Chapter 2
Fundamentals of Innovation Policy for Growth and Development

David Feige

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

D. Feige (✉)
Center for International Science and Technology Policy, The George Washington University, Washington, D.C., USA
e-mail: dfeige@gwu.edu

N. S. Vonortas et al. (eds.), *Innovation Policy,* SpringerBriefs in Entrepreneurship and Innovation, DOI 10.1007/978-1-4939-2233-8_2

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.

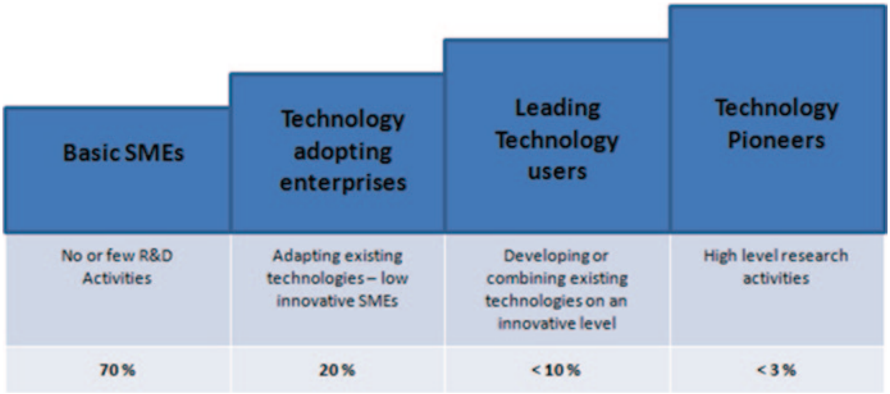

Fig. 2.1 The research stairway (EURAB 2004)

Entrepreneurs can arise, of course, in any industry. Within the context of our discussion of technology and innovation, we are particularly interested in the role that entrepreneurs (and small firms) play in commercializing new technologies. In line with Schumpeter's hypothesis with respect to innovation and firm size, it was at one time believed that large firms were more innovative than small ones. However, more recent research suggests that, although large firms have an advantage innovating in certain industries (as mentioned in Sect. 2.4.1) small firms are, on average, disproportionately responsible for innovation as a whole (Acs and Audretsch 2001). Their relative advantage seems greater when it comes to radical innovation.

They do so in primarily two ways. One is by commercializing research performed in universities; this may happen either when an inventor decides to commercialize his/her own research or through a licensing arrangement. The second is through "spin-offs" from existing firms; a common phenomenon is that an entrepreneurial individual produces an invention within the context of a larger firm to which they assign more value than the firm itself does. In such cases, the entrepreneur may leave the firm, taking their invention with them, and commercialize it under the auspices of a new company (Auerswald and Branscomb 2003). Such practice has been, in fact, institutionalized in certain large companies which sense a window of opportunity on the one hand—spin-off firms that may succeed may be folded back into the corporation later on—while dissipating internal conflicts on the other. In this way entrepreneurs play a key role as conduits of knowledge spillovers, addressed in our discussion of endogenous growth theories in Sect. 2.2.2. While several large companies are attempting to set up innovative units internally to stem the flood of talent leaving the firm and to capture more of the value of such innovations as they come online, such efforts have met with mixed success.[4]

[4] The early example of Xerox's PARC and the current Skunk Works of Lockheed Martin are cases in point.

2.4.3 Policy Interventions Supporting Entrepreneurship and Small Businesses

The focus of policy with respect to commercialization has focused primarily on support to entrepreneurship and small businesses in recognition of their central role in the innovation process. We will touch on a few support mechanisms here; including (1) financing and technical assistance programs (often provided through science parks and business incubators), (2) government procurement, and (3) National Systems of Entrepreneurship.

