are tilted too much toward innovation, so q rises and ultimately exceeds q^*. In the process, (normalized) consumption ultimately declines and the transversality condition is violated. Conversely, if the economy starts above the saddle path at a point like (q_0, c_0'') with $c_0'' > c_0$, consumption is "too high", and innovation effort is insufficient to keep pace with frontier growth, so q drifts downward and the economy falls further and further behind the world technology frontier. In this situation, (normalized) consumption rises continuously and ultimately violates feasibility. In summary, the saddle path selects the unique c_0 at each q_0 that is compatible with convergence to the BGP, while deviations c_0' or c_0'' generate unstable transition dynamics.

Firm Dynamics

In our baseline model, the firm size distribution is indeterminate, because the technology to introduce new intermediates is linear. We discuss how this can be relaxed in the next section. Nevertheless, there is an important reallocation process already in the equilibrium of this model: from equation (9), any firm that does not innovate (and thus has constant n) will shrink, while firms that introduce/adopt from the frontier new intermediates will grow. This reallocation process is at the root of economic development in this model—the faster economic development is, the more reallocation there is.

Missing from our model are several other important aspects of firm dynamics, which we will add in the next section. For now, note that in our baseline model there is no "creative destruction", whereby growth by other firms directly takes away from the intermediates that the firm controls (rather, the reallocation effect in our model is indirect, working through the market process, which reduces the employment level of existing intermediate inputs). Second, there is no firm or intermediate exit. Every intermediate receives less and less labor over time, but it always continues to be produced.

Our baseline model was purposefully kept simple in order to clarify the economic intuitions and mechanisms (and facilitate future work building on it). In the next section we present several extensions. Before doing this, in the next subsection, we summarize the major comparative statics that already follow from this proposition.

Comparative Statics and Dynamics

Here we simply collect the results that are implied by our baseline model. How these implications line up with the data is discussed in Section 5.

Institutions: We have already seen the effects of institutions via the β variable, representing the security of property rights. Of course, in reality, there are many other dimensions of institutions that matter including those that impact entrants, the process of reallocation, the innovation process, and the absorptive capacity of the economy which is influenced by public and private tertiary education and other investments in human capital. In our model, all of these effects go in the same direction, and thus the first implication we would like to highlight is:

Implication 1: Countries with better institutions will have higher relative positions in the long run (and thus higher income per capita relative to others). Moreover, an improvement in institutions will lead to an acceleration in technological and economic development in the short to medium run.

Education Systems and Management Practices: A key parameter in the model is θ, which measures the absorptive capacity of the economy for technologies from the world frontier. As noted previously, this parameter is shaped by many factors, including institutions. Other important determinants of absorptive capacity comprise the education system (how open it is to scientific ideas and new developments, including those abroad) and management practices that influence the ability of managers and organizations to recognize and adapt useful technologies that are available around the world. For example, Bloom and Van Reenen (2007) show the importance of systematic performance monitoring, setting appropriate targets and providing incentives for performance for a range of firm-level outcomes. This discussion leads to our second implication:

Implication 2: Countries with better education systems and management practices will have higher relative positions in the long run (and thus higher income per capita relative to others). Moreover, improvements in education systems and management practices will lead to an acceleration in technological and economic development in the short to medium run.

Appropriate Technology: As discussed in Section 2, an important consideration considered in the literature is whether the technologies at the frontier are appropriate to the conditions of the country. Inappropriateness may result from differences in geographic factors (different diseases and agricultural conditions, such as the presence of different pathogens), differences in cultures (determining which technologies may or may not be adopted in a developing economy), and differences in factor endowments (whether in the country in question there is a shortage of skilled workers or capital relative to the requirements of the frontier technologies).

Inappropriate technology considerations both slow down the adoption of techniques from the frontier and may also make adopted techniques less productive. The former channel is already embedded in our model and can be represented by the variable ι in the $b(q, \iota)$ function (which we suppressed so far to simplify the notation). A higher ι can be interpreted as making frontier technologies less appropriate and thus shifting the b function down. One could also make the efficiency with which these technologies can be used in the developing economy a function of ι, though we do not need this additional channel for the next implication:

Implication 3: Countries for whom world technologies are less appropriate will have lower relative positions in the long run (and thus lower income per capita relative to others). Moreover, an improvement in the degree of appropriateness of world technology for a country will lead to an acceleration in technological and economic development in the short to medium run.

This discussion also provides a warning about the implications of the rapid advances in artificial intelligence (AI) for developing economies. To the extent that AI models are optimized for use in technologically more advanced economies and aim to save on scarce factors in these economies, they may be inappropriate to the conditions of developing economies and could serve to widen income and technology gaps between nations.

Finally, if backwardness makes some frontier technologies less appropriate to the conditions of a follower economy, this could act as a force counterbalancing the "technological advantage to being backward."

4 Extensions and Further Results

In this section, we discuss several extensions of our framework. To save space, we outline these extensions without providing the full details (which in some cases would require significant additional analysis).

4.1 Credit and Technology

Credit matters for technology adoption and adaptation, since many technology-related activities require upfront investments. There are many ways in which credit market frictions can be introduced into our baseline framework. The simplest would be to assume that firms need to borrow from financial institutions for their technology adoption effort

Z, and this necessitates monitoring which is costly. Assuming that these monitoring costs are constant as a fraction of outlays, the relevant (internal) interest rate for firms would be $\bar{r} = r + \omega$, where $\bar{r}$ is the required rate of return for firms investing in technology adoption, r is the rate of return for the representative household, and $\omega > 0$ is a constant wedge between these two due to the monitoring costs. The above analysis immediately implies that a higher ω depresses the country's relative technology position and thus the following result is immediate:

Implication 4: Countries with worse credit markets will have lower relative positions in the long run (and thus lower income per capita relative to others). Moreover, an improvement in credit market conditions will lead to an acceleration in technological and economic development in the short to medium run.

There are several other ways in which credit market conditions affect technology choices, and some of which we discuss below.

