Chapter 2
Fundamentals of Innovation Policy for Growth and Development

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2.1 Introduction

This book deals with technology and innovation and their relationship to economic growth. The emphasis is on policy rather than the underlying economics and the book is designed to be accessible to readers who lack a foundation in economics beyond the principles of the subject. The centrality of economics to an understanding of the underlying processes of economic growth, however, necessitates some discussion of the topic. We have attempted to introduce these concepts in a way that is understandable to the lay reader.

This chapter serves as an overview. It begins with a short discussion of the models of economic growth to provide a foundation for understanding how economists view, from a macro-economic perspective, the role that technology and innovation play in the economic growth process. We will then proceed to a more micro-level discussion, beginning with the creation of new technologies (invention), and their commercialization (innovation) and spread (diffusion) across the economy. We will then return to the macro-economic level with a discussion of the relationship between technology and international economic competitiveness.

It is worthwhile first to define some basic terms so that the reader understands the vocabulary used throughout the book. The words “science and technology” are frequently used together but their separate meanings are sometimes lost in the process. Similarly, the terms “technology” and “innovation” are sometimes used interchangeably. For our purposes, *science* is the systematic search for new knowledge. *Technology* is the application of that knowledge to the production process. *Innovation* can be distinguished from technology by understanding that technology is only one way to innovate. Although it is the most common form of innovation in developed countries, there are other forms of innovation including innovations in

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marketing or organizational form. Other terms will be introduced in the course of this chapter as well.

This book has a strong policy focus. As such, the assumption that underpins its content is that policymakers can intervene (productively) to encourage the production and use of new technologies. While the existence of market failures suggests a useful role for governments, it is true that not all government intervention is helpful and can occasionally be counterproductive. We will attempt throughout to highlight what we believe to be the appropriate role of government in encouraging and accelerating the process of technology creation, commercialization, and diffusion.

2.2 Models of Economic Growth

This section provides an overview of some of the primary economic growth theories and the way they have evolved over time to account for the role of technology and innovation in the economic growth process. It provides context for more policy-oriented sections to follow. We define economic growth as a sustainable increase in GDP per capita. The section will explore neoclassical growth theory; endogenous growth models; and evolutionary models; followed by a brief discussion of the convergence hypothesis.

2.2.1 The Neoclassical Growth Model[1]

The neoclassical growth model, also known as the "Solow-Swan" model, was probably the first modern model of economic growth to explicitly recognize the role of technology as a central driver of economic growth. It is associated most closely with Robert Solow, who observed in 1957 that a large part of U.S. economic growth was unexplained by the contributions of capital and labor, the two factors that characterized earlier models. Solow (1957) attributed this unexplained element to technological change and referred to it as Total Factor Productivity, or TFP (Moses Abramowitz referred to it as "the measure of our ignorance" in recognition of the fact that we have very little understanding of the myriad factors that contribute to it and the degree to which each does so). In Solow's model, only growth in technology can result in sustainable economic growth. Importantly, Solow's model assumes that technology is produced exogenously (outside of the model). We shall see in a moment that this has been a key point of contention with some of the more recent models.

Additionally, the model identified a "steady-state" rate of growth, or the growth rate that a country could theoretically sustain in the long term. "Over-performing" countries, or those above the steady-state rate of growth, would inevitably regress

[1] Sect. 3.1 and 3.2 draw on Greenhalgh and Rogers (2010).

to that rate of growth; while those countries performing at a sub-optimal level (a level below their steady state) would naturally increase their growth rate until they reached that sustainable rate. An important implication of Solow's model, then, is that it suggests that underperforming countries will grow faster than better performing economies do. That is, the poorer a country is (in terms of GDP per capita) the more quickly it would grow relative to wealthier ones. This suggested the inevitability of "convergence", or the gradual catch-up of poorer countries to richer ones.

2.2.2 Endogenous Growth Theories

Solow's model began to receive serious challenges in the 1970s as some of its key assumptions appeared to conflict with observed reality. The first was its assumption that technology was produced outside of the model, which seemed inconsistent with the fact that much invention and innovation is part and parcel of the economic system and is very much determined by the everyday decisions of the economic units in this system. Second, the model continued to under-explain actual observed rates of economic growth. And third, while some countries appeared to be converging others appeared to be diverging from the leading economies. An important set of these challenges coalesced into what is known as the endogenous growth theory (or New Growth Theory), most closely associated with Paul Romer (1986).