2.4.3.1 Finance and Technical Assistance

Financing for small enterprises has long been of interest to policymakers. Particular attention has been paid to the so-called "valley of death" that frequently engulfs small enterprises between basic and early applied research, on the one hand, and initial innovation and commercialization, on the other. This refers to the funding gap that exists that is not addressed by either the typical public sector programs supporting research, by angel investors, or by venture capital; thus resulting in the vast majority of small business failures. This subject is more thoroughly covered in Chap. 6 of this book, but the Small Business Innovation research (SBIR) program in the United States is a well publicized attempt by the public sector to address it. The SBIR is generally regarded as a fairly successful model for financing early stage innovation and has been adopted by several countries around the world. Technical assistance programs are another form of non-financial support and may include basic business skills training, help with marketing or product development, or linkages to domestic or export markets. These services are often provided in the context of a business incubator, which provides access to both financing and technical assistance in addition to physical space for the enterprise to operate.

2.4.3.2 Government Procurement

Government procurement is another, probably underutilized, tool that governments have at their disposal to encourage innovative activity among small firms. The military has often played an important role in sourcing leading-edge technologies that ultimately found commercial application, especially in developed countries (semiconductors is a widely cited example); and much of this work was contracted through small businesses. Small firms can similarly play a role in other, non-defense industries through set-aside grants designed to source innovative products or to source technologies specifically from small firms.

2.4.3.3 National Systems of Entrepreneurship

Brief mention was made in Sect. 2.4.2 of the concept of National Systems of Entrepreneurship (Acs et al. 2013). This approach recognizes that the creation of systematic innovative entrepreneurship requires a holistic “ecosystem” approach (including funding, mentorship opportunities, market linkages, and a catalytic environment with respect to business rules and regulations); and that governments have an important role in filling the “gaps” that exist in the entrepreneurial ecosystem. This suggests that regulations should be harmonized and oriented toward the support of entrepreneurial activity; and that this should be accompanied by the development of technological infrastructure as well as efforts to change national cultures that often hinder entrepreneurial activity. These may include media campaigns to try to change the attitudes of individuals toward entrepreneurship as a career as well as changing the attitudes of society toward entrepreneurs.

2.5 Technology Diffusion

Technology diffusion refers to the spread of technology throughout an economy. Diffusion is the principal determinant of the contribution that a specific technology makes to economic growth. In this section we outline the diffusion process before proceeding to specific policy interventions that can be used to affect the speed with which diffusion takes place; and conclude with a discussion of international diffusion processes and the role that multinational companies (MNCs) play in that process.

2.5.1 The Diffusion Process

One of the key observations made with respect to the diffusion process is that diffusion does not happen suddenly, but is rather a gradual process that begins haltingly, speeds up once it hits a “takeoff point”, and then slows down as the market for the particular innovation saturates. (This pattern takes the form of an “S” shape). Additionally, new technologies are typically adopted by different people at different times. Widespread diffusion of a given technology depends largely upon the extent to which creators of a new technology are successfully able to reach innovators and early adopters, who provide important feedback on the technology before it reaches a wider audience. The S-shaped diffusion curve, overlaid on the adoption curve, is illustrated in Fig. 2.2 below.

Importantly, however, different innovations diffuse at different rates. The speed of diffusion is determined by many factors, among which include (1) the degree to which the new technology represents an improvement over the old, (2) the cost of

