ENVIRONMENT & DEVELOPMENT ECONOMICS

ESSAYS IN HONOR OF SIR PARTHA DASGUPTA

edited by Scott Barrett,
Karl-Göran Mäler, and Eric S. Maskin

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Contents

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Preface

This is an unusual Festschrift, but it would have to be, for it is honoring a singular economist. Partha Dasgupta has devoted himself to more than research and writing, seminars and lectures. Perhaps because he was born in India and later lived and worked in England and the United States, Partha has endeavored to bring academics from these two worlds (the "South" and the "North," we sometimes call them) into contact with each other. This book is a tribute to that enterprise.

The contributors to this book include Nobel laureates and young academics just starting out, professors privileged to work at the world's top universities and people making the best of the opportunities afforded by their home institutions in developing countries. Many of the authors are his closest friends. They include his former teachers and students and his current and former collaborators. Unusual for a Festschrift, some other authors barely know him personally (we'll explain why below).

Partha has long chastised development economists for neglecting the natural environment, despite its importance to the livelihoods of the rural poor. He has also leaned on environmental economists for thinking about the environment as an amenity, while overlooking its relevance to poverty. If the literature ignored the connections between poverty and the environment, he believed, then so would the lecturers and professors teaching these subjects in developing countries; and then so would *their* students neglect these issues. The economics they would learn would be divorced from the world in which they and so many of their fellow citizens lived. Together with one of us (Mäler), he launched an initiative with the Beijer Institute of Ecological Economics of the Royal Swedish Academy of Sciences to conduct teaching and research workshops in environmental economics for lecturers and professors living and working in developing countries. Partha's convening power was such that faculty on these workshops included some of the world's leading economists, many of them contributors to this volume. A better teaching and research program on this subject could not be found anywhere in the world.

The workshops were beld "on location," in places like Elmina, Ghana; Kathmandu, Nepal; near Mount Kinabalu on the island of Borneo; and on the coast of Bahia, Brazil. The logistics of gathering everyone in these places were sometimes a headache, but the payoff was huge: by bringing together people from the same region—in most cases, for the first time—the Beijer workshops spawned a number of professional networks. These include the South Asian Network for Development and Environmental Economics (SANDEE), the Latin American and Caribbean Environmental Economics Program

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Learning, Growth, and Development: A Lecture in Honor of Sir Partha Dasgupta[1]

Joseph E. Stiglitz[2]

It is a great pleasure to deliver this address to honor my long-time friend and coauthor Partha Dasgupta. Our friendship and collaboration go back some forty-five years to the mid 1960s, when we were both students and research fellows at Cambridge. At the time, it was perhaps the most exciting place in economics in the world. To its own luminaries (Robinson, Kaldor, Meade, Champernowne, Farrell, Kahn, and Sraffa, to name but a few) were added a roster of visiting greats: Solow, Arrow, Radner, Minsky, and Diamond. And a younger generation of economists was just emerging, including future stars like James Mirrlees, Geoff Heal, Tony Atkinson, and Partha Dasgupta

We were all enthralled by growth theory, attempting to understand what makes economies grow and why some economies grow better than others. But there was, at the same time, an ongoing debate about capitalism. There was not then the presumption that prevailed for the three decades beginning with

[1] Slightly revised version of a keynote address that was delivered at the Annual Bank Conference on Development Economics, Stockholm, 2 June 2010, and subsequently published in the publication of the World Bank's Annual Bank Conference on Development Economics 2010: Development Challenges in a Post-Crisis World. Reprinted with permission.

[2] Joseph Stiglitz is University Professor at Columbia University; former chair of the Brooks World Poverty Institute, University of Manchester; and co-president of the Initiative for Policy Dialogue. The author owes a long-term debt to Partha Dasgupta for the ideas discussed here and in the many areas on which we have worked together over more than forty years. I am also greatly indebted to Bruce Greenwald. Much of the research discussed here represents joint work with Greenwald, some of which is reported in our forthcoming book *Creating a Learning Society: A New Approach to Growth, Development, and Social Progress: An Essay in Honor of Kenneth Arrow* (Columbia University Press). The basic ideas were briefly presented in Greenwald and Stiglitz (2006). I am also indebted to Jonathan Dingel, An Li, Sebastian Rondeau, Eamon Kircher-Allen, and Laurence Wilse-Samson for research assistance. Financial assistance from the Hewlett Foundation and the Institute for New Economic Thinking is gratefully acknowledged.

Margaret Thatcher and Ronald Reagan—that markets were efficient and stable. On the contrary, one of the memorable moments was when Frank Hahn first derived his results on the dynamic instability of markets;[3] as he put it, he had put the golden nail in the coffin of capitalism. We were concerned too about the inequality and poverty that seemed to accompany capitalism, and about the problems of development. There was still a hope that planning could replace a flawed market.

Even in those heady days, Partha stood out. He tackled new problems and raised new questions, some of which he would pursue in later years. Not since Edgeworth (1925) had an economic theorist tried to think deeply about population policy (Dasgupta 1969). The environment was not the concern that it is today—this was before the oil price shocks of the 1970s turned everyone's attention to the issues. Partha's pioneering work with Geoff Heal defined the field of the economics of natural resources for a generation (Dasgupta and Heal 1979).

The high hopes all of us shared for Partha's future contributions to economics have been more than realized. Year after year, his papers have presented insights into an increasing range of topics, and he has been joined by an increasingly large constellation of collaborators. But most monumental was his work *An Inquiry into Well-Being and Destitution,* (Dasgupta 1993), which identified the nexus between development, growth, inequality, and the environment. No one who read that work or his subsequent related work (e.g., Dasgupta 2001) could ever approach the problems of development as they had before.

Our interests overlapped in many ways; even when we were not writing together, his thinking influenced me. We worked together on issues of taxation,[4] cost-benefit analysis (Dasgupta and Stiglitz 1974; Dasgupta, Blitzer, and Stiglitz 1981), research and development (R&D) and innovation (the subject of this chapter) (Dasgupta and Stiglitz 1980a, 1980b, 1981a, 1982, 1988a, 1988b; Dasgupta, Gilbert, and Stiglitz 1983), risk,[5] and natural resources,[6] and on research projects that involved intertwining issues of natural resources, innovation, market structures, and uncertainty.[7] At other times, we worked in parallel; for example, on theories of efficiency wages, on markets with imperfect

[3] Later published; see Hahn (1966). Karl Shell and I extended this result in Shell and Stiglitz (1967).

[4] In particular, on the questions of when production efficiency was desirable, the optimal supply of public goods in the presence of distortionary taxation, and "third-best" approaches to optimal taxation when there were constraints on the set of feasible taxes. See especially Dasgupta and Stiglitz (1971, 1972).

[5] See, for instance, Dasgupta and Stiglitz (1977), where we showed that the presumption in favor of tariffs over quotas did not hold in the face of uncertainty and incomplete insurance markets.

[6] This included a large study done for the Department of Energy (Dasgupta et al. 1977).

[7] See Dasgupta, Heal, and Stiglitz (1980); Dasgupta and Stiglitz (1981b, 1981c, 1982); Dasgupta, Gilbert, and Stiglitz (1982, 1983). In many of these studies, we found that the study

information, and on theories of social capital.[8] My most recent project, as chair of the International Commission on the Measurement of Economic Performance and Social Progress (Fitoussi, Sen, and Stiglitz 2010), was in many ways inspired by *An Inquiry into Well-Being and Destitution.*

2.1 ENDOGENOUS LEARNING AND DEVELOPMENT: SCHUMPETERIAN ECONOMICS

It is customary in a Festschrift to write a chapter inspired by the work of the honoree. In this case, there are so many topics I could have chosen. But I shall choose one that I believe is central to development, that has been a source of concern to Partha and me since our days as graduate students, and on which we collaborated extensively in the following years: innovation.[9]

While much of the most widely read work in growth theory of the 1960s assumed exogenous technical progress, that was an assumption of convenience. We spent much time talking about and attempting to model the determinants of the pace of innovation (later called endogenous growth theory).[10]

Solow's seminal work (1957), in which he showed how one could decompose the sources of economic growth, had demonstrated why this task was so important: the vast majority of increases in per capita income were attributable to technological change (the unexplained Solow residual) rather than capital accumulation. To leave unexplained the determinants of technological change was, in short, to leave unexplained most of growth.