Endogenous growth models made three key assumptions distinct from Solow's model. First, they assumed that the production of technology is endogenous (internal), rather than exogenous (external), to the model. That is, they recognized the explicit role of economic units such as firms in the production of new technologies. Second, they assumed that knowledge could "accumulate"; that knowledge is a cumulative process that could be maintained and added to over time. Finally, they also assumed that knowledge "spills over"; that knowledge produced by one firm may be useful to others. Further, this process is inter-temporal; that is, firms can benefit from knowledge that was produced by other firms at an earlier point in time.

The endogenous growth model has important implications. While Solow's model assumed that capital has diminishing returns (that is, each additional dollar of capital results in a lower amount of additional output, everything else constant), in Romer's model, although individual firms may face diminishing returns to capital, the economy as a whole does not. This suggests that growth is possible in the long run and contrasts with Solow's prediction that growth could not be sustained at levels above their "steady state". While other variations on the endogenous growth model exist (see, for example, Lucas 1988), Romer's remains the most widely known.

2.2.3 Evolutionary Economics

Many of the ideas embodied in the endogenous growth models had already been discussed previously in a loose coalition of economic thought called evolutionary economics, such as the ideas on the nature of knowledge, the way it accumulates, and the possibilities for systemic learning and for increasing returns. However, evolutionary economics also challenged some of the basic concepts of neoclassicism which also continued in endogenous growth and is thus considered a separate (and challenging) school of thought.

Evolutionary economics is inspired by biological processes and focuses principally on two ideas (Verspagen 2005). The first is that firms are "chosen" by the market based on their ability to adapt to changing circumstances. The second is that innovation simultaneously (and continuously) introduces novelty into the system, effectively creating a "moving target" that firms need to adjust to. A third can be added regarding the way firms make decisions: rather than maximizing profits (which requires a huge amount of information), they develop and follow "sticky" routines and maximize "satisfying" behavior (i.e., make their owners feel happy with their investment). The constant interaction between the ever-changing system and the firms that inhabit it determines the "winners" that emerge. Importantly, these outcomes are difficult to predict. One strain of evolutionary economics postulates that technological development (and therefore economic growth) is dictated largely by technological trajectories or paradigms, which determine the parameters within which technology will advance for extended periods of time. These provide the context for specific innovations which "cluster" in time because a series of incremental innovations closely follow a radical one. The largest and most significant of these innovations may be so-called General Purpose Technologies, or GPTs, that are characterized by their broad application throughout the economy, such as ICT, biotechnology, or new materials.

There are two key distinctions between evolutionary economics and endogenous growth theory. First, endogenous growth theory assumes that firms are aware of the entire range of potential technologies and as such can "jump" from one technology to another as technologies prove themselves to provide a more profitable set of outcomes. Evolutionary economics, on the other hand, suggests that firms tend only to be aware of technologies very close to their current technology and are thus not necessarily able to take advantage of new technologies as they present themselves. Second, endogenous growth theory assumes "weak uncertainty" associated with policy choices (that is, the range of outcomes related to a policy choice are known but the specific outcome that will result is not); while evolutionary economics adheres to "strong uncertainty" (that policymakers are not even aware of the full range of outcomes). Therefore, while endogenous growth theory assumes that a series of policy levers can be pulled to result in a fairly predictable outcome, evolutionary theory suggests it is much more difficult to know what the outcome of specific policies will be.

2.2.4 The Convergence Hypothesis

We close this section with a brief word on the convergence hypothesis. It was mentioned earlier that Solow's model predicts convergence; but that we observe a combination of convergence and divergence. That is, some countries appear to be converging with (catching up to) the leading economies, while others appear to be diverging from them. A concise characterization of the convergence hypothesis was given by Baumol et al. (1989). When the productivity level of one or more countries is substantially superior to that of a number of other economies, largely as a result of differences in productive techniques, then laggard countries that are not too far behind the leaders will be in a position to embark upon a catch-up process. Many of them will actually do so. The catch-up process will continue as long as the economies approaching the leader's performance have a lot to learn from the leader. As the distance among the two groups narrows, the stock of unabsorbed knowledge will diminish and even approach exhaustion. The catch-up process will then weaken or even terminate unless some other unrelated influence comes into play. Meanwhile, those countries that are so far behind the leaders that find it impractical to profit substantially from the leaders' knowledge will generally not be able to participate in the convergence process at all. Many such economies will find themselves falling further behind, widening the gap between wealthy and poor nations.