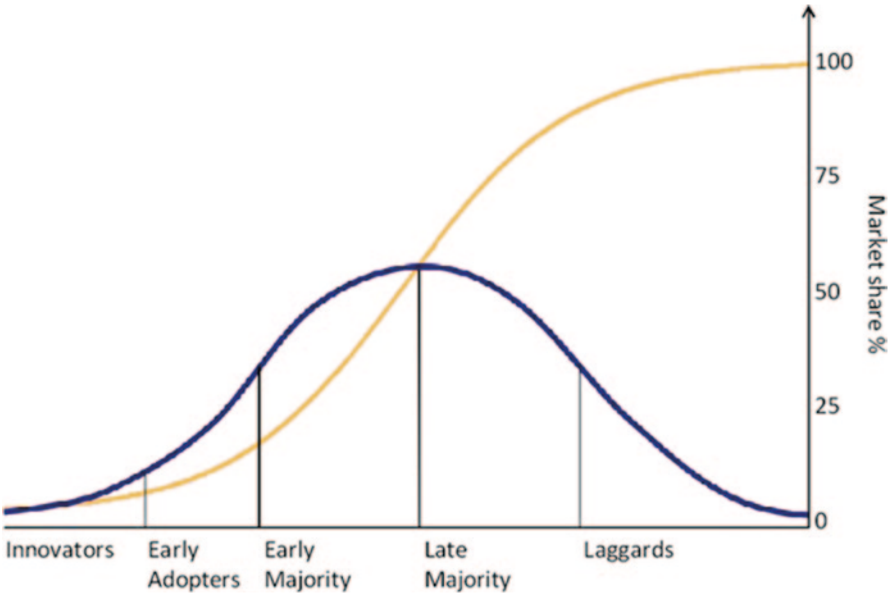

Fig. 2.2 Diffusion and adoption curves. ("Everett Rogers", Wikipedia: The Free Encyclopedia. 2014)

adopting the innovation (including both the technology and any complementary technologies that must be purchased to accommodate it), (3) improvements made to the technology in the course of the diffusion process, (4) the degree of uncertainty about the new technology, (5) the existence of complementary technologies, (6) the existence of "network effects", which arise when each user benefits from the addition of new users (think, for example, of cell phone networks), and (7) the extent to which improvements are made to the incumbent technology in an effort to stave off its replacement (Hall 2005; Rosegger 1986; Stoneman and Battisti 2010).

2.5.2 Diffusion Policy

Governments can play an important role in either speeding or slowing diffusion. One excellent example is the patent system; stronger patent protection (typical in more developed countries) often slows the diffusion process by the granting of a temporary monopoly over new technologies. Looser patent protection in developing countries, on the other hand, can play an important role in speeding diffusion by allowing for easy imitation of existing technologies. It is important to recognize the trade-off here; stronger patent protection creates an incentive system more aligned with the creation of new technologies, while looser protection spurs diffusion. Thus, choice of a patent regime depends greatly on a country's position as a technology leader or a technology laggard, with leaders adopting stronger patent protection and laggards favoring weaker protection. These different perspectives have given rise to a heated debate internationally about the extent to which developing countries should be able to establish weak IPR regimes.

Governments can also promote diffusion of certain technologies by setting standards; or by establishing regulations that encourage the uptake of certain technologies. A common example is the importance of emissions standards in promoting the diffusion of alternatives to carbon. On the other hand, governments can also slow the diffusion process, for example through the slowness of regulatory change. Finally, governments can promote diffusion of certain technologies over others by “picking winners” (favoring one technological solution over another) through the use of subsidies such as tax breaks. This is generally considered a more inefficient mechanism for promoting diffusion than the use of regulations that do not favor specific technologies. Regulation tends to be more effective at allowing the market to determine the technologies that ultimately win out.

2.5.3 International Diffusion

One additional area of interest is diffusion across borders. Multinational corporations (MNCs) are the primary agents of international diffusion, primarily through foreign direct investment (FDI) but also through other mechanisms, such as exports. While FDI is an important source of both job creation and exports in receiving (host) countries, the principal attraction of foreign investment is the access that it provides to the “black box”: technologies that can be exploited by the host country for its benefit. FDI can result in technology transfer, which refers to the intentional sharing of technologies with local firms by MNCs; or technology spillovers, which are unintentional or incidental to the investment.

However, the extent to which these occur is highly dependent on the absorptive capacity of host countries—including the technological gap between the MNC and host country firms, and the extent to which the country and its firms conduct research and development to enable them to better “understand” technologies produced outside of the country—as well as firm strategies regarding the nature of the FDI they are making. FDI can be divided into (1) asset-augmenting FDI, which seeks to exploit and leverage local capabilities (such as the acquisition of either R&D facilities or technological capabilities) and is more likely to generate host-country benefits; and (2) asset-seeking FDI (such as investment in extractive industries), which aims principally to take advantage of local natural resources or to gain access to local markets, and is basically exploitative in nature.[5] The nature of that investment, though, tends to be determined by the extent to which local (host country) absorptive capacity[6] exists (as well as host country policy); that is,

[5] Dunning (1993) originally defined four categories of FDI (market-seeking, resource-seeking, efficiency-seeking, and strategic asset-seeking); these have been condensed in the more recent literature to these two.