In the context of development, the matter was even more compelling. As I have repeatedly noted, what separates developed from less developed countries is not just a gap in resources but a gap in knowledge. The pace at which developing countries grow is largely determined by the pace at which they close that gap. Conventional economics and development theory and practice have given short shrift to these issues. They have focused on how to increase static efficiency; that

of natural resources provided a concrete context within which we could investigate issues of broader concern.

[8] See, in particular, a paper published in a volume edited by Partha in an area in which he has devoted much of his time during the past decade: Stiglitz (2000).

[9] Moreover, the techniques (and second-best reasoning) employed below are those we employed in our joint papers on public finance (see note 4).

[10] Perhaps most notable was the work of Kaldor (1957) and Kaldor and Mirrlees (1962); and that of Karl Shell and William Nordhaus (Shell 1966, 1967; Nordhaus 1969a, 1969b). Also influential were Uzawa (1965), Arrow (1962a, 1962b), and Nelson and Phelps (1965). My own paper with Tony Atkinson (Atkinson and Stiglitz 1969) was influenced by Kaldor. I discuss these developments at greater length in my 1990 paper. For a more recent contribution to the theory of endogenous growth, with some perspectives on the intervening literature, see Stiglitz (2006a).

is, given the state of knowledge within the country, how to move the country closer to its production (or utilities) possibilities curve. This was the focus of the Washington Consensus policies, including trade liberalization. But that meant policy was focusing on something that was, in a sense, of second-order importance: gains in moving to the production possibilities curve (say, as a result of trade liberalization) were one-off. Increases in income attributable to higher investment were dwarfed by those attributable to closing the knowledge gap. If one could only understand how to close that gap more rapidly and how to move the knowledge frontier out at a faster pace, one might be able to design policies that would have far larger impacts on standards of living. Ignoring the most important source of increases in income was bad enough; making matters even worse was that policy conclusions focusing only on static considerations and ignoring dynamics were likely to be wrong and misguided. For instance, if technological change is exogenous (and there are no problems of information asymmetries, no environmental externalities, etc.), the presumption is that markets are efficient and the role for government is very limited. But that may not be the case when technological change is endogenous.[11] One of the major objectives of this chapter is to explore the design of optimal government interventions.

Trade-offs can exist between static efficiency and dynamics. From the perspective of long-term well-being, it may be optimal to maintain static inefficiencies—possibly forever—because of dynamic benefits that might be generated by such seemingly distortionary behavior.

The idea of static versus dynamic trade-offs is familiar: the patent system introduces an inefficiency in the use of knowledge by restricting its free flow (because knowledge is a public good, with non-rivalrous consumption—when provided to an additional individual it does not subtract from that available to others). Moreover, patents reduce competition and in some cases even give rise to (perhaps temporary) monopolies, which in turn give rise to static inefficiencies. We countenance these inefficiencies in the belief that the restrictions incentivize research and that the dynamic gains outweigh the static costs.[12]

These concerns are even more central to development economics, where the focus of attention should be on how to bring about the transformation of the economy and society (Stiglitz 1998). Learning new ways of producing, of doing business, and of organizing economic, political, and social activities is at the heart of development. Dynamics cannot be ignored. Here we focus

[11] Indeed, Arrow (1951) and Debreu (1959), in their proofs of the Pareto efficiency of the market economy (the first fundamental theorem of welfare economics), assumed that technology was fixed, or at least that changes in technology were exogenous. As I explain in this chapter, there are good reasons to believe that when technical change is endogenous, the market equilibrium will not be Pareto-efficient.

[12] Whether and under what conditions that is so is, of course, another matter. Elsewhere, I have argued that intellectual property rights may actually impede innovation, especially if they are not well designed. See Henry and Stiglitz (2010) and Stiglitz (2006b, 2008). The adverse effects may be particularly marked in developing countries. See Stiglitz (2004, 2013).

more narrowly on "economic learning": improving workers' productivity. In this context, the central issue is *how can developing countries maximize these knowledge-related improvements in productivity or, more accurately, balance out the short-run costs and the long-run gains?* Exploring this issue is the central objective of this chapter.

Arrow's (1962a, 1962b) pioneering work provided a framework for analyzing endogenous technological progress: some progress was the result of deliberate allocation of resources to R&D, while much was learning that occurred as one produced or invested (learning by doing).[13] Here, we explore the improvements in productivity that result from learning by doing.[14]

Arrow noted that market structure (i.e., whether there was a monopoly or competition) affected incentives to innovate. But market structures themselves are endogenous, one of the points Partha and I stressed in our joint work. Knowledge can be viewed as a fixed cost; sectors in which R&D or learning are particularly important can be viewed as natural monopolies.

In short, if technological progress is endogenous, there is a raft of market failures: markets are not likely to be perfectly competitive; benefits of research or learning are likely to spill over to others; firms engaged in research will appropriate only a portion of the societal benefits arising from their research; and attempts to strengthen appropriation will introduce further distortions in the economy. Many of these market failures (e.g., those arising from imperfections of competition and the inability to appropriate all the benefits of R&D) may result in underinvestment in research.[15] Yet attempts to correct this problem—for example, through strong patent protection—may result in overinvestment: the private return from obtaining a patent typically exceeds the social return, which is simply the availability of the knowledge shortly before it otherwise would have been available.

Markets may not only invest too much or too little in research, they may invest too much in some kinds of research (me-too patents in the drug industry) and too little in others (especially in basic research).

[13] There is a large empirical literature on the evidence for learning by doing, cited in Arrow (1962a) and Solow (1997). See, in particular, Hirsch (1952), Alchian (1963), and Argote and Epple (1990). For additional theoretical work, see, for instance, Fudenberg and Tirole (1982), Spence, (1981), Cabral and Riordan (1994), and Besanko et al. (2010).

[14] Arrow assumed that learning was a by-product of investment. We simplify by assuming that it is a by-product of production (the input of labor). We comment briefly on how assuming it was a by-product of investment would alter our conclusions. See also Korinek and Servén (2010). Solow (1997) provided an insightful discussion of the Arrow model and its limits, as well as a bibliography of some of the research on learning-by-doing that occurred in the intervening thirty-five years, including the work of Levhari (1966, 1967), Sheshinski (1967), and Young (1991, 1997).

[15] More accurately, they result in less R&D or less learning than would occur in the first-best situation; given the lower output associated with monopoly, conditional on the monopoly power persisting, the optimal degree of investment in R&D is lower.

Analyzing the efficiency of the market is a complex task, and at the time Partha and I embarked on our work, a third of a century ago, few attempts had been made to do so. Remarkably, in spite of the constant praise of the market system's "innovativeness," we found no general theorems on the efficiency of markets with respect to the pace and direction of innovation. In a series of papers, we modeled the interactions between industrial structure and the pace of innovation, viewing them as both endogenous and simultaneously determined (Dasgupta and Stiglitz 1980a, 1980b). Only in such a context could one begin to analyze the efficiency of markets.

We were, I think, greatly influenced by the ideas of Schumpeter (1912, 1943), who had been long neglected by the mainstream. Schumpeter had argued—and we agreed—that if there was virtue in a market economy, it lay more with its dynamism, its ability to innovate, than with the kind of allocative efficiency stressed by the standard Arrow-Debreu model. Schumpeter grasped the dynamic/static trade-off.

Economists had long been preoccupied with the dangers of monopolies. Schumpeter dismissed these worries. He observed that in many of the markets in which innovation was most important competition (as conventionally defined) was limited; there was one, or at most only a few, firms. (Modern economic theory, including our joint work, clarified why this was to be expected: the non-convexities associated with research and learning by doing give rise to a "natural" monopoly.) But Schumpeter took a more benign view of monopolies than did the rest of the economics profession. Monopolies could generate the profits necessary to fund research—especially important in an era when financial markets were less developed, and venture capital firms did not exist. Borrowing to finance speculative research was limited because, if the research project failed, there was nothing for the lender to seize. In real estate, at least there is some collateral.