Firm Size Distribution

Because the technology to introduce new intermediates is linear, the baseline model does not pin down whether new technologies will be adopted by entrants or incumbents. Consequently, different firm size distributions and dynamics are consistent with the unique macroeconomic equilibrium characterized above. This feature of the model can be easily relaxed by following Klette and Kortum (2004)—assuming that active firms that have more intermediates can more cheaply adopt new technologies and also adding convexity in the cost of adoption. In particular, we can posit a convex cost of the form $n \cdot \gamma(\frac{Z}{n})$, where Z this total technology adoption effort of the firm and n is the number of intermediates it controls. When the γ function is strictly convex, a higher n corresponds to a lower cost of technology adoption. This form captures the intuitive notion that when a firm controls more intermediates (or more generally new technologies), it has more knowledge to build upon. The cost of adopting the technology for the first time for new entrants could be different (lower or higher, provided that there is not an infinite supply of potential entrants). Under some weak assumptions, this form generates stationary firm size distributions, which can then be compared to those observed in the data (see Klette and Kortum, 2004).

One advantage of this extension is that, as shown by, among others, Hsieh and Klenow (2014), firm size distributions differ across countries, and the model can thus provide potential mechanisms for explaining why there may be such differences.

Firm Exit and Reallocation

As noted above, there is no firm or intermediate product exit in our baseline model. While this does not prevent the presence of reallocation of labor away from firms that are not innovative towards those that enter or adopt new technologies, it does not enable the model to speak to the process of older less efficient firms exiting the market. There are two ways in which this can be added to the model. The first is to once again follow Klette and Kortum (2004), and allow technology adoption/innovation to replace existing intermediates by a process of creative destruction. This approach has led to a growing literature in firm dynamics, mostly applied in the context of developed economies, and it can be fruitfully used in this context as well. We find a second approach more interesting and natural in the current setting. This follows Acemoglu et al. (2018) and introduces fixed operating costs. Let Q_t denote the set of intermediates produced at time t, with measure $|Q_t|$; each active intermediate requires $\psi > 0$ units of the final good to operate, so total operating costs equal $\psi\,|Q_t|$. The final-good production technology is therefore

$$Y_t = |Q_t|^{\frac{\sigma-2}{\sigma-1}} \left(\int_{j \in Q_t} y_{jt}^{\frac{\sigma-1}{\sigma}} \, dj \right)^{\frac{\sigma}{\sigma-1}},$$

where Q_t need not coincide with the set of invented intermediates, since some varieties may shut down and cease production.

An immediate implication of this formulation is that firms that fall below a certain threshold for the ratio of the number of active intermediates n they operate relative to the total number of intermediates, $|Q|$, will exit the market. Denoting this threshold by ν^*, firms will shut down and all of their intermediates will no longer be in the set Q_t. However, this formulation would imply that entrants would immediately shut down. To avoid this, we also assume that firms do not have to pay ψ when they enter, and they transition to a mature firm stage at some Poisson rate χ, and they only start paying this fixed cost after this stage.

Since in the baseline model all firms are identical in terms of their productivity and technology adoption, this variation does not change anything substantial. However, this exit channel becomes more interesting when, as in Acemoglu et al. (2018), we also have firms that differ in terms of their technology capacity (and perhaps also productivity in operating existing intermediates). In this case, the economy's absorptive capacity endogenously increases when the composition of firms is selected favorably towards those with high technology capacity. However, the fact that all continuing firms use the labor resources slows down the reallocation process and the longer firms with low technological capabilities survive, the worse the composition of firms will be. In this case, economies that slow down this reallocation process would have a worse relative technology position. Factors that slow down reallocation include inefficient regulations, institutional distortions that hit more productive firms more heavily, credit market problems, and implicit subsidies to informality (for example via additional taxes or regulations that formal firms face). We summarize this implication (which was only verbally explained here) as follows:

Implication 5: Countries that make reallocation of labor away from less efficient firms harder (e.g., by implicitly subsidizing informality or taxing growing firms) will have lower relative positions in the long run (and thus lower income per capita relative to others). Moreover, an improvement in the ease of such reallocation will lead to an acceleration in technological and economic development in the short to medium run.

Credit market conditions are another factor that affects reallocation, and thus this implication also points to another channel via which credit market access can affect technology and economic development. In particular, better credit access for more promising firms would facilitate reallocation, whereas in financial systems where incumbents can get access to credit but new firms cannot (which is often the case in bank-based financial systems), such reallocation will be hampered.

Similarly, these considerations also point to another channel via which management practices may matter. In Implication 2, the only way by which management practices affect the country's relative position is via the absorption of world technologies. Better management practices may also facilitate the operation of firms that have multiple intermediate lines. If so, it would be easier for firms operating multiple technologies—which tend to be the higher-innovation potential firms—to grow and induce reallocation of labor from declining or stagnant firms.

4.2 Innovation versus Adoption

Following Acemoglu (2009), our baseline model features only one type of technology effort, which thus stands both for adoption and adaptation, as well as for true innovation, extending the world technology frontier. Acemoglu et al. (2006) explicitly allow for two different types of technology decisions—innovation and imitation. This is straightforward to introduce into our model as well, and one way of doing so would be to assume that adoption has the technology described above, while innovation builds only on a country's own technological know-how, and thus takes a form closer to the standard endogenous technological change models. For example, a different type of innovation effort, denoted by Z^{innov} leads to new innovations at the rate $B^{innov} \cdot Z^{innov}$. If B^{innov} is not too small, then the equilibrium will have a very intuitive structure, whereby countries far from the world technology frontier—say q less than some threshold q^{innov}—focus on imitation, adoption and adaptation, while those closer to the world technology frontier direct their resources toward innovation.

This perspective could have implications about how education systems, credit access, and other regulations should vary depending on whether a country is in the imitation or innovation phase.

4.3 Thresholds in the Technological Advantage of Being Backward

The assumption that all countries, regardless of their distance to the technology frontier, can absorb ideas and techniques from that frontier may be relaxed. For example, we could allow for a threshold effect whereby countries that are very behind the world frontier (e.g., $q < q^{backward}$), become much less efficient in this absorption. In this case, the world income distribution would become bimodal. Countries that start above $q^{backward}$ would have dynamics identical to the one we have characterized here, while those below $q^{backward}$ may settle into a much lower level of technology or continuously fall further and further behind the world frontier. More involved threshold effects and more specific requisites for absorbing techniques and ideas from the world frontier can also be introduced into the framework.

5 Revisiting the Evidence on Technology and Development

In this section, we revisit a number of correlations related to technology and economic development and look at them through the lenses of our model. It is useful to emphasize that these correlations do not necessarily establish causal relations—though for many of these variables there is also causal evidence in the literature supporting the same conclusions. In any case, they are salient features of the co-evolution of technology and economic development and as such, any satisfactory framework of the role of technology in development ought to account for these correlations. It is also our hope that the framework in this chapter encourages others to estimate the causal effect of these factors on economic development more systematically.