The convergence hypothesis was empirically tested and debated over the years. According to Baumol et al. (1989), a country's ability to "converge" with leading economies is a function of (1) capital accumulation, (2) technological innovation, and (3) imitative entrepreneurship (which borrows ideas from abroad and adapts them to local circumstances).

Abramowitz (1986), on the other hand, highlights the role of social capabilities (effective institutions, including incentives and markets) in determining which countries are best able to close the gap (converge) with countries at the technological frontier. He adds to social capability the importance of "technological congruence", that is, the transferability of the leader's technology to follower countries. Essentially, countries that have developed sufficient capabilities and technological congruence are able to close the gap with the leaders due to the fact that they are able to copy and absorb the technologies the leaders have produced. As the stock of unabsorbed knowledge and technology shrinks, the pace at which convergence happens slows until it eventually comes to a halt as there are no more technologies to copy. (At that point, countries that have caught up can continue increasing their growth rate above that of other technological leaders only by producing their own new technologies). Those countries, however, that lack the capabilities to "understand" and therefore copy and absorb the technologies produced by the leaders, will fall further behind, resulting in divergence from the leaders.

Importantly, the convergence hypothesis predicts a different set of outcomes from those produced by Solow's model. While Solow assumes that convergence is inevitable, convergence theory suggests that it is not; and that good policy can play an important role in determining whether a country takes the path of convergence or of divergence.

2.3 Technology Creation (Invention)

We have now provided some context for the importance of technology in the economic growth process. We proceed in the next three sections to a discussion of how the growth of technology is nurtured. This section focuses on the creation of new technologies. We look first at the mechanics of technology creation. This is followed by a discussion of the rationale for government intervention in the support of research; and concludes with two sections that look more closely at issues of specific interest to policymakers.

2.3.1 The Research Chain

The process of technology creation is often divided into three stages: basic research, applied research, and development (although in reality the lines between the three are blurred). *Basic research* is distinct from applied research in that it is conducted without consideration for a specific application. *Applied research*, on the other hand, is undertaken with a specific need in mind. *Development* is the design, construction, and testing of prototypes of new products and processes. Research is critical because it is the foundation for technology (which, it will be recalled, was defined in Sect. 2.1 as the application of new knowledge to the production process). Technology, in turn, is central to productivity growth, as discussed in Sect. 2.3.

2.3.2 Economic Arguments for Policy Intervention in Research Activity

Most arguments for public intervention in research relate to the more basic and generic aspects of research; as the government is generally considered to be too far removed from the market to play a useful role in applied research.

There are two primary economic arguments that justify public intervention in research activity. The first rests primarily on the theory of *market failures*. This argument suggests that:

- The social returns related to research activity outweigh private benefits, implying that private sector actors are likely to under-invest in research; and
- A high level of uncertainty characterizes R&D and innovative activity, which can be only partly insured.

In addition, market failures can arise due to the fact that certain investments can be made only at significant scale; and as a result of information asymmetries between the parties conducting research and those funding it.

The second economic argument is based on *system failures*. One case of this is when introduction of an initial technology leads to "lock-in" along a sub-optimal technological trajectory—such as, arguably, fossil fuels today. A second case, discussed in greater depth in Sect. 2.6.4.2, relates to the need for coordination among institutional actors in order to promote the diffusion of innovations. A third case in which the government can play a useful role is in making strategic R&D investments both within technology cycles and in managing the transition from one technology life cycle to another. In addition, public intervention can also be important in developing human capital for the purpose of promoting absorption of technology.