Moreover, in Schumpeter's view, in these dynamic settings conventional competition would be replaced by Schumpeterian competition. Competition *for* the market would replace competition *in* the market, and there would be a succession of monopolies. There were strong incentives for innovation provided by the contest to capture the monopoly rents.

Schumpeter thus countenanced monopoly: he saw it as a small price in static inefficiency to pay for a greater pace of innovation associated with monopoly. Until the development of the modern theory of the economics of information, the presumption in conventional economics was that markets, by themselves, result in efficiency (with well-known exceptions, such as those associated with pollution). Schumpeterian competition seemed to create a similar presumption for dynamic economies, in which the center of attention is on innovation.

As a result of my research on the economics of information, I had less sanguine views of the outcome of these market processes. Knowledge (say, about new technology) can be viewed as a special kind of information. Not

surprisingly, then, the economics of information and the economics of knowledge were very similar.[16] Both information and knowledge had public goods properties and large associated externalities.

Markets in which information was endogenous were generally not efficient (see Greenwald and Stiglitz 1986).[17] Given that we had established the inefficiency of market economies in which information was endogenous, it was also clear that economies in which knowledge was endogenous would also be inefficient. There was a presumption *against* unfettered markets.

As a point of departure, we wanted to test the robustness of some of Schumpeter's ideas, which for the most part had not been formally modeled but nonetheless had come to be widely accepted by economists focusing on innovation. At the same time, we wanted to shed light on some key policy debates.

Our analysis called into the question the way Schumpeter had posed the questions. We argued that if market structure itself were endogenous and affected by, say, the technology of technological progress, the right question was not what the effect of monopoly power on innovation was but under what circumstances the market structure that emerged endogenously would lead to efficient allocation of resources to innovation. Or, more broadly, what government interventions would enhance societal well-being? Such interventions could take a myriad of forms: antitrust policies, patent laws, government-funded research, or government incentives for research; for example, through the tax system.

Our results also called into question much of the conventional wisdom and some of what Schumpeter claimed.[18] For instance, Schumpeter too easily dismissed the distortions that arose from monopoly and underestimated the ability of monopolies to maintain their position. Firms had an incentive and the means to deter entry of rivals and maintain their monopoly (Dasgupta and Stiglitz 1980b, 1988b; Gilbert and Newbery 1982). Some of these actions, though privately profitable, were highly socially costly (Stiglitz 1981, 1987b). Monopolization could result in both short-run inefficiencies and a slower pace

[16] This was one of the central points made in my 1974 lecture before the Association of University Teachers of Economics in Manchester (Stiglitz 1975b). In November 1978, I elaborated on the problems arising from the public-good nature of knowledge in a lecture to an InterAmericn Development Bank-CEPAL meeting in Buenos Aires (published later as Stiglitz 1987a). Knowledge is a special kind of public good—a global public good, the benefits of which could accrue to anyone in the world. After developing the concept of international public goods in an address to a UN meeting in Vienna (Stiglitz 1995a), I applied that concept to knowledge (Stiglitz 1999).

[17] Beginning in the late 1960s, I had explored the nature of these inefficiencies. In Stiglitz (1975a), I showed that there could exist Pareto-inferior equilibria, and, in Newbery and Stiglitz (1982), we showed that trade restrictions could make everyone in all countries better off.

[18] For a broad overview, see my introduction to the 2010 edition of Schumpeter's classic *Socialism, Capitalism, and Democracy.*

of innovation.[19] We wrote about this before Microsoft's abuses became well known. In a sense, our work laid out a framework to evaluate claims about the benefits associated with attempts to limit competition, explaining both the private incentives and the high social costs of these anticompetitive practices.

2.1.1 The Infant Industry Argument for Protection

In a later work, we linked this broad conceptual work to our interest in development and, in particular, to the question of industrial policy and whether innovation and learning[20] provided a justification, for instance, for industrial tariffs (Dasgupta and Stiglitz 1988a). While earlier literature had developed the infant industry argument for protection, conventional wisdom in the previous quarter-century had moved against it.[21]

This reaction was partly for reasons of political economy: the infants never grew up, and the argument often seemed more abused than used (America's ethanol subsidies are a case in point). Not content with these political arguments—especially since the most successful countries, those in East Asia, had arguably employed industrial policies with considerable success—many economists attacked the economics itself.

Critics of infant industry protection argued that learning by itself does not imply a market failure. Firms take learning benefits into account in their behavior. They are willing to produce at a loss, knowing that they will be more competitive in the future.

Dasgupta and I provided what was perhaps the obvious answer to this argument: firms faced capital constraints. They couldn't borrow to make up for their shortfall. The retort was that even if capital market imperfections existed, it made more sense to correct those imperfections than to create new ones. If the government couldn't correct the market failure, it should subsidize the firms directly rather than through distortionary tariffs.

But Dasgupta and I provided a novel reply to this retort, based on insights from the emerging field of information economics—one to which the critics of industrial policy have never offered an effective response. We argued that capital market imperfections result from information imperfections, and these

[19] A point I discussed more extensively in chapter 5 of *Making Globalization Work* (Stiglitz 2006b).

[20] Our thinking in this area was greatly influenced by Kenneth Arrow, who first developed the theory of learning by doing in his classic paper (Arrow 1962a). I studied general equilibrium theory under Arrow at MIT, and he visited Cambridge in 1969–70, when Dasgupta and I were both working there.

[21] Dasgupta, in his carefully reasoned exposition of the appropriate role of government in *An Inquiry into Well-Being and Destitution* (1993), seems to express some misgivings as to whether the government should undertake industrial policies.

information imperfections help explain why subsidies may not work. The government may not know which firms to subsidize, just as the market may not know which firms to lend to; it may not know which firms will be most successful in learning or in R&D. But with a tariff or other trade interventions (such as the exchange rate interventions described below), the firms that believe they will be profitable—with their learning—self-select into the market.[22]

Partha and I thus provided a fully articulated rationale for infant industry protection based on information asymmetries and a theory of learning by doing. But while the model provided a convincing refutation of the critique of the infant industry argument, it did not fully answer the question of when and how the government should intervene (putting aside political economy considerations).

One of the reasons countries engage in infant industry protection is that they want to enter the fast-moving high-growth sectors—sectors with significant learning. The industrial sector is subject to faster learning than agriculture, so countries wanted to move into that sector. But industry was not their current comparative advantage; without some government intervention, they could not enter the industrial sector and therefore could not learn. Unfettered markets can keep a country from entering more dynamic sectors, especially if the learning is external to the firm.

But this argument for infant industry protection is not fully convincing,[23] as all countries will benefit from the learning as a result of lower prices, so long as markets remain competitive. Moving into a more dynamic sector does not guarantee a country greater (innovation) rents. And those not in the sector benefitted from the learning going on elsewhere, so long as markets were competitive.

Consider a two-country, two-good model, in which we assume all persons have the same utility function $\ln U = .5 \ln C_1 + .5 \ln C_2$.[24] Each good is

[22] This is not to suggest that self-selection processes would necessarily be efficient. Indeed, in the absence of coordination, there can easily be too few or too many competitors for the patent prize. While the price system may provide an effective way of coordinating production and consumption in a static model, it does not and cannot do the same with respect to innovation. The virtue of such self-selection processes was, however, that the costs of any mistakes fell (for the most part) on those undertaking the research project. Still, markets demand compensation for risk-bearing, so innovation is retarded. For a broader discussion of these issues in the context of R&D, see Stiglitz (2008).

[23] We put aside for the moment the earlier objection—that if firms would eventually have a comparative advantage in the industrial sector, they should have an incentive to invest in learning today. We return to this issue later in the chapter.