Institutions and Technology

Institutional factors are argued to be a major determinant of technological development (e.g., Acemoglu and Robinson, 2012, and Acemoglu and Johnson, 2023). Acemoglu (2025) reviews this evidence and discusses a framework in which institutions and technology are jointly determined. That paper also presented correlations between institutional factors and technology. Figure 4 replicates these correlations here. The first panel shows that countries with better institutions, as measured by the World Bank's rule of law index, have higher aggregate TFP, which indicate a combination of more efficient production and better use of technology.[10] More relevant for our focus here, the second panel shows that the advanced technology index already used in the Introduction of this chapter is also strongly associated with institutions. Acemoglu (2025) also provides some evidence that this link between institutions and technology is causal. These pronounced and robust associations are consistent with Implication 1 discussed above.

Future work further exploring the causal component of this correlation, the channels via which institutions matter for technology adoption and development, and the question of which dimensions of institutions matter more would be particularly useful in this context.

Education and Technology

Another strong correlation in the data is between higher education in a country and technology adoption. Figure 5 shows that the fraction of the population with tertiary education is strongly associated with TFP, as well as with the advanced technology index presented above.[11] This is the pattern implied by Implication 2. Once again, further work

[10] The World Bank describes this index as capturing "the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence." See `https://databank.worldbank.org/metadataglossary/worldwide-governance-indicators/series/RL.PER.RNK.UPPER`. This index combines information from various other measures on property rights enforcement, contract enforcement, civil rights, judicial independence, competitiveness, transparency, control of violence, and civil liberties. Further details can be found at `https://www.worldbank.org/content/dam/sites/govindicators/doc/rl.pdf` and Kaufmann et al. (2011). Data is available for 138 countries.

TFP is computed following Caselli (2005) and corrects for human capital differences, for which the available data is only available in five year intervals up to 2010. For this reason, for the left panel, the rule of law index from the World Bank is averaged over 2008-2011. See Acemoglu (2025) for further details on the construction of these variables and sources. Data is available for 98 countries.

[11] The share of population with tertiary education is defined as the share of the population in the 25-64 age range that has at least some tertiary education. The data is from Barro and Lee (2013), available at `https://ourworldindata.org/grapher/share-of-the-population-with-completed-tertiary-education`. We use the data from 2010 for panel (a) since TFP data is only available up to 2010 (84 countries), and the data from 2020 for panel (b), since the Advanced Technology Index is averaged for years 2019-22, as in the rest of

(a) Rule of Law and Aggregate TFP Across Countries

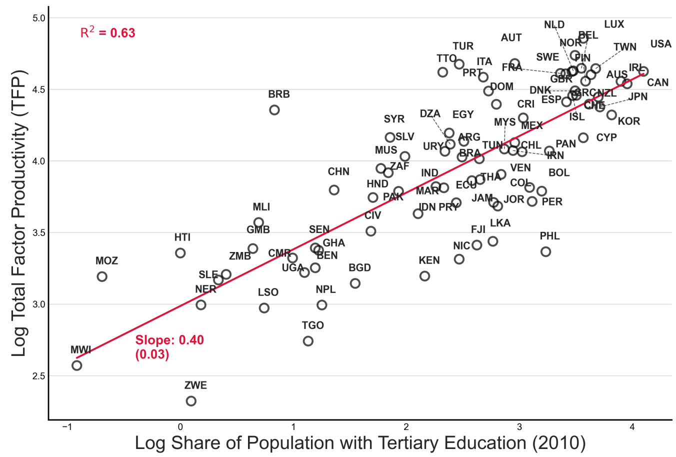
(b) Rule of Law and the Advanced Technology Index Across Countries

Figure 4: **Institutions, Productivity, and Technology Adoption**

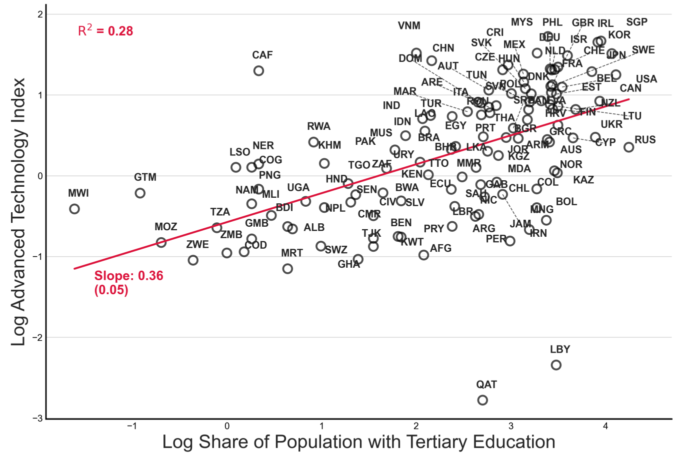
Note: The top panel plots the correlation between the World Bank's rule of law index (averaged 2008-2011) and the logarithm of aggregate TFP (corrected for human capital, data up to 2010). The bottom panel plots the correlation between the rule of law index (averaged 2019-2022) and the logarithm of the Advanced Technology Index (averaged 2019-2022). Country labels are shown in both graphs, and the red line in each panel represents the linear fit. See footnote 10 for further details.

exploring the causality of this relationship would be very useful.

the paper (121 countries).



(a) **Tertiary Education and Total Factor Productivity**



(b) **Tertiary Education and Advanced Technology Adoption**

Figure 5: **Tertiary Education, Total Factor Productivity, and Advanced Technology Adoption Across Countries**

Note: Panel (a) shows the country-level correlation between the share of the population aged 25–64 with at least some tertiary education (from Barro and Lee, 2013) in 2010 and the logarithm of total factor productivity (TFP, computed following Caselli (2005) and corrected for human capital, up to 2010). Panel (b) shows the correlation between the same education measure (in 2020) and the logarithm of the Advanced Technology Index (averaged 2019–22). Country labels are shown in both graphs, and the red line represents the linear fit.

Management Practices and Technology

Implication 2 also suggested the possibility of a correlation between management practices and technology adoption. Here, in addition to cross-country correlations, firm-level data also support this implication. Bloom and Van Reenen (2007) show that better management practices at the firm level are associated with higher productivity, profitability, Tobin's Q, and survival rates. Figure 6a complements this conclusion by showing a strong correlation between firm-level management practices score and the likelihood that a firm has positive research and development spending using the World Bank Enterprise Survey. A strong association is again visible.[12]

Figures 6b and 6c look at the macro-level variation. They use the Bloom-Van Reenen data, aggregated to the country level, and then plot the correlation between TFP and management practices, and between our advanced technology index and management practices. There is once more a very strong correlation consistent with Implication 2.