[6] Absorptive capacity was originally defined by Cohen and Levinthal (1989, p. 569) as “a firm’s ability to identify, assimilate, and exploit knowledge from the environment”.

absorptive capacity and firm decisions regarding the nature of their investment are co-determinant.

Governments thus have an important role to play in building local capacities such that a country is better positioned both to attract the investment it seeks and to access the technologies that will allow it to climb up the value chain. It is worth noting here the temptation that policymakers face to establish local content requirements. Although these would seem on the surface an effective way of assuring the transfer of technology, they often tend to drive investment away, thus precluding local firms from benefiting from the presence of foreign firms. The exception to this is larger countries (such as India, Brazil, or China) which boast attractive enough local markets allowing them a stronger negotiating position *vis-à-vis* MNCs.

One additional point should be made here. The diffusion process in developing countries often hinges on entrepreneurial individuals who adapt and adopt technologies from abroad. This process, in which individual entrepreneurs are the agents through which a country identifies the sectors and sub-sectors in which it holds a current or potential competitive advantage, has been dubbed "self-discovery" by Rodrik and Hausmann (2002) and "imitative entrepreneurship" by Baumol (1968). Because of the simultaneous nature of innovation and diffusion within this process, it becomes increasingly difficult to distinguish one from the other. While innovation and diffusion are concomitant processes to a certain extent in developed countries as well, the lines become further blurred in developing countries because most inventions do not originate there.

2.6 Technology, Innovation, and International Economic Competitiveness

Technology and innovation are central to economic competitiveness. In more developed countries, competitiveness is primarily a function of their ability to develop new technologies; while in developing countries competitiveness is dependent upon their ability to utilize existing technologies. In this section we first review the definition and ways of assessing competitiveness. We then proceed to a discussion of the decentralized nature of the drivers of competitiveness; before concluding with a discussion of a pair of particularly topical issues with respect to policy around innovation and competitiveness: clusters and systems of innovation.

2.6.1 Defining Competitiveness

Competitiveness is a frequently used (and almost as frequently misused) term in policy circles. While the term carries different meanings at the firm, industry, and national levels, for the purposes of this report, we will define competitiveness as the ability of a country to generate sustained increases in productivity resulting in a high and rising standard of living for its people. Productivity, on the other hand, is a measure of the efficiency with which a country is able to convert its inputs (resources) into outputs (products and services) that have value on domestic and/or international markets.

Michael Porter (1990) draws a distinction between what he refers to as "comparative advantage" and what he calls "competitive advantage". Comparative advantage arises from the exploitation of "inherited" or "basic" factors of production, such as fertile land or cheap labor. Competitive advantages, on the other hand, are "created"; they include advanced infrastructure and skilled human resources, and require some effort (investment) on the part of the country to produce. Only the latter can generate sustained increases in a country's standard of living because only enhancements to a country's competitive advantage allow for increases in productivity, which translate into increases in wages. Technology and innovation are central to a country's capacity to generate competitive advantage.

2.6.2 Assessing Competitiveness: The Global Competitiveness Index

The Global Competitiveness Index (GCI) is a composite index published annually by the World Economic Forum. Contrary to popular misconceptions, the GCI does not actually measure "competitiveness". (Competitiveness, as noted above, is defined as productivity, and thus can be measured already without the help of the GCI). Rather, it is an attempt to *explain* differing levels of productivity among countries and to predict the ability of a country to achieve high and rising levels of productivity (and, by extension, national prosperity) in the future. It therefore uses a model (hypothesis) about the factors (indicators) that contribute to a country's level of competitiveness and their relative importance; and then uses a combination of hard data and a survey of company executives to assign scores to a country on each factor. The factors are categorized into a set of broad "pillars" that include institutions; infrastructure; macroeconomic stability; health and primary education; higher education and training; goods market efficiency; labor market efficiency; financial market sophistication; technological readiness; market size; business sophistication; and innovation. The twelve pillars are further condensed into three categories that are roughly aligned with the stages of development of a country (defined by GDP per capita). By identifying the areas in which a country has demonstrable weaknesses, policymakers are able to make targeted improvements to address those shortcomings. Although it suffers from a number of imperfections, both in the content of the related survey as well as its sampling techniques, the GCI does show a broadly positive correlation with GDP per capita levels and remains the most popular tool for assessing and explaining a country's overall competitiveness.