[24] What is essential in this example is the unitary elasticity of substitution. There are problems in modeling long-term economic growth with nonunitary elasticity of substitution and differential rates of growth of productivity. With an elasticity of substitution less than unity, the high-productivity growth sector's share of global GDP shrinks to zero; while with an elasticity of substitution greater than unity, it expands to unity. Both limits are uninteresting. At the same time, it is unsatisfactory simply to assume a unitary elasticity of substitution. A finite period model of the kind presented below avoids this modeling dilemma.

produced by labor alone; the two countries are the same size; and country 1 specializes in good 1, while country 2 specializes in good 2. It is trivial to show that half of global income goes to country 1, half to country 2. If country 1 has rapid technical progress (endogenous or exogenous) but goods are produced competitively, prices will fall in proportion to productivity, so that while revenue per unit produced falls in proportion to productivity, revenue per hour remains the same. Country 2 benefits fully from country 1's learning. It should not envy the other country that has specialized in the seemingly more dynamic sector.

A rationale may still exist for encouraging the more dynamic sector, but it lies elsewhere—with the *externalities* the tradable high-learning sector generates, for instance, to the nontradable sector. Here we provide the real answer to the critics of industrial policy. Industrial policy is not focused on picking winners, and it is not predicated on the belief that government can do a better job than the private sector of picking winners. It is based on the notion that learning involves spillovers (externalities) that will be imperfectly internalized in a market economy, and that in circumstances in which learning might largely be internalized—where there is a monopoly—the distortions created by the monopoly itself require government intervention.

I present here a general theory of growth and development based on endogenous learning with endogenous capital constraints derived from underlying market imperfections. It is based on joint work with Bruce Greenwald on what we call the "infant economy argument for protection." The theory offers a policy framework that is markedly different from that of the Washington Consensus, which rests on neoclassical models with well-functioning markets in which technology is either fixed or, if it is changing, the changes are simply assumed to be exogenous, unaffected by anything the government might do. The latter theory focuses on the importance of allocative efficiency given a level of technology. Theories of endogenous learning, by contrast, focus on the determinants of learning.[25] Unlike the standard infant industry theory, the theory presented here examines how a society, not just a particular sector, learns.

The theory shows that in some circumstances Schumpeter's criticism of competition may contain a grain of truth; in general, with full competition, the pace of innovation is suboptimal. There may even be a grain of truth in his perspectives on monopoly: monopolies are more likely to internalize the benefits of learning (R&D), and this factor by itself would suggest a faster pace of innovation. But monopolies constrain production, and that means that they have less incentive to innovate, as Arrow long ago argued. And even

[25] Important inquiries investigating the relationship between learning spillovers, growth, trade, and government policy include Young (1991), Hoff (1997), Hausmann and Rodrik (2003), and Hausmann, Hwang, and Rodrik (2007).

with monopoly, there are likely to be important spillovers to other sectors, the benefits of which the monopolist will not take into account. In short, neither unfettered competitive markets nor unbridled monopolies are likely to lead to socially efficient levels of innovation. Government policies—sometimes called industrial policies—are required. In the context of a highly simplified model, we characterize those policies, identifying both broad-based and sectoral policies that would lead to welfare improvements and a higher level of innovation.

2.2 OUTLINE OF THE CHAPTER

I proceed methodically in the analysis of the infant economy argument for protection based on the theory of learning. I first consider a closed economy, explaining why government intervention is desirable. In the context of a closed economy, I begin by considering a two-period model, and then investigate long-run growth models. Next, I examine the special case of government intervention in the context of monopolistic competition. The remainder of the chapter considers an open economy, asking when countries that are stuck in the less dynamic sectors suffer as a result. To answer that question, I construct a model of dynamic trade equilibrium. First I consider a model that contains only tradable commodities, then I introduce nontradables. The remarkable result is that, in the presence of certain policy restrictions, not only might it be desirable for countries to promote exports and not only might exchange rate policy be an effective mechanism for doing so, but it may even pay countries to permanently maintain an exchange rate that is so undervalued that it creates permanent reserve accumulations.

Like much of the modern economics of the public sector, the nature of the optimal interventions depends on the instruments and powers of government. Whether the government can abolish monopolies or undo their distortionary behavior has implications for the desirable levels of research and learning. It makes a difference, too, if the government can raise revenues to subsidize or support research or learning only through distortionary taxation rather than through lump sum taxes. The economics of the second best is of particular relevance here: R&D and learning give rise to market imperfections, and all policies have to take into account the presence of these imperfections (sometimes referred to as distortions) if they cannot undo them. Well-designed distortions in one market can partially offset distortions in others.

I use the word "distortions" with care: common usage suggests that governments should simply do away with them. But as the term has come to be used, it simply refers to deviations from the way a classical model with, say, perfect information might function. Information is inherently imperfect, and these imperfections cannot be legislated away. Nor can the market power that arises from the returns to scale inherent in research be legislated away. That is why simultaneously endogenizing market structure and innovation is so important. Similarly, the costs associated with R&D (or the "losses" associated with expanding production to "invest" in learning) cannot be ignored; they have to be paid for. Monopoly rents are one way of doing so, but—as I argue here—a far from ideal way. There are ways to impose even distortionary taxes (i.e., taxes that give rise to a loss of consumer surplus) that increase societal well-being and the speed of innovation.

2.3 GOVERNMENT INTERVENTION IN CLOSED ECONOMIES WITH LEARNING BY DOING

When there is learning by doing, today's production has benefits for the future. We must ask, will firms take that into account, and what are the consequences of not doing so?

The answers to these questions revolve around whether the learning is internal to the industry or internal to the firm. If learning is internal only to the firm, then the larger the firm, the lower its cost. Each firm is, in a sense, a natural monopoly. There cannot be competition. And, in general, when competition is restricted, market allocations are not efficient. But now there are two inefficiencies: in addition to the static inefficiencies associated with the exercise of monopoly power, there may be dynamic inefficiencies. These may be complex: products in which firms have more monopoly power will have less production, and the lower production will lead to less learning. Productivity growth in these sectors may, accordingly, be slower.[26] In addition to the static consequence of the loss of consumer surplus from underproduction, there is a dynamic cost: the lower learning and higher costs in subsequent periods associated with monopoly today result in lower output in future periods. Of course, labor not used in the monopolized sector gets displaced to other sectors, but if those sectors are sectors with less learning, the overall rate of growth of the economy is reduced. Moreover, monopoly power will result in lower real wages; lower real wages will normally result in lower equilibrium labor supply; and, if learning depends on production (i.e., increases with labor supply), there will be less learning (slower increases in productivity) even if the monopolized sectors did not have an advantage in learning.

[26] Though given the lower level of production, the level of investment in learning/R&D may be optimal.

In short, we will typically see lower societal innovation with monopoly *even in the absence of learning spillovers*—that is, even where the monopolist fully internalizes the benefits of learning—for two reasons: (1) because of underproduction in future periods as a result of monopoly power, the benefits that accrue to the monopolist from innovation are lower than they would be with efficient production; and (2) the lower real wages lead to lower production on average and hence less learning. In addition, the pattern of production will be distorted from what is optimal; that is, the pattern that would emerge from a careful balancing of static costs and dynamic gains. If monopoly power is greater in the more dynamic sectors—because those are sectors where the natural monopoly nature of learning is strongest—resources are displaced from learning sectors to others and, again, there is a presumption that the pace of innovation is lower.

On the other hand, if learning is external to the firm—so much so that others in the industry benefit from its learning as much as it does—the industry can be competitive, but because of the externality, there will be underproduction of goods generating (positive) externalities such as learning.

In short, whether learning is internal or external to the firm, the market equilibrium will not, in general, be Pareto efficient. Government has a role to play in correcting the market misallocations.

While the result on the inefficiency of market equilibrium is robust, the result that a competitive equilibrium can exist if there are full spillovers of knowledge is not. If there are not *full* spillovers, then the firm engaging in learning has a competitive advantage, and the earlier argument about the existence of a natural monopoly is restored. On the other hand, the result that there is always a natural monopoly is also not robust. We can obtain an equilibrium with many firms if the diseconomies of scale are large enough to outweigh the economies of scale in learning.

In the following analysis, we make two important distinctions. The first concerns the structure of the product market. As we have noted, endogenous learning makes some market structures infeasible: in the absence of full within-industry spillovers, a natural monopoly exists. With full spillovers, there can be many firms in the industry; there will be competition, but no firm will take into account the learning benefit its production confers on others. It is possible that the market might best be described as monopolistically competitive, with only one firm in the industry but spillovers to other industries. In this case, we will see two distortions: underproduction as a result of the exercise of monopoly power and underproduction as a result of failing to take into account the learning benefits that accrue to others.