Inappropriate Technologies

Recent work by Moscona and Sastry (Moscona and Sastry) documents the importance of technology and appropriateness for adoption and productivity, focusing on agricultural technologies and seeds. The source of inappropriateness here is differences in the pathogens affecting crops across countries, which vary widely across geographies. These differences are summarized by a country-pair and crop-level variable, "CPP mismatch", measuring how mismatched the pathogens affecting a crop in a developing (destination) country are to the pathogens affecting the same crop in the origin country where new seeds were developed. They then look at how this mismatch impacts the destination country.[13] Figure 7 replicates one of their main results, showing that this mismatch leads

[12]Panel 6a uses the World Bank Enterprise Survey data (available at `https://www.enterprisesurveys.org/en/enterprisesurveys`). We select the universe of manufacturing firms operating in eight industries (Food, Garments, Pharmaceutical, Chemicals & Chemical Products, Fabricated Metal Products, Electrical & Computer Products, Machinery & Equipment, Motor Vehicles, Other Manufacturing), that have non-missing information on management score and R&D spending. This yields a sample of 77706 firms from 158 countries. The variable on management score is constructed from a survey that asks firms how many performance indicators they monitor. An answer of "none" corresponds to a score of 0, "1-2 indicators" to a score of 1.5, "3-9 indicators" to a score of 6, and "10 or more indicators" to a score of 12. The variable on R&D spending is a dummy equal to 1 if the firm reports having any R&D spending in the previous fiscal year. Observations in the scatter plot are averaged at country-industry level, resulting in 651 data points.

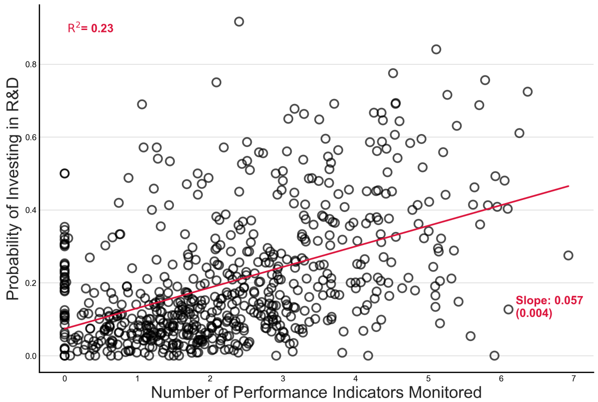
Panel 6b uses the World Management Survey data (available at `https://worldmanagementsurvey.org/data/wms-data/download-public-data/` for management score) and total factor productivity (TFP) data from Caselli (2005). Data available for 28 countries.

Panel 6c uses the same World Management Survey data (for management score) and the advanced technology index constructed as in the Introduction of this chapter. Data available for 33 countries.

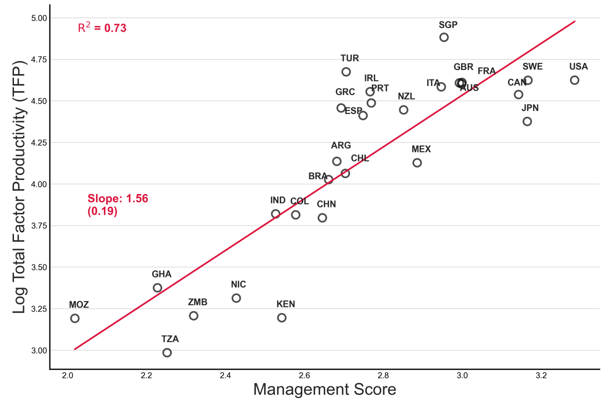
[13]The variables in this figure are constructed as follows. CPP (Crop Pest and Pathogen) mismatch for a given crop k between two locations l and l' is calculated as one minus a similarity score. This similarity score is the number of common pests and pathogens for crop k in both locations, divided by the geometric mean of the total number of pests and pathogens for that crop in each location individually. A value of 0 means the locations have identical pests and pathogens for the crop, while a value of 1 means they have no pests and pathogens in common. The formula is:

$$\text{CPP Mismatch}_{k,l,l'} = 1 - \frac{\text{Number of Common CPPs}_{k,l,l'}}{\sqrt{\text{Number of CPPs}_{k,l} \times \text{Number of CPPs}_{k,l'}}}$$

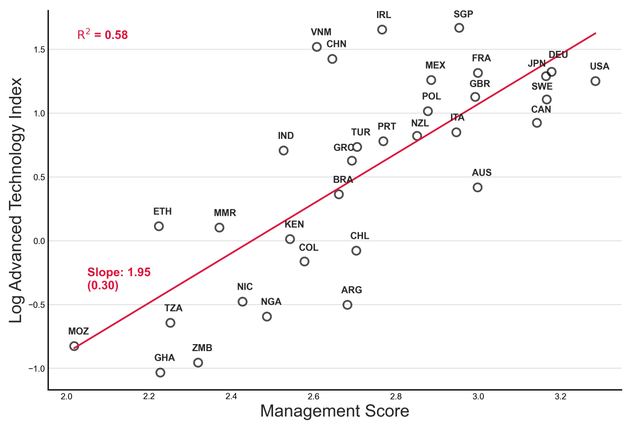
Technology transfer is defined as a dummy variable that is equal to one if in the destination country a patent that cites (or is part of the same family of) the original crop-specific patent. For each crop, a



(a) **Management Quality and Innovation Effort**



(b) **Management Practices and Total Factor Productivity Across Countries**



(c) **Management Practices and Advanced Technology Across Countries**

Figure 6: **Management Practices, Innovation Effort, Technology Adoption, and Productivity**

Note: Panel (a) shows the firm-level correlation between management quality, proxied by the number of performance indicators monitored by the firm, and R&D spending, using data on manufacturing firms from the World Bank Enterprise Survey. Each point in the scatter plot represents the average management score and the average likelihood of spending on R&D for a given country-industry pair. Panel (b) shows the cross-country correlation between management scores from the World Management Survey and the logarithm of total factor productivity (TFP, computed following Caselli (2005) and corrected for human capital, up to 2010). Panel (c) shows the cross-country correlation between management scores from the World Management Survey and the logarithm of the Advanced Technology Index (averaged 2019–22). Country labels are shown in the scatterplots. In all panels, the red line represents the linear fit.

to a much lower likelihood of these new seeds being adopted in a country.