For our purposes, it is probably most important to note that the GCI distinguishes among three types of economies, each of which demonstrate a set of characteristics that also (with a few exceptions) correspond roughly to GDP per capita levels. *Factor-driven economies* tend to be based heavily on the exploitation of basic factors of production and are characterized by primary product exports. *Efficiency-driven*

Global Competitiveness Index		
Basic requirements subindex	**Efficiency enchancers subindex**	**Innovation and sophistication factors subindex**
1. Institutions 2. Infrastructure 3. Macroeconomic environment 4. Health and primary education	5. Higher education and training 6. Goods market efficiency 7. Labor market efficiency 8. Financial market development 9. Technological Readiness 10. Market size	11. Business sophistication 12. Innovation
Key for **factor-driven** economies	Key for **efficiency-driven** economies	Key for **innovation-driven** economies

Fig. 2.3 Pillars of the global competitiveness index. (Adapted from Schwab 2013)

economies are characterized by their ability to produce existing products efficiently (generally by deploying existing process technologies) but tend not to produce new products or processes. *Innovation-driven economies*, on the other hand, are the source of significant new products and processes. Section 2.5.3 on the international diffusion of technology discussed the way that MNCs make decisions regarding where they locate specific activities within global value chains. We can think of these categories (while they obviously require a certain degree of simplification) as the rough contours that determine where those activities are located. They are therefore both reflective of, and a determinant of, a country's ability to generate higher value addition.

The 12 key "pillars" of the Index, as well as the stage of development with which each is most closely associated, is summarized above (Fig. 2.3).

It is worthwhile noting that the depiction above assumes that progression through the three stages (factor-driven through innovation-driven) is essentially linear in nature; and that a country must develop its basic requirements prior to developing its efficiency enhancers; which must precede development of its innovation and sophistication factors.

2.6.3 Competitiveness as a Decentralized Process

The fact that most measures of competitiveness use the national level as the economic unit of measurement obscures that fact that competitiveness is in large part a subnational process, dependent on the specific factors of production located in regions within countries. This is particularly true in larger countries. The mechanics of this process are a matter of some dispute, however.

There are two principal schools of thought regarding the way that decentralized economic growth happens. One of these, popularized by Michael Porter as "industrial clusters" but is an idea that dates back to Alfred Marshall's work on agglomeration economies from the late 19th century, is discussed in greater depth in Chap. 5 of this book. For now, it suffices to note that cluster-based approaches assume that competitiveness is generated by inter-firm and inter-industry effects; that is, the dynamic interaction of firms in a given sector and the related industries and institutions that support them. Many of the most dynamic clusters are based on science and technology. These include not only Silicon Valley but the ICT cluster in Bangalore, India, life sciences in Boston, Massachusetts, and aerospace in Sao Jose dos Campos, Brazil.

A competing theory arises from the field of urban economics, first postulated by Jane Jacobs (1969). This school of thought asserts that the agglomeration of people, not industries, drives productivity increases; and that knowledge spillovers occur not just within industries but across them. This field focuses on urban areas as hotbeds of innovation and stresses the importance of diversification rather than specialization.

The fact that competitiveness is largely determined at the sub-national level suggests that policymakers at the local and regional level have a critical role to play in this process; and that it is necessary that policymakers at the national level coordinate their efforts closely with local and regional officials.

2.6.4 Policy Implications

2.6.4.1 Clusters and Technology Parks

Many regions globally have made cluster policy a staple of their economic development strategies. Similarly, technology parks, which have been defined as "mixed-use real-estate developments built close to universities that seek to encourage industry-university knowledge transfer" have become a popular tool for driving regional development. As we have devoted an entire chapter to clusters and technology parks in this book, we will not go into great detail here. There are two issues worth highlighting, however.

First, many governments have become wedded to the idea of generating "high-tech" industries in their area, and have gone to great lengths to try to "create" such industries. Most regions that have attempted to create industries from scratch have failed in doing so sustainably. It is generally better policy to build on a region's existing advantages than to attempt to build something with no prior history in the area. Second, while it is true that technology and innovation are critical drivers of productivity growth, it is the view of the authors that disproportionate focus has been placed on developing "high-technology" industries. Such a focus ignores the fact that any industry, irrespective of how it is categorized, can demonstrate high levels of productivity and therefore drive economic growth. Technology can be viewed as an "enabler": firms in "low-tech" industries may still incorporate technology to enable them to achieve higher productivity levels.