The second concerns the nature of spillovers. Traditional analyses assumed full spillovers within the sector within the country and no spillovers to other sectors or other countries. This is extreme. In fact, the production of any good involves many stages, and some of the stages may involve processes that are

Table 2.1 Spillovers and market structures

	No cross-firm spillovers	Full cross-firm spillovers
Perfect competition	X (not feasible)	Underinvestment in learning
Monopolistic competition	Restricted output	Both market distortions

similar to those used in another seemingly distinct sector. The result is that innovations in one sector may benefit other sectors that look markedly different. Inventory control and cash management techniques affect virtually every firm in an economy. Just-in-time production or assembly lines are examples of production processes that affect many industries. Sectors that are similar may, of course, benefit more. (Indeed, the same argument holds within a sector. An innovation in one technology in a given sector may have limited spillovers for other technologies—the spillovers may be greater to other products using analogous technologies.)[27] There are equally important economy-wide "technologies." A financial system developed to serve the manufacturing sector may equally serve the rural sector. In the discussion in this and tbe next section, we use a general formulation that has as limiting cases no and perfect spillovers.

Table 2.1 outlines the three cases. Most of our attention will focus on the cases with perfect competition and full spillovers, or monopolistic competition and no spillovers.[28]

One of the important methodological implications of the analysis is that not only must one simultaneously consider market structure and innovation (both are endogenous), but the analysis must be conducted within a general equilibrium framework. In a partial equilibrium context, one might conclude—as Schumpeter did—that monopoly was better than competition because it internalized the benefits of learning, without noting adverse general equilibrium effects (in the simple model presented here, arising from the impacts on real wages and labor supply).

[27] Atkinson and I (1969) thus described learning as "localized." Because countries differ, too, some learning that may be relevant in one country may be of limited benefit in other countries. Most changes in technology, however, could confer benefits across borders. And, as we have noted, improvements in skills (techniques) in one sector have spillover benefits to other sectors in which analogous skills are employed. Hidalgo and colleagues (2007) recently characterized the product space, attempting to identify the "capabilities" that different sectors have in common. Presumably, if two products entail similar capabilities, learning that enhances a particular capability in one sector will have spillover benefits to related sectors for which that same capability is relevant.

[28] If there are spillovers across sectors (products), but spillovers external to the firm are not full, there is a natural multiproduct monopoly (under our assumptions of linear technology) as a result of these natural economies of scope. These economies of scope and scale and offsetting diseconomies of scope and scale (e.g., arising from limits of the span of control and the benefits of managerial specialization) help define the boundaries of firms.

2.3.1 Optimal Resource Allocations with Learning: Basic Intuition

It is easy to describe the efficient resource allocations without learning: in each period, the marginal benefit of producing one more unit of a good must equal its marginal cost. In the case of a good produced by labor alone, the marginal rate of substitution between the good and leisure (which should be the same for all persons) should equal the marginal rate of transformation; that is, the marginal product of labor. With learning, producing or investing more today has future benefits—lower future production costs—and this needs to be taken into account. This can easily be done:

(1) The value of the marginal product + *total* future cost savings = marginal cost today.

This contrasts with the competitive equilibrium without learning, where

(2) The value of the marginal product = marginal cost today;

and with the monopolistically competitive equilibrium with learning, where

(3) Marginal revenue product + future cost savings *to the firm* = marginal cost today.

The competitive scenario neglects all the learning benefits; the monopolistically competitive firms underestimate the static benefit of production, ignore learning benefits to other firms, and, because production may be lower, assign a lower value even to firm cost savings.

Understanding the structure of learning and knowledge dissemination is essential to understanding efficient production. We are concerned with societal learning, not just sectoral or firm learning. For example, some sectors may have stronger learning curves; that is, the elasticity of learning may be larger for a firm. But what matters is not just the ability of a firm or sector to learn but also the benefits that sector (firm) transmits to other sectors (firms) and the extent to which it does not appropriate for itself the benefits of the learning.

If learning in one sector generates more externalities to other sectors than do others, production in that sector should be increased (relative to what it would be in the market equilibrium that ignored these learning externalities) at the expense of others. The dynamic (future) benefits need to be offset against the static (short-run) costs.

2.3.2 Part 1: A Two-Period Model

This section is divided into five parts. First, we consider a "direct control" problem in which government can determine the amount of labor allocated to each sector. Second, we provide a price interpretation of this optimum. Third, we examine some special features of the symmetric sectors case. Fourth, we analyze optimal interventions using standard optimal tax theory (i.e., we investigate indirect control mechanisms through taxes and subsidies), assuming that government can levy lump sum taxes. Finally, we analyze government intervention in more realistic contexts, in which government cannot impose such taxes.

2.3.2.1 Optimum Learning

A simple two-period model in which labor is the only input to production suffices to bring out the major issues.[29] Assume (for simplicity) that utility is separable between goods in the two periods and between goods and labor:

$$W = U(x^t) - v(L^t) + \delta\left[U(x^{t+1}) - v(L^{t+1})\right], \tag{1}$$

where $\mathbf{x}^t$ is the vector of consumption $\{x_k^t\}$ at time t and L^t is aggregate labor supply at time t. The disutility of work is the same in all sectors, and L^t is aggregate labor input in period t:

$$L^t = \Sigma L_k^t \quad \text{and} \quad L^{t+1} = \Sigma L_k^{t+1},$$

where L_k^t is the input of labor in sector k in period t.

Production is described by (in the appropriate choice of units)

$$x_k^t = L_k^t \tag{2}$$

In this simple model, the more output of good j in period t, the lower the production costs in period $t + 1$. We assume

$$x_k^{t+1} = L_k^{t+1} \cdot H^k\left[\mathbf{L}^t\right], \tag{3}$$

where $\mathbf{L}^t$ is the vector of labor inputs at time t $\{L_k^t\}$.

The learning functions H^k and their properties are at the center of this analysis. This formulation assumes that there are full within-sector externalities, that is, the amount of learning in sector k depends on the total production (input) in sector k. (Without loss of generality, if there are many firms in a sector and there are imperfect learning spillovers among the firms, we simply

[29] Later, we discuss how the results are changed if learning is related to investment, as in Arrow's original paper.

define the output of the different firms as different commodities, with these commodities being perfect substitutes for each other.)

In the following analysis, two properties of these learning functions will play a central role:

(a) Learning elasticity—how much sectoral productivity is increased as a result of an increase in labor input.

We define

$$h_k = d\left(\ln H^k\right)/d\left(\ln L_k^t\right) \geq 0, \tag{4}$$

where h_k is the elasticity of the learning curve in sector k.

(b) Learning spillovers—the extent to which learning in sector j spills over to sector K, defined as H_j^k.

$$\partial H^k/\partial L_j^t > 0,\ j \neq k, \text{ if there are learning externalities,}$$

while

$$\partial H^k/\partial L_j^t = 0,\ j \neq k, \text{ if there are no learning externalities between sectors } j \text{ and } k.$$

There may be larger spillovers from one sector to another, and more generally, the extent of cross-sector spillovers may depend as well on the production technologies being employed in the different sectors.

At various points in the discussion, we will find it convenient to focus on two special cases, one with no learning spillovers and one with full learning spillovers. In the special case with no learning externalities,

$$H_j^k = 0 \text{ for all } j \neq k,$$

and we write, for simplicity

$$x_k^{t+1} = L_k^{t+1}\psi_k\left(L_k^t\right). \tag{5}$$

In the other case, with full learning spillovers,

$$H \equiv H^k = H^j, \text{ all } j, k.$$

Optimization of (1) with respect to L_k^j, $j = t, t + 1$ yields (in the obvious notation)

$$U_k^t = v'^t - B_k \tag{6}$$

$$U_k^{t+1} H^k = v'^{t+1}, \tag{7}$$

where B_k is the learning benefit from increased output from (input into) sector k:

$$B_k = \delta \Sigma_j U_j^{t+1}\left(x^{t+1}\right) L_j^{t+1} H_k^j \tag{8}$$

The first equation simply says that in allocating labor in the first period, we take into account the learning benefits. The learning benefit is the increased output in *each* of the sectors as a result of increased learning, multiplied by the marginal utility of consumption of that good, all brought back to present values by the discount factor, δ. $B_k \geq 0$ implies that, so long as there are any learning benefits, production the first period goes beyond the level that would have occurred with static efficiency (which entails $U_k^t = v'^t$). Obviously, *sectors with more learning benefits expand production more* (relative to the level of production in the equilibrium with no learning). So too, the smaller δ is, the less we value the future learning benefits.