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technological frontier is defined as the first country that introduced a crop-specific innovation.

Observations in the scatter plot are averaged at country level for the 63 countries object of the study. Data are obtained from Centre for Agriculture and Bioscience International's Crop Protection Compendium (CPC) and the International Union for the Protection of New Varieties of Plants (UPOV). Further details are provided in Moscona and Sastry (Moscona and Sastry).

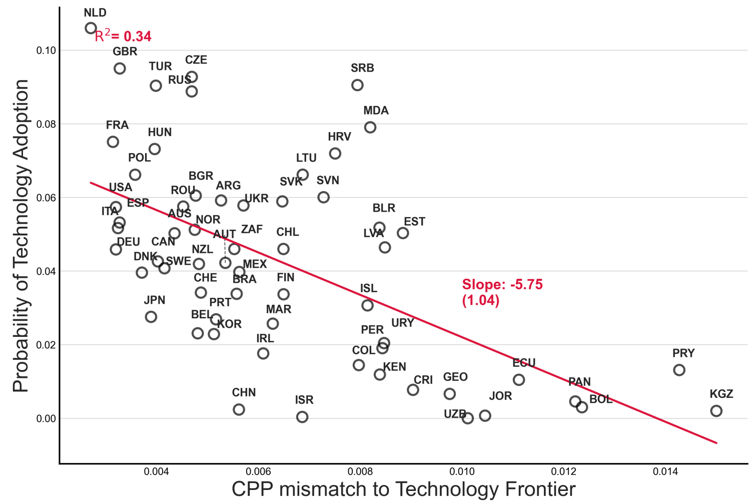


Figure 7: **Technology-Environment Mismatch and Seed Adoption**
Note: This figure, based on Moscona and Sastry (Moscona and Sastry), shows the correlation between CPP (Crop Pest and Pathogen) mismatch and the likelihood of technology transfer for agricultural seeds. CPP mismatch measures the difference in crop pathogens between the location where a seed was developed and a potential destination country. Technology transfer is a dummy for whether a patent related to the new seed is filed in the destination country. Each point represents the average for one of the 63 countries in the study. The red line represents the linear fit. See footnote 13 for further details.

Overall, this pattern is in line with our Implication 3. Extending this type of research beyond agriculture to the more macroeconomic level would be one interesting direction of future research.

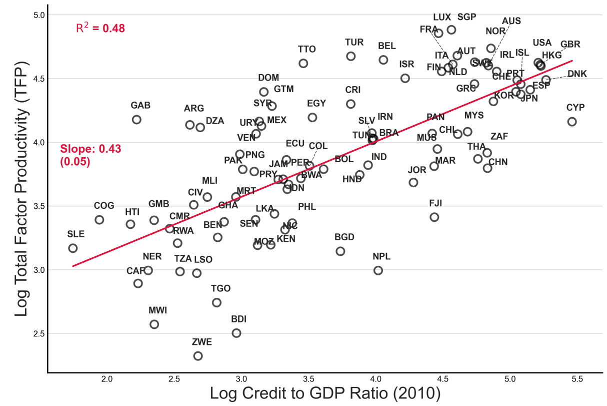
Credit and Technology

Figure 8a shows the firm-level correlation between access to finance and likelihood of research and development spending in the World Bank Enterprise Survey, indicating that firms with better access to finance are more likely to undertake innovation. Figures 8b and 8c depict the country-level correlation between credit to GDP ratio and total factor productivity on the one hand and our advanced technology index on the other.[14] In

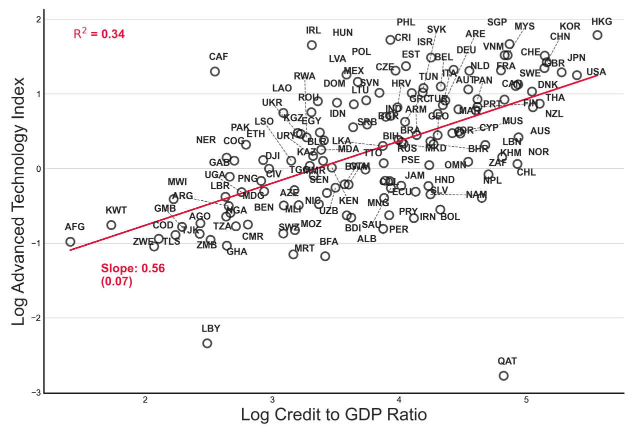
[14]Panel 8a uses the World Bank Enterprise Survey data (available at `https://www.enterprisesurveys.org/en/enterprisesurveys`). We select the universe of manufacturing firms, pertaining to eight industries (Food, Garments, Pharmaceutical, Chemicals & Chemical Products, Fabricated Metal Products, Electrical & Computer Products, Machinery & Equipment, Motor Vehicles, Other Manufacturing), that have non-missing information on access to finance and R&D spending. It results in a sample of 74179 firms from 155 countries. The variable on access to finance is a binary variable taking value 1 if the firm reports having any access to finance (bank loan/line of credit). The variable on R&D spending is a binary variable taking value 1 if the firm reports having any R&D spending in the previous fiscal year. Observations in the scatter plot are averaged at country-industry level, resulting in 632 data points.

Panel 8b correlates the World Bank's credit to GDP ratio indicator, available at `https://data.worldbank.org/indicator/FS.AST.PRVT.GD.ZS` and total factor productivity (TFP) data from Caselli (2005). Since TFP all cases these correlations are also strong and robust, and consistent with our model's Implications 4.

(a) **Firm-Level Evidence: Access to Finance and R&D Spending**



(b) **Credit-to-GDP Ratio and Total Factor Productivity Across Countries**



(c) **Cross-Country Evidence: Credit/GDP and the Advanced Technology Index**

Figure 8: **Financial Development, Technology Investment, and Productivity**

Note: Panel (a) shows the firm-level correlation between a firm's access to finance and its R&D spending, using data on manufacturing firms from the World Bank Enterprise Survey. Each point in the scatter plot represents the share of firms that have access to finance and the share of firms that have positive R&D expenditure for a given country-industry pair. Panel (b) shows the cross-country correlation between the credit-to-GDP ratio in 2010 (computed by the World Bank) and the logarithm of total factor productivity (TFP, computed following Caselli (2005) and corrected for human capital, up to 2010). Panel (c) shows the correlation between the credit-to-GDP ratio (latest available year, mostly 2022–2023) and the logarithm of the Advanced Technology Index (averaged 2019–22). Country labels are shown; the red line is the linear fit in each panel.

data is only available in five year intervals up to 2010, we use the credit-to-GDP ratio from 2010 as well. Data is available for 91 countries.