2.6.4.2 Systems of Innovation[7]

We alluded in Sect. 2.3.3.3 to the limitations associated with the linear model. In response to these limitations, attention turned in the late 1980s to innovation systems, which look at the process of technological advancement from a more systemic, interactive, and evolutionary standpoint. Innovation systems can be viewed from either the national, regional, or sectoral level.

Freeman (1987) defined innovation systems as "…the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies." This approach focuses on the linkages among the agents involved in innovation, including private enterprises, universities, and public research institutes. Technical advancement and innovation are viewed as the outcome of relationships among these entities targeting the production, dissemination, and application of knowledge. The innovative performance of a country, according to this view, depends on how these actors relate to each other as elements of a collective system of knowledge creation and use.

For policymakers, an understanding of the national innovation system, or NIS, can help identify leverage points for enhancing innovative performance and overall competitiveness. It can help pinpoint mismatches within the system, both among institutions and with respect to government policies that hinder technology development and innovation; as well as the absence of necessary institutions within the system. Policies that seek to enhance the innovative capacity of firms, particularly their ability to identify and absorb technologies, are most valuable in this context. (OECD 1996; Lundvall et al. 2007; Edquist 2005).

Regional innovation systems (RIS) are closely related to clusters. An RIS features (1) firms that interact with each other, in particular those that tend to cluster; and (2) supporting regional infrastructure including private research laboratories, universities and colleges, and technology transfer agencies. An RIS can contain several clusters as long as there are firms and knowledge organizations that interact systematically within the boundaries of that region. Policymakers at sub-national levels may then focus on networking among firms and development of common infrastructure to support these systems.

An additional innovation systems concept is that of sectoral systems of innovation. Sectoral systems of innovation (Malerba 2004) stress the nature, structure, organization, and dynamics of innovation and production at the sector level; and focus primarily on firms, capabilities, and learning processes as the major drivers of innovation and growth, while also emphasizing the role of other actors in the system, including individuals, users, universities, government, and financiers and the linkages among them.

[7] This section draws substantially on Chap. 4 of Vonortas and Aridi (2012).

The innovation systems concept, although criticized for its lack of detail, is important because of the changing dynamics of international competition. Historically, advanced countries could assume that they would appropriate the benefits of technologies they produced. However, the rapidly developing capabilities of non-Western countries, particularly in Asia, to adopt and diffuse technologies produced elsewhere implies a need for a systemic approach to capturing those benefits; one embodied in the systems approach to innovation. This implies an important coordination role for policymakers to assure that the elements of the innovation system are working effectively together.

References

Abramowitz, M. (1986). Catching up, forging ahead, and falling behind. *Journal of Economic History, 46*(2), pp. 386–406.

Acs, Z., & Audretsch, D. B. (2001). Innovation in large and small firms: An empirical analysis. *The American economic review, 78*(4), 678–690.

Acs, Z., et al. (2013). National systems of entrepreneurship: Measurement systems and policy implications. George mason university school of public policy research paper no. 2012–08, 5 August 2013.

Albu, N. (2011). Research and development spending in the EU: 2020 growth strategy in perspective. Working paper FG1 no. 8, December 2011, SWP Berlin.

Auerswald, P., & Branscomb, L. (2003). Start-ups and spin-offs: Collective entrepreneurship between invention and innovation. In David H. (Ed.), *The emergence of entrepreneurship policy: Governance, start-ups, and growth in the knowledge economy*. Cambridge: Cambridge University Press.

Baumol, W. J. (1968). Entrepreneurship in economic theory. *American Economic Review Papers and Proceedings,* 58:64–71.

Baumol, W. J., Blackman, S. A. B., & Edward N. W. (1989). *Productivity and American leadership the long view*. Cambridge: MIT Press, c1989.

Cohen, W. M., & Levinthal, D. A. (1989). Innovation and learning: The two faces of R and D. *The Economic Journal, 99,* 569–596.