To see what that entails more precisely, we focus on three polar cases:

(a) *No spillovers*

$$H_j^k = 0 \quad j \neq k.$$

Then

$$B_k = \delta \xi_k h_k U_k^t\left(x^t\right), \tag{9}$$

where

$$\xi_k = \left(U_k^{t+1} x_k^{t+1} / U_k^t x_k^t\right).$$

The magnitude of the learning benefit depends on the discount rate (the larger δ, the more we value future benefits) and the learning elasticity h_k. Indeed, without spillovers, the learning benefit is simply proportional to the learning elasticity.[30]

One might have thought that because of the fixed-cost nature of learning, production in larger sectors would have increased more. But the magnitude of

[30] While this is precisely true in the case of logarithmic utility functions discussed in this chapter, in the more general case, the analysis is somewhat more complicated because of the endogeneity of ξ_k.

expansion of production entails a careful balancing of the marginal benefit of learning (the dynamic gain) and the marginal costs of the first period distortion (the static cost). The formulas derived in this chapter analyze what that entails. In effect, they show that what matters is the learning elasticity and not the scale but changes in the scale between the two periods, captured by the variable ξ_k. The reason for this is that the cost of the distortion (relative to the size of the economy) is related to the size of the sector (relative to that of the economy); but the benefits of the distortion—the learning—accrue to that sector, and that sector only.

Normally, we would expect that, as a result of productivity increases, consumption of each good would increase. In the case of separability with respect to consumption,

$$U = \Sigma_k u_k\left(x_k\right),$$

and the effect on $U_k x_k = u'_k x_k$ of an increase in x_k depends on the elasticity of marginal utility for commodity k, η_k, where $\eta_k = -d(\ln u'_k)/d(\ln x_k)$:

$$d\left[\ln\left(U_k x_k\right)\right] / d\left(\ln x_k\right) = 1 - \eta_k$$

Because normally $x_k^{t+1} > x_k^t$,[31] ξ_k is greater than or less than unity, depending on whether η_k is greater or less than unity. If η_k is less then unity, marginal utility diminishes slowly, the elasticity of demand is greater than unity, and the value of learning is greater.

In the case of the logarithmic utility function, $\xi_k = 1$, so

$$B_k = \delta h_k U_k^t\left(x^t\right) \tag{10}$$

(b) *Full spillovers*

The case of full spillovers can most simply be analyzed by rewriting our maximization problem as

$$\operatorname{Max} W = U\left(x^t\right) - v\left(L^t\right) + \delta\left[U\left(H\left(x^t\right) L^{t+1}\right) - v\left(L^{t+1}\right)\right]. \tag{11}$$

[31] Under normal circumstances, growth (an increase in H, productivity) will lead to an increase in consumption; but matters are slightly more complicated, as first-period consumption is subsidized because of the benefit of learning. If H_o, the increase in productivity with no subsidies, is large relative to δh_k (the value of the learning benefits), then $x_k^{t+1} > x_k^t$.

For simplicity, we assume homothetic preferences, which allows us to rewrite our utility function $U = U(\varphi(x))$ where φ has constant returns to scale. This generates the first-order condition

$$U'^t \varphi_k - v' = -\delta U'^{t+1} H_k \Sigma_j \varphi_j \left(x^{t+1}\right) L_j^{t+1}$$
$$= U'^t \varphi_k \left[-\delta h_k \xi^* / \gamma_k\right],$$

where

$$\xi^* = U'^{t+1} \varphi^{t+1} / \ U'^t \varphi^t,$$

$$\gamma_k = d(\ln \varphi) / d(\ln x_k) = \varphi_k x_k / \varphi,$$

and where we have made use of the result that with constant returns

$$\Sigma_j \varphi_j \left(x^{t+1}\right) L_j^{t+1} H = \Sigma_j \varphi_j \left(x^{t+1}\right) x_j^{t+1} = \varphi.$$

(The later discussion will make clear that in the competitive equilibrium without learning, $U'^t\varphi_k = p_k v'$, γ_k has a natural interpretation: $\gamma_k = s_k$, the share of income spent on the kth commodity.)

We can now rewrite the first-order condition for first-period consumption:

$$U'^t \varphi_k [1 + \delta h_k \xi^* / \gamma_k] = v'.$$

Again, the learning benefit is proportional to the discount factor and the learning elasticity, and inversely proportional to the "share" of sector k (γ_k). The smaller the share, the larger the relative spillover—the societal benefit relative to the distortion in the sector itself. Obviously, as before, if $U = \ln \varphi$, then $\xi^* = 1$.

(c) *Full spillovers in some sectors and no spillovers in others.*

For simplicity, we focus on two sectors, labeled s for spillovers and 0 for no spillovers. Then our maximand becomes

$$\text{Max } W = U\left(x_s^t, x_0^t\right) - v\left(L^t\right)$$
$$+ \delta\left[U\left(H^s\left(x_s^t\right) L_s^{t+1}, H^s\left(x_s^t\right) H^0\left(L_0^t\right) L_0^{t+1}\right) - v\left(L^{t+1}\right)\right],$$

yielding the first-order conditions

$$U_s^t - v'\left(L^t\right) = \delta H^{s\prime}\left(x_s^t\right)\left[U_s^{t+1} L_s^{t+1} + U_0^{t+1} H^0\left(L_0^t\right) L_0^{t+1}\right]$$
$$= \delta h^s\left(x_s^t\right)\ \left[U_s^{t+1}\left(x_s^{t+1} / x_s^t\right) + U_0^{t+1}\ x_0^{t+1} / x_s^t\right]$$

and

$$U_0^t - v'\left(L^t\right) = \delta H^s\left(x_s^t\right) U_0^{t+1} H^{0\prime}\left(L_0^t\right) L_0^{t+1}$$
$$= \delta h^0\left(x_0^t\right) U_0^{t+1} x_0^{t+1} / x_0^t.$$

Provided that the learning elasticities are similar, learning induces a far larger expansion in the sector with spillovers than the sector without. For instance, with logarithmic utility functions, $U = \alpha_s \log x_s + \alpha_0 \log x_0$, $\alpha_s + \alpha_0 = 1$

$$U_s^t - v'\left(L^t\right) = -\delta h^s\left(x_s^t\right) / x_s^t = -\delta h^s U_s^t\left(1 + \frac{\alpha_0}{\alpha_s}\right),$$

while

$$U_0^t - v'\left(L^t\right) = -\delta \alpha_0 h^0\left(x_0^t\right) / x_0^t = -\delta h^0 U_0^t / \alpha_0$$

If, for instance, $h^0 = h^s$ (i.e., the learning elasticities are the same), the sector with spillovers is expanded much more than the sector without:

$$U^t_s = v' / \left[1 + \delta h\left(1 + \alpha_0 / \alpha_s\right)\right],$$

$$U_0^t = v' / \left[1 + \delta h / \alpha_0\right].$$

2.3.2.2 *Price Interpretation*

The equations describing the optimal allocation of resources have an obvious price interpretation. Let

$U_k^t / v'^t = p_k^t$ = marginal rate of substitution between good k and leisure in period t.

Let q_k^t = marginal rate of transformation between labor and good k in period t.

$$q_k^t = 1 \text{ for all } k,$$

and

$$q_k^{t+1} = 1/H^k, \text{ for all } k.$$

Then (7) implies that

$$p_k^{t+1} = q_k^{t+1} \text{ for all } k. \tag{12}$$

In the first-best allocation, in the second period, the consumer price (equals the marginal rate of substitution) equals the producer price (equals the marginal rate of transformation).