2.3.3 Issues of Interest to Policymakers

2.3.3.1 Intellectual Property Rights (IPRs)

One of the most widely discussed policy issues with respect to the creation of new technologies is that of intellectual property rights, or IPRs. IPRs encompass patents, trademarks, copyrights, and trade secrets; these are discussed more extensively in Chap. 7 of this book. We will focus briefly here on patents. Patents in effect grant the inventor a temporary monopoly, thereby allowing them to capture all of the economic benefits from their invention over a limited period of time; in exchange for the inventor's agreement to put all knowledge related to the invention into the public domain. The patent system is therefore an attempt to solve the appropriability problem addressed above.

Several concerns have been raised, however, with respect to the patent system. One relates to the duration of patents and whether it should be uniform across sectors and technologies given the great differences among them. A second involves questions about whether the exercise of some of the rights associated with owning a patent may in fact discourage, rather than encourage, invention. One example is the practice of obtaining patents (with no intention of using them) for the knowledge surrounding an invention a firm currently holds a patent to, thereby preventing other firms from "inventing around" the patent that the firm hopes to exploit. A third issue concerns the cost of the patent system and whether that disproportionately benefits larger firms relative to smaller ones. A fourth involves the length of time necessary to obtain a patent, which may make the technology to be covered by the patent obsolete by the time patent approval is granted. Finally, lax IPR systems in many developing countries have also raised criticisms from more developed countries. In many cases these have been established specifically to promote the diffusion of technologies (discussed in Sect. 2.5) in countries that lack the capacity to produce leading-edge research; but this remains an ongoing subject of controversy.

It is also unclear to what extent patents are central to the decisions of firms to produce (applied) research. Research shows that firms outside of the pharmaceuticals and chemicals sectors rely on patent protection to only a very limited extent (or not at all) to protect their inventions,[2] preferring instead to establish first-mover advantage or the development of complementary capabilities to create a market

[2] Mansfield's work (referenced in Cohen 2010, pp. 182–183)

position that cannot easily be imitated. Firms also in some cases choose not to patent in order to avoid having to put knowledge into the public domain (preferring to resort to trade secrets instead).

2.3.3.2 R&D Composition

Another (often overlooked) issue of interest to policymakers is the composition of R&D spending. Many countries have attempted to target an "optimal" level of R&D spending (3 % of GDP, which was chosen by the European Union in their 2020 growth strategy,[3] seems to be a particularly common target for developed economies, although Korea and a few others have higher stated targets), but have neglected any attention to the split between basic and applied research spending. As noted earlier in this section, while applied research is the basis for products and services that can be commercialized in the near future, basic research plays a critical role in producing the foundation for the technologies that will drive competitiveness in the future. The amount of funding devoted to applied research (most of which is funded by companies) relative to basic research (most of which is funded by governments) typically increases as countries develop. However, there are frequently voiced concerns that insufficient resources are being devoted to basic research activities, thereby potentially compromising a country's future competitiveness. Of additional import is the destination of R&D funding; whether it is oriented toward defense application, for example, or designated for uses that are more likely ultimately to have commercial application.

2.3.3.3 Non-Linear Research Models

We have mentioned that the neat division of research activity into basic research, applied research, and development is an oversimplification of the way that new technologies are developed. This is typically referred to as the *linear model*, and implies that the process of technology creation occurs in a predictable order. In reality, the process is often more iterative than linear. The publication of *Pasteur's Quadrant*, by (Stokes 1997) epitomizes this thinking; calling into question the linear model (basic research leads to applied research which in turn leads to development, production and marketing of new products) while suggesting that the process involves a stronger feedback mechanism (from the market to research) than the linear model envisioned and could be initiated at multiple points in the "research chain". This fact has important policy implications as it suggests that governments will need to strike a balance between "supply-led" policies (in which R&D funding is typically driven by the missions of public organizations) that characterize the linear model and "demand-led", or user-driven, policies, such as those promoting market innovations, that recognize that the end markets play an important role in informing the research that is conducted.

[3] As cited in Albu (2011).

2.3.4 Policy Tools Available to Support Basic Research

Governments can tweak the intellectual property system to obtain desired outcomes; for example, the Bayh-Dole Act in the U.S., which granted the rights to intellectual property produced by universities with federal funding to the universities themselves, has probably incentivized universities to produce more research of value than they might have in its absence (more on this in Chap. 3). However, governments have other tools at their disposal as well. We will mention two; direct support to R&D and tax incentive programs.