Panel 8c uses the same World Bank credit to GDP ratio indicator and the advanced technology index constructed as in the Introduction of this chapter. Since the advanced technology index is averaged for years 2019-22, for this panel we use the latest available credit-to-GDP ratio, mostly 2022 or 2023. Data is available for 138 countries.

Informality, Business Dynamism and Technology

Figures 9a and 9b show a strong negative relationship between informality and both TFP and our advanced technology index. This is consistent with our Implication 5. Figure 9c provides another piece of evidence, from the World Bank Enterprise Survey. It shows very different business dynamism in high income and low-income countries in this data set. On the vertical axis, we have a summary measure of a firm's growth since its entry—its current size relative to its size at entry. In high-income countries, by age 26 and beyond, surviving firms are more than 10 times the size they were when they first entered. In developing countries, we do not see such rapid growth. Even by age 26 and beyond, firms are only about twice as large as they were when they entered. This highlights a very slow reallocation process (and arguably technological improvement process) firms.[15] This pattern is once again reminiscent of Implication 5.

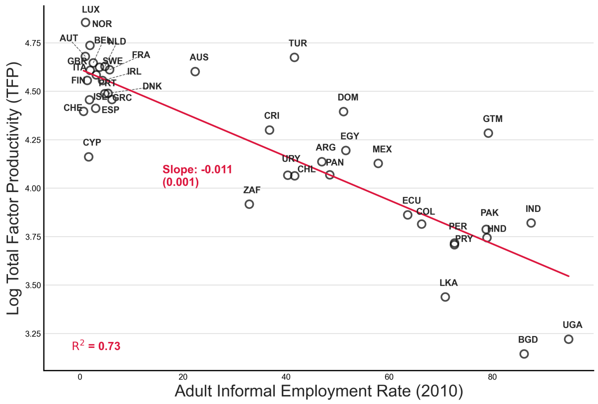
6 Conclusion

Measures of technology adoption and technical efficiency are strongly correlated with economic development. At the very least, the development process appears to be intimately linked with the dynamics of technological upgrading. Nevertheless, the role of technology and determinants of technology adoption have received limited attention in the economic development literature—even though issues of technology adoption have been studied in specific contexts, such as in agriculture, manufacturing, health, and communications,

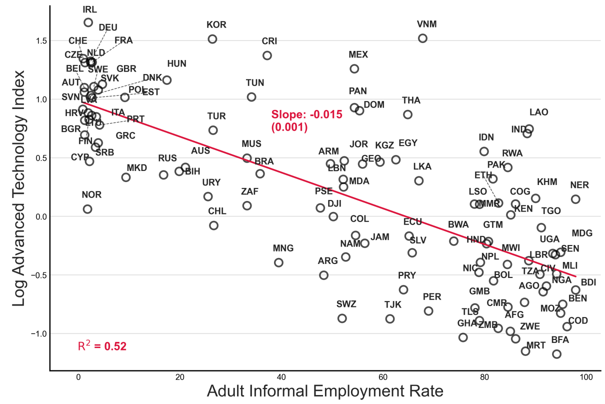
[15] Panels 9a and 9b use the World Bank's non-regular (informal) employment indicator. For each country, it is defined as the percentage of adults aged 25 and older in informal employment with respect to total employment in the same age group. Data is available at https://humancapital.worldbank.org/en/indicator/WB_HCP_EMP_NIFL_A. Panel 9a plots this measure against the logarithm of total factor productivity (TFP). Since TFP data is only available in five year intervals up to 2010, we use the share of informal employment for the year 2010 as well. Data is available for 40 countries.

Panel 9b plots the same measure of informal employment against the logarithm of the Advanced Technology Index (averaged 2019-22). Since the advanced technology index is averaged for years 2019-22, we use the latest available year for informal employment, mostly in the 2020-2022 period. Data is available for 108 countries.

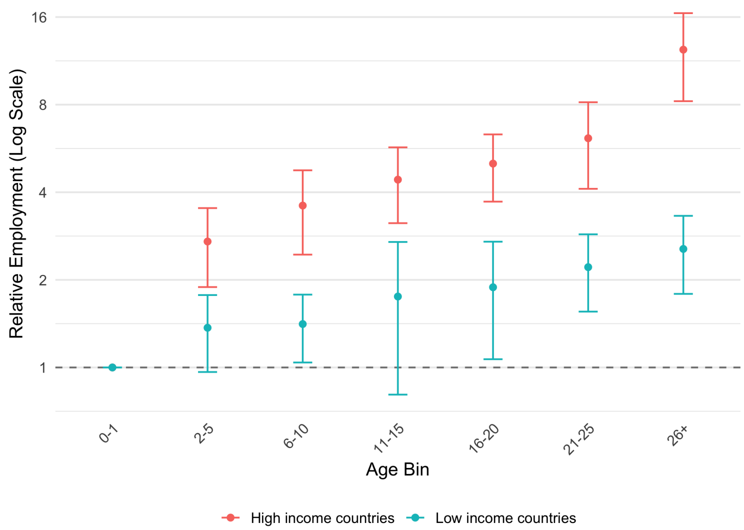
Panel 9c uses the World Bank Enterprise Survey data (available at https://www.enterprisesurveys.org/en/enterprisesurveys). We select the universe of manufacturing firms, pertaining to 8 industries (Food, Garments, Pharmaceutical, Chemicals & Chemical Products, Fabricated Metal Products, Electrical & Computer Products, Machinery & Equipment, Motor Vehicles, Other Manufacturing), that have non-missing information on firm age, size at birth and employment. We compute for each firm the ratio between current employment and employment at birth (0-1 years of age). We then aggregate the data at country level, by computing the average of this ratio for firms in different age bins: 2-5, 6-10, 11-15, 16-20, 21-25, and 26+ years of age. The plot shows the average of this ratio for firms in each age bin, separately for high-income and low-income countries. We define high-income and low-income countries according to the UNIDO classification, available at https://stat.unido.org/manufacturing-news/unido-launches-updated-country-groupings-2025. Data is available for 62 countries (44 high-income and 18 low-income). Middle-income countries are excluded from this figure for visual clarity.