The first period allocation is somewhat more complicated. Equation (6) implies that

$$p_k^t = q_k^t - \Omega_k p_k^t = 1 - \Omega p_k^t = 1/\left(1+\Omega_k\right), \tag{13}$$

where Ω_k is the marginal (normalized by the marginal utility) learning benefit from producing more of good k in the first period (this includes the learning benefits to *all* sectors):

$$\begin{aligned}\Omega_k &\equiv B_k / U_k^t = \delta[\Sigma_j U_j\left(x^{t+1}\right) L_j^{t+1} H_k^j]/U_k^t. \\ &= \delta \Sigma \xi_{jk} d\left(\ln H^j\right)/d\left(\ln x_k^t\right) > 0.\end{aligned} \tag{14}$$

$$\text{where } \xi_{jk} = \frac{U_j^{t+1} x_j^{t+1}}{U_k^t x_k^t}$$

Optimal production entails producing in the first period beyond the point of the static efficiency condition, where the marginal rate of substitution equals the marginal rate of transformation. The extent to which we expand production depends on the direct learning effects *and* on the indirect benefits to other sectors. It is not just the direct learning benefits that count. If a sector has more spillovers to others, we might want to expand its production even if its own learning elasticity is lower.

Consider our two polar cases. First, assume there are no learning spillovers, so $H_j^k = 0$ for $j \neq k$. Then

$$\Omega_k = \delta \xi_{kk} h_k.$$

In the case of a logarithmic utility function, $\xi_{kk} = 1$. The extent to which the marginal rate of substitution is less than the marginal rate of transformation (i.e., the extent to which production is expanded beyond the level of static efficiency) depends on the elasticity of learning. If marginal utility diminishes rapidly, sectors for which there is a lot of learning will have correspondingly smaller values of ξ_{kk}, diminishing the extent to which output is expanded. The higher δ is (the less future utility is discounted), the more important the learning benefits are and thus the higher the level of production in the first period.

Second, consider the case with full spillovers. Then where

$$\xi_{kk} = U_j^{t+1} \cdot x_j^{t+1} / U_k^t x_k^t$$

$$\Omega_k = \delta h_k \xi^* / \gamma_k.$$

where ξ^* and γ_k are as defined earlier.

The price interpretation is useful because it provides an easy and direct contrast between optimal resource allocations and the competitive equilibrium without government intervention. (We will discuss the monopolistically competitive equilibrium later.) In the competitive equilibrium,

$$U_k^t / v'^t = q_k^t = 1 \text{ for all } k$$

$$U_k^{t+1} / v'^{t+1} = f q_k^{t+1} = 1/H^k, \text{ for all } k;$$

that is, production in the first period ignores *all* learning benefits but, conditional on the learning that has occurred, second-period production is efficient. Clearly, there will be underproduction in the first period, especially in those sectors in which learning is important. (Later, we will also contrast the optimal allocation with that generated by monopoly.)

2.3.2.3 Symmetric Case

The above analysis derived general formulas for analyzing optimal production/learning if government could directly control inputs/outputs in every sector. We also provided a price interpretation of the optimum. Much of our discussion focused on the desirability of increasing activities that generate learning externalities compared with those that did not.

But there is a broader macroeconomic issue: even if all sectors were identical (symmetric), so that 1/nth of the labor supply ought to (and, in market equilibrium, will) be devoted to each commodity, there may be too little output (labor supply) in the first period. If labor supply is inelastic and the number of goods is fixed at n, in the symmetric equilibrium, 1/nth of the labor force is allocated to each good. It is obvious that the market equilibrium has the efficient amount of learning in each sector; there is no learning distortion, even though there are learning externalities. This is important, for it illustrates the large discrepancy between partial and general equilibrium analysis. (Partial equilibrium analysis would have led us to the conclusion that there was an underinvestment in learning.)

The symmetric equilibrium also provides an easy context in which to compare the market equilibrium with the optimum. For simplicity, we will assume no spillovers across sectors.

The social welfare maximization problem can be easily written as

$$\begin{aligned} \underset{\{L^t, L^{t+1}\}}{\text{Max}} \quad & U^t(L^t/n, L^t/n, L^t/n, \ldots) - v^t(L^t) \\ & + \delta[U^{t+1}(\Psi(L^t/n)L^{t+1}/n, \Psi(L^t/n)L^{t+1}/n, \Psi(L^t/n)L^{t+1}/n, \ldots) \\ & - v^{t+1}(L^{t+1})], \end{aligned}$$

where n is the number of commodities, and where we have assumed separability between labor and goods but not necessarily between goods; where $\psi_k(L_k^t)$ is the learning function giving output per unit input;[32] and where, because of the assumption of symmetry, we can, without loss of generality, drop the subscript on the learning function.

The first order condition can be written

$$\Sigma U_i^t / n - v^{t\prime} = U_i^t - v^{t\prime} = -\delta \Sigma U_i^{t+1} \psi'(L_i^t) L^{t+1}/n = -\delta U_i^{t+1} \psi'(L_i^t) L^{t+1}.$$

In competitive equilibrium

$$U_i^t - v^{t\prime} = 0,$$

so it is clear that (in general) there is too little production the first period. The only exception is the case where L^t is fixed (i.e., cannot be increased). Then, trivially, the market equilibrium is efficient.

The first-order condition for L^{t+1} is

$$U_i^{t+1} \psi(L_i^t) - v^{t+1\prime} = 0.$$

In competitive equilibrium, the price is $1/[\psi(L_i^t)]$, so that, conditional on the state of knowledge in the second period, output is efficient.

If the government were to subsidize first period production by τ, so that the first-order condition is

[32] Recall that in terms of our previous notation, ψ is the special case of H where there are no spillovers.

$$U_i^t - v^{t\prime}(1-\tau) = 0$$

and sets

$$\tau^* = \delta U_i^{t+1} \psi'(L^t/n) L^{t+1} / (v^{t\prime}),$$

raising the revenue through a lump sum tax, then the government can replicate the first best optimum.[33]

It is useful to rewrite the above expression as[34]

$$\begin{aligned} \tau^* &= \delta\left[v^{t+1\prime} L^{t+1} / v^{t\prime} L^t\right] h \\ &= \delta \varsigma h, \end{aligned}$$

where ς is our new relative scale parameter, slightly different from that used earlier:

$$\varsigma = v^{t+1\prime} L^{t+1} / v^{t\prime} L^t.$$

For instance, assume constant marginal disutility of work, $v' = 1$ (a constant) and logarithmic utility of goods, $U = \Sigma \ln X_i$. It is easy to show that in the case of symmetry, the results are the same if we had a single consumption good. For notational simplicity, we will assume that, and drop the subscript on X. Then

$$x^t = 1 - \tau^* = L^t$$

and

$$x^{t+1} = \Psi,$$

so

$$L^{t+1} = x^{t+1} / \Psi = 1$$

and

$$\tau^* = \delta h / (1 - \tau^*).$$

[33] $U_i^t - v^{t\prime} = -\tau^* v' = -\delta U_i^{t+1} \psi'(L_i^t) L^{t+1}$.

[34] The symmetric equilibrium can be treated as if there were a single commodity. Without loss of generality, we then write $U'^t = U_i^t$. From the first-oder condition for L^t, recalling that, in equilibrium, $x^t = L^t$

$$U'^t(L^t) - v^{t\prime}(L^t)\,(1-\tau) = 0,$$

τ^* is thus the solution to the quadratic equation

$$\tau^{*2} - \tau^* + \delta h = 0.$$

For small δh, the solution can be approximated by

$$\tau^* \approx \delta h,$$

as before.