Direct support (generally in the form of grants and contracts) ranges from about 20% of total research expenditures in East Asian countries such as Korea and Japan to up to 50% in select European Union countries (the U.S.'s federal share is about 33% of total research expenditures) to higher shares in countries like Brazil (Steen 2012). Much of the public funding in developed countries tends to be directed to universities, which, for example, conduct over half of all basic research in the U.S. Such direct funding for research offers policymakers the advantage of being able to choose where the funding goes while still keeping at some distance from the market.

An alternative to direct support is indirect support through the provision of tax incentives to companies. Such incentives provide matching funds to companies for every dollar of research that they conduct; or for every dollar of research they conduct above a certain baseline (usually determined by past R&D investments by the company). Tax incentives are controversial because of the difficulties associated with linking them to actual increases in company R&D spending. Most research suggests that there is approximately a 1:1 ratio between government spending and research funding allocated; that is, companies increase their total R&D spending by, on average, exactly the amount they receive from the government; which may seem an inefficient subsidy mechanism in catalyzing additional R&D investment.

An additional policy option available to governments is the support of collaborative research partnerships. These partnerships may take the form of public-private arrangements (such as those between governments and private companies) or private-private arrangements (which encourage companies to work together, often through strategic alliances or joint ventures, to produce basic research). This is the subject of Chap. 4 of this book.

2.4 Commercialization of New Technologies (Innovation)

We now turn to a discussion of the commercialization of new technologies, typically the idea associated with innovation. Only a small percentage of all inventions actually become innovations; that is, very few inventions actually find commercial application. Most research suggests that only about 2% of all patents find commercial use. As not all inventions are patented, this is only a representative figure; but does provide some sense of the limited number of new technologies that are created that actually make it to market. Because of this, it is important to understand the dynamics of the commercialization process.

2.4.1 Commercialization and Large Firms

Schumpeter, J. (1942) and his followers at one time asserted that large firms are more capable of generating innovations than small firms are. While extensive research since then has shown this to be inconsistent with the evidence, large firms do play a very important role in commercializing technologies in certain industries, including for instance highly capital-intensive industries such as pharmaceuticals and chemicals and industries requiring the integration of complex products such as automobiles, aircraft, and military equipment. Possessing access to many resources, large firms account for the majority of absolute spending on R&D in the US. In addition, large firms are also the source of numerous spin-offs (discussed in Sect. 2.4.2), thus playing a central role in the innovation ecosystem.

2.4.2 Commercialization and Entrepreneurship/Small Firms

Entrepreneurship was initially largely ignored in discussions of national systems of innovation (discussed in Sect. 2.6.4.2) but has, in the last decade, become a priority in policy circles. Of most interest for this book is the category of entrepreneurs we refer to as *growth entrepreneurs* (also referred to as "opportunity entrepreneurs"), which we define as individuals or teams of people who exploit a previously unidentified or unexploited business opportunity. We distinguish this group from *necessity entrepreneurs*, most commonly found in developing countries, who have turned to entrepreneurship as a livelihood only in the absence of other job opportunities. Within the category of companies set up by growth entrepreneurs, the most important sub-set is R&D-intensive companies. In developed countries this group contributes disproportionately to job creation and innovation and is therefore of great interest to policymakers. Only between 2–4 % of all small and medium sized enterprises (SMEs) can be classified in this group at any point in time. The entire "Research Stairway", and the percentage of firms that fall into each category of research intensity, is illustrated in Fig. 2.1.

Another, largely overlapping, sub-set of companies set up by growth entrepreneurs is the so-called "gazelles", those enterprises that have demonstrated sustained, above average growth in profits. According to a recent report, only about 4 % of respondents fell into this category; but accounted for about 40 % of new job creation in the United States (Endeavor 2011).

While entrepreneurial activity has frequently been attributed to the somewhat mystical qualities of a few gifted or creative individuals, the reality is that it is driven by the interaction of these individuals with the system within which they operate. Thus, the concept of "National Systems of Entrepreneurship" (Acs et al. 2013) has arisen in recognition of this systemic element to the "creation" of entrepreneurs. This recognizes that policymakers have a role in creating an environment supportive of those individuals who have entrepreneurial aspirations, a subject that will be discussed in greater depth in Sect. 2.4.3.

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