(a) **Informality and Total Factor Productivity Across Countries**



(b) **Cross-Country Evidence: Informality and the Advanced Technology Index**



(c) **Firm Life-Cycle Growth: Business Dynamism in High- vs Low-Income Countries**

Figure 9: **Informality, Technology, Business Dynamism, and Productivity**

Note: Panel (a) shows the cross-country correlation between the share of informal employment (adults aged 25+ in informal jobs as a share of total employment, World Bank) and the logarithm of total factor productivity (TFP, computed following Caselli (2005) and corrected for human capital; both for 2010). Panel (b) plots the same informality measure (latest available year, mostly 2020–2022) against the logarithm of the Advanced Technology Index (averaged 2019–22). In both panels, country labels are shown and the red line is the linear fit. Panel (c) shows firm life-cycle growth—the ratio of current to entry size—by firm age bins for high- and low-income countries, using World Bank Enterprise Survey data.

and with regards to the potential costs of inappropriateness of frontier technologies for developing economies.

This chapter has built a tractable framework for the study of technology adoption and diffusion in the context of economic development. Firms in countries behind the technology frontier can rapidly adopt new technologies available from the world frontier, which incorporates the idea of "economic advantages from being backward", originally proposed by Gerschenkron (1962) and implicitly featuring in the work of Nelson and Phelps (1966). Because countries farther away from the world frontier can adopt technologies faster, in the steady-state equilibrium of this framework all countries grow at the same rate as the world frontier, even though their distance to the frontier and their income levels vary. Specifically, lower absorptive capacity (because of weak education systems, poor management practices, or barriers to technology adoption), institutional distortions, inappropriateness of technology (mismatch between frontier technologies and the needs of the country), and credit market frictions slow down technology adoption. Any economy facing such issues will be further from the world technological frontier and hence have relatively lower income per capita.

The chapter additionally discussed the implications of the choice between innovation and imitation, as well as the importance of market selection in favor of higher-productivity and higher-absorptive capacity firms in the process of economic development.

We illustrated the main comparative statics of the framework with a number of correlations based on cross-country and firm-level data. In addition to the aforementioned correlation between economic development and technology, we show that institutional factors, management practices, the extent of tertiary education in the workforce, and credit market conditions are strongly correlated with technology. There is also micro-data evidence supporting (1) the idea that frontier technologies are inappropriate to the conditions and factor endowments of many developing countries, and (2) the idea that the prevailing selection process for firms in local economies affects technology diffusion.

The tractability of our framework enables several extensions that could be important for understanding other aspects of the development process. We list a few of those here.

1. This chapter outlines how this framework can be extended by introducing an explicit choice between imitation-based and innovation-based development strategies. Fully characterizing the implications of this extended framework would be useful for several reasons. First, it can shed further light on issues of a potential middle-income trap. Second, it may provide further insights about which types of policies and institutional designs might be appropriate for countries at different stages of development—based on whether they are engaged in imitation-based or innovation-based technological development (thus building on and extending Acemoglu et al., 2006).

2. For simplicity, we presented a closed-economy model. Incorporating international trade would enable the framework to speak to questions of whether openness to

trade and the diffusion of technologies are complements or substitutes. (Infant industry arguments suggest that they are substitutes, while perspectives exploring the possibility to learn from imported advanced technologies or joint ventures with foreign companies point in the other direction).

3. Institutional dimensions of technology adoption can be more systematically studied within this framework, for example, by enabling existing firms to take actions that slow down new technology adoption by others. Alternatively, technology adoption may be blocked by officials demanding bribes. Political economy factors could also interact with industrial subsidies and trade policy. A broader modeling of institutions would additionally enable the incorporation of the effects of different management practices into this framework—for example, because imperfections in the court system do not allow owners or shareholders to discipline managers, which thus favors family or owner-operated firms in certain developing economies.

4. Richer firm-level dynamics can be easily incorporated into this framework. Specifically, it is straightforward to embed the structure of Klette and Kortum (2004), so that firms that adopt more advanced technologies replace others—i.e., there is a process of creative destruction. This would add a direct channel of resource allocation away from firms operating older technologies towards those with more advanced technologies. It would be particularly interesting to simultaneously model and estimate both direct and indirect channels of labor reallocation away from less efficient firms. The presence of creative destruction also opens the way to a richer analysis of political economy in this context.

5. Our baseline framework allows adoption of technologies from a unique world frontier (which could be a combination of the technological know-how of several advanced economies). In practice, historical, cultural, and ethnic ties may facilitate technology adoption, and incorporating this aspect would add a "country-network" dimension to the diffusion of technology—whereby it is the technologies of advanced economies more similar to a developing country (e.g., sharing a language) that are more relevant for its adoption decisions.

6. Our framework follows the standard endogenous growth literature in adopting a monopolistically competitive market structure where each (intermediate) firm faces a constant elasticity demand for its products. More realistic and richer market structures can be incorporated, especially to allow for the role of large firms to block competition and entry. Oligopolistic competition would also create a link between technology adoption decisions, the size distribution of firms, and markups.

7. An important dimension of technology adoption is learning from the experience of other firms, which can be straightforwardly incorporated into this framework. For example, the productivity of different technologies can be stochastic and firms can decide to invest more resources to try out technologies that have been more successfully adopted by others in their industry or region. Other dimensions of information exchange, including from governmental bodies that facilitate such exchange, can also be incorporated, allowing an analysis of a broader range of policies. Conversely, how a lack of relevant information slows down the acquisition of knowledge and adoption can be studied using this framework as well. Another dimension of learning could be by managers and research personnel in relation to how quickly and effectively they can absorb developments at the world scientific and technological frontier.

8. The issue of inappropriate technology can be more explicitly modeled, for example, by allowing different types of innovations to advance at varied rates in the world technology frontier, with firms making explicit decisions about which types of technologies to target depending on their (economic) environmental conditions and their access to different types of factors (such as credit and skilled labor).

9. The extension we outlined with endogenous firm exit can be developed fully, and this would enable a unified analysis of technology adoption and misallocation in the context of economic development. In particular, estimation or quantitative evaluation of this extended model would enable more insights about whether misallocation is caused by some mechanism that prevents new products from replacing existing products, or rather because resources become trapped in inefficient firms or establishments that do not exit.

10. More generally, more detailed versions of this framework still remain tractable and may be more appropriate for quantitative analysis of technology and economic development.