Cohen, W. M. (2010) Chapter 4: Fifty years of empirical studies of innovative activity and performance. In Hall and Rosenberg (Eds.), *Handbook of the Economics of Innovation,* Vol. 2, pp. 182–183.

Dunning, J. (1993). *Multinational enterprises and the global economy*. Harlow: Addison-Wesley.

Dutta, S., & Lanvin, B. (2013). High level segment: 1st July 2013. *The global innovation index 2013: The local dynamics of innovation*. http://www.globalinnovationindex.org/userfiles/file/blog/blog-july-1.pdf.

Edquist, C. (2005). Systems of innovation: perspectives and challeng*es*. In J. Fagerberg, D. Mowery, & R. R. Nelson (Eds.), *The Oxford Handbook of Innovation*. Norfolk: Oxford University Press.

EURAB (European Advisory Research Board). (2004). SMEs and ERA, report and recommendations, EURAB 04.028-final. http://ec.europa.eu/research/eurab/pdf/eurab_04_028_sme_era.pdf.

Freeman, C. (1987). *Technology policy and economic performance: Lessons from Japan*. London: Pinter.

Greenhalgh, C. & Rogers, M. (2010). Chapter 9: Models of economic growth. *Innovation, intellectual property, and economic growth* (pp. 213–242). Princeton: Princeton University Press.

Hall, B. H. (2005). Innovation and diffusion. In Fagerberg, J., Mowery, D. C., & Nelson, R. R. (Eds.), *The Oxford Handbook of Innovation*. Oxford University Press.

Jacobs, J. (1969). *The economy of cities*. New York: Random House.

Lucas, R. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22,* 3–42.

Lundvall, et al. (2007). National systems of production, innovation, and competence-building. In Polenske, K. R. (Ed.), *The Economic Geography of Innovation*. Cambridge University Press.
Malerba, F. (2004). Sectoral systems of innovation: Basic concepts. In F. Malerba (Ed.), *Sectoral systems of innovation*. Cambridge University Press.
Morris, R. (2011). 2011 high-impact entrepreneurship global report. Endeavor center for high-impact entrepreneurship and the global entrepreneurship monitor.
OECD. (1996). The knowledge-based economy. Technical report. Organization for economic cooperation and development.
Porter, M. E. (1990/1998). *The competitive advantage of nations*. New York: Free Press.
Rodrik, D., & Hausmann, R. (2002). Economic development as self-discovery. NBER Working Paper Series #8952.
Rosegger, G. (1986). The Economics of Production and Innovation: An Industrial Perspective. Pergamon Press.
Romer, P. (1986). Increasing returns and long run growth. *Journal of Political Economy, 94* (2):1002–1038.
Schwab, K. (2013). The global competitiveness report 2012–2013. World economic forum. http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf.
Schumpeter, J. (1942). Capitalism, Socialism, and Democracy. Routledge.
Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics, 39*(3), 312–320.
Steen, J. V. (2012). Modes of public funding of research and development: Towards internationally comparable indicators. OECD Science, technology and industry working papers, 2012/04, OECD Publishing. http://dx.doi.org/10.1787/5k98ssns1gzs-en.
Stokes, D. E. (1997). *Pasteur's quadrant: Basic science and technological innovation*. Washington, DC: Brookings Institution Press.
Stoneman, P., & Battisti, G. (2010). Chapter 17: The diffusion of new technology. In Hall & Rosenberg (Eds.), *Handbook of the Economics of Innovation,* Vol. 2, pp. 733–760.
Verspagen, B. (2005). Innovation and economic growth. In J. Fagerberg, D. C. Mowery, & R. R. Nelson (Eds.), *The Oxford handbook of innovation*. Oxford: Oxford University Press.
Vonortas, N. S. (2013). Justifying Public Intervention in Research and Development.
Vonortas, N., & Aridi, A. (2012). The Innovation Policy Handbook. Center for International Science and Technology Policy, George Washington University, 2 June 2012.
Wikipedia: The Free Encyclopedia. (2014). Everett Rogers. http://en.wikipedia.org/wiki/File:Diffusionofideas.PNG.