11. Last and certainly not least, more empirical work using both micro and macro data is necessary to expand our understanding of technology adoption and diffusion, and our hope is that the predictions and interpretations provided by our framework will be useful in structuring such investigations.

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Appendix

A1 Construction of Publication, Project, and Technology Measures

For Figure 1a, we analyzed articles published between 2000 and 2025 from three sources: (i) the *Journal of Development Economics*; (ii) top general-interest economics journals (*Econometrica*, *Journal of Political Economy*, *Quarterly Journal of Economics*, *Review of Economic Studies*, *Review of Economics and Statistics*, *The Economic Journal*, and *Journal of the European Economic Association*); and (iii) all American Economic Association (AEA) journals (*American Economic Review*, *AER: Insights*, *American Economic Journal: Applied Economics*, *American Economic Journal: Economic Policy*, *American Economic Journal: Macroeconomics*, *American Economic Journal: Microeconomics*, *Journal of Economic Literature*, and *Journal of Economic Perspectives*). We obtained metadata for the general-interest economics journals and the *Journal of Development Economics* from EconLit, and for AEA journals by scraping the AEA website. We restricted our sample to articles classified under JEL codes O1 (Economic Development) and O2 (Development Planning and Policy), yielding 4716 articles. We identified eight keyword themes: Technology, Health, Education, Environment, Poverty, Gender, Institutions, and Finance. The keywords associated with each theme are reported below. An article is classified under a given theme if its abstract contains at least one of the keywords listed for that theme. Note that the classification is not exclusive: a paper can be classified into multiple themes. Of the 4,716 articles, 3,420 (72.5 percent) are classified into at least one of the eight themes.

An economic development paper is classified into a given topic if its abstract contains at least one of the keywords listed below for that topic. Notice that the classification is not exclusive, i.e. a paper can be classified into multiple topics. The same set of keywords is used to classify also World Bank projects. In this case, the classification is based on the "Project Development Objective" field.

For Figure 1b, we obtained the metadata of loans and credit guarantees provided for development assistance between 2001 and 2025 downloaded from the World Bank Projects & Operations database (`https://projects.worldbank.org/en/projects-operations/projects-list`). This data consists of 13,761 projects with a total commitment amount $2.38 trillion (in 2024 US dollars). We identify the same eight keyword themes as for the development economics publications. Also, the same set of keywords is used to classify World Bank projects. In this case, the classification is based on the "Project Development Objective" field. Once again, project classification is not exclusive to a single theme.

Finally, for Figure 2, the variables in different panels are constructed as follows:

Telegram per capita is defined as the number of telegrams sent in a country in 1900 divided by its population in the same year, computed from various sources by Comin and Hobijn (2010) (29 countries).

Telephone penetration is defined as the number of mainline telephone lines connecting a customer's equipment to the public switched telephone network in 1950, divided by the population of the country in that year, and is from Comin and Hobijn (2010) (62 countries).

Internet usage is defined as the share of individuals using the Internet in a country in 2000, and is retrieved from the World Bank (`https://data.worldbank.org/indicator/IT.NET.USER.ZS`, 184 countries).

The advanced technology index is computed in Acemoglu (2025) as follows: $\sum_i \left(\text{export value}_{ic} \times \text{ATP}_i\right) / \sum_i \text{export value}_{ic}$, where export value$_{ic}$ is the value of exports of country c in product i and ATP$_i$ is a dummy equal to one for products that are classified as "advanced technology products" by the Census Bureau. Out of 5830 products at the six-digit HS code level, 240 are classified as advanced technology products by the Census Bureau. These products are in aerospace, information & communications, electronics, biotechnology, life science, flexible manufacturing, opto-electronics, advanced materials, weapons and nuclear technology. See `https://www2.census.gov/ces/wp/1989/CES-WP-89-01.pdf`. The export values are computed from the UN Comtrade data and are averaged over 2019-2022. We use the logarithm of this index in the fourth panel (138 countries).

In all four panels, the horizontal axis is log GDP per capita (PPP-adjusted) in the indicated year, retrieved from Comin and Hobijn (2010) for the first two panels and from the World Bank's World Development Indicators (`https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD`) for the last two panels.

A2 Description of Keyword Themes for Figures 1a and 1b

Technology: digital, technology, technical change, technological progress, technology adoption, innovation, productivity growth, technology transfer, technology diffusion, technological transfer, automation, R&D, research and development, patent, industrialization, internet, software, hardware, artificial intelligence, machine learning.

Health: health, medical, hospital, disease, vaccine, nutrition, maternal, pandemic, pharmaceutical, hiv, malaria, covid, tuberculosis, healthcare, clinic, patient, medicine, epidemic, sanitary, mental health, infant mortality, life expectancy, public health, sanitation, hygiene, medical device, health insurance, health outcome, child health.

Education: education, school, university, college, learning, teacher, student, literacy, training, higher education, curriculum, classroom, academic, vocational, skill development, pedagogy, educational attainment, human capital, early childhood education, primary education, secondary education, tertiary education, edtech, student outcome.

Environment: climate, environment, renewable, green, pollution, disaster, flood, drought, forest, biodiversity, sanitation, waste, resilience, sustainable, agriculture, irrigation, ecosystem, nature, emission, carbon, energy efficiency, solar, wind, hydro, clean energy, land management, coastal, marine, deforestation, erosion, watershed, conservation, livestock, fisheries, farming, climate change, global warming, natural resource, water management, air quality, soil degradation, environmental policy, conservation biology, ecology, waste management.

Poverty: poverty, social protection, safety net, cash transfer, refugee, displacement, conflict, fragile, vulnerable, inclusion, poor household, social assistance, humanitarian, internally displaced, crisis response, emergency response, inequality, food security, malnutrition, homelessness, social exclusion, basic needs, living standard, development aid.

Gender: gender, women, girl, maternal, gender based, female, empowerment, reproductive, gender based violence, sexual violence, women owned, female headed, female labor force participation, gender inequality, gender gap, family planning, patriarchy, feminism, gender roles, sexual orientation.

Institutions: governance, institution, public sector, public policy, accountability, transparency, rule of law, justice, administration, capacity building, civil service, decentralization, procurement, audit, corruption, parliament, bureaucracy, bureaucrat, political stability, regulatory quality, government effectiveness, property rights, legal system, judiciary, democracy, autocracy, election, political economy.

Finance: finance, fiscal, enterprise, sme, banking, credit, loan, microfinance, microcredit, financial inclusion, financial development, stock market, bond market, foreign direct investment, capital flows, monetary policy, central bank.