Other special cases can similarly be solved for explicitly. Assume, for instance, that we had a learning function that was linear (rather than constant elasticity), with

$$\Psi = 1 - \vartheta L,$$

where ϑ is a small number (limited learning). Assume constant marginal utility of consumption ($U' = 1$) and quadratic disutility of leisure ($v = .5L^2$).

we can derive $d\ln L^t/d\ln \tau = (\tau/1-\tau)\varepsilon^c_{Lw}$, where ε^c_{Lw} is the elasticity of supply of labor. From the first order condition for L^{t+1}, recalling that $x^{t+1} = H(L^t)L^{t+1}$,

$$HU'^{t+1}\left(HL^{t+1}\right) - v^{t\prime}\left(L^{t+1}\right) = 0,$$

we can derive

$$d\ln L^{t+1}/d\ln H = \varepsilon_{Lw},$$

from which it follows that

$$d\ln L^{t+1}/d\ln L^t h = h\,\varepsilon_{Lw.}$$

Hence, at $\tau = 0$,

$$v^{t+1\prime}L^{t+1}/v^{t\prime}L^t \approx 1 + (1+v)H_o\varepsilon_{Lw}.$$

$$d\ln\left[v^{t+1\prime}L^{t+1}/v^{t\prime}L^t\right]/d\ln\tau = (1+v)\left[h\,\varepsilon_{Lw} - 1\right](\tau/1-\tau)\,\varepsilon^c_{Lw},$$

Hence

$$v^{t+1\prime}L^{t+1}/v^{t\prime}L^t \approx \left[1 + (1+v)H_o\varepsilon_{Lw}\right]\left[1 + (1+v)\left(h\,\varepsilon_{Lw} - 1\right)(\tau/1-\tau)\,\varepsilon^c_{Lw}\right].$$

It follows that for small h,

$$\tau^* \approx \delta h[1 + (1+v)(H_o - 1)\varepsilon_{Lw}]$$

The subsidy increases with h, δ, v, and ε_{Lw}.

Then it is straightforward that $L^{t+1} = \Psi = 1 - \vartheta L^t$, $\Psi' = -\vartheta$, and $L^t = 1 - \tau^*$. Hence,

$$\tau^* = \delta\vartheta[1 - \vartheta(1-\tau^*)]/(1-\tau^*),$$

so τ^* is the solution to the quadratic equation

$$\tau^{*2} - (1 + \delta\vartheta^2)\tau^* - \delta\vartheta(1-\vartheta) = 0.$$

For small subsidies (small ϑ), τ^* can be approximated by

$$\tau^* \approx \delta\vartheta(1-\vartheta)/(1-\delta\vartheta^2) \approx \delta\vartheta,$$

again, proportional to the discount factor and the learning parameter.

Even though we can impose lump sum taxes, subsidies distort static allocations. Optimal interventions balance these static losses with the dynamic gains. The above formulas show the outcomes of this balancing.[35]

2.3.2.4 *Optimal Learning with Optimal Taxation: Lump Sum Taxation*

So far, we have derived the optimal allocation (assuming that government directly controls production and consumption) and analyzed price interpretations of the resulting equilibrium. It may be useful to redo the analysis using more standard techniques in public finance. We begin by assuming that the government can only impose excise taxes and subsidies and lump sum taxes. The government faces an indirect control problem. With lump sum taxation, assuming that first-period subsidies must be paid by a lump sum tax in the first period (i.e., there are no intertemporal budget constraints, so the government cannot borrow from the future to finance this period's deficits), we can write social welfare using the indirect utility function, giving the level of utility as a function of prices and "income":

[35] These formulae provide a characterization of the equilibrium, but it is important to note that, in general, the elasticities can themselves depend on taxes and subsidies. With full spillovers, the learning function is $\Psi = \Psi(L^t/n, L^t/n, \ldots)$ for all sectors. An increase in L^t thus increases learning by Ψ_i. Denoting by Ψ^* the function $\Psi(L^t/n, L^t/n, \ldots)$, with $\Psi^{*\prime} = \Psi_i$, we can write the first-order condition with full spillovers as

$$\Sigma U_i^t/n - v^{t\prime} = U_i^t - v^{t\prime} = -\delta\Sigma\, U_i^{t+1}\Psi^{*\prime}\left(L_i^t\right)L^{t+1}/n = -\delta U_i^{t+1}\Psi'^*\left(L^t\right)L^{t+1}$$

Substituting Ψ^* for Ψ, we obtain exactly the same results, though with a slightly different interpretation. It is likely, because of learning spillovers, that normally $\Psi^{*\prime}$ would be greater than Ψ', implying a higher level of subsidy.

$$V^t\left(\boldsymbol{p}^t,-T\right)+\delta V^{t+1}(\boldsymbol{p}^{t+1},0) \tag{15}$$

$$p_i^t=(1-\tau_i) \tag{16}$$

$$p_i^{t+1}=1/H^i, \tag{17}$$

where τ_j is the first-period subsidy to commodity j. Under our normalization, in a competitive market without subsidies, the (consumer) price of all goods would be unity; a subsidy on good j of τ_j brings down the competitive price to $1-\tau_j$. In a competitive market, in the second period, the price is just the cost of production.

There are two spillovers from a subsidy on sector j:

1. An increase in the subsidy on commodity j affects demand (and supply) for commodity i. That in turn has two effects: an impact on learning in those sectors (the benefits of which can spill over to other sectors) and an impact on the government's budget constraint; for example, if demand shifts toward highly subsidized products, the government would face a budgetary shortfall, which would necessitate a decrease in the subsidy on some other commodities.
2. The expansion of sector j affects learning in sector i.

It is easy to establish that, provided the sectors are not too different, it pays to subsidize consumption of every good in the first period. But if sectors are very different, it may pay to impose a tax on a sector, even if there is some learning in that sector. If the learning elasticity of a sector is much larger than that of others, and that sector has large spillovers to others, and there is some sector that is a substitute for the high-learning sector, then it may pay to tax that sector, in order to encourage learning in the high-learning sector.[36]

We can easily derive the optimal tax/subsidy rate[37] :

$$V^t\left(\boldsymbol{p}^t,-T\right)+\delta V^{t+1}\left(\boldsymbol{p}_i^{t+1},0\right)$$

subject to (15) and (16) and to the government's budget constraint,

$$T=\Sigma\tau_i x_i.$$

The first-order conditions are given by

[36] Since, in the first period (omitting the superscript t), $\Sigma p_i x_i = L + \Sigma\tau_i x_i$, at $\tau = 0$, $\Sigma\, dx_i/d\,\tau_j = dL/d\tau_j > 0$. Both the income and substitution effects lead to an increased labor supply.

[37] We make use of the fact that $V_{pi} = -V_I x_i$.

$$-V_{p_j}^t-\mu[x_j^t+\Sigma\tau_i(dx_i^t\ /d\tau_j)]-\delta\Sigma_k V_{p_k}^{t+1}\ \Sigma_i\left[\left(1/H^k\right)^2\right]H_i^k\ dx_i\ /d\tau_j=0, \tag{18a}$$

$$-V_I^t-\mu[-1+\Sigma\tau_j(dx_j^t\ /dI)]-\delta\Sigma_k V_{p_k}^{t+1}\ \Sigma_i\left[\left(1/H^k\right)^2\right]H_i^k\ dx_i\ /dI=0, \tag{18b}$$

where μ is the Lagrange multiplier associated with the government budget constraint. Using the Slutsky equation[38] we obtain (multiplying (18b) by x_j^t and subtracting (18a))

$$-\mu\Sigma\tau_j(dx_j^t/d\tau_i)_U+\delta\Sigma_k V_{pk}^{t+1}\ \Sigma_i\left[\left(1/H^k\right)^2\right]H_i^k\left(dx_i/dp_j\right)_U=0.$$

The term $[\Sigma\tau_j\,(dx_j^t/d\tau_i)]$ reflects the spillovers to the budget constraint: the increase in output of sector i affects the aggregate subsidies and, therefore, the aggregate lump sum tax. We define,

$$\delta V_I^{t+1}/\mu=\rho, \tag{19}$$

the intertemporal marginal rate of substitution, reflecting the pure rate of time discount plus the diminution of the marginal utility of income as a result of growth. (Normally, δ is less than unity, and with growth and diminishing marginal utility of income, V_I^{t+1}/V_I^t is less than unity, so ρ is less than one.) Then, using the standard "tricks" of optimal tax theory (combining the Slutsky equation with the symmetry of the compensated price elasticities), we can rewrite (18c) as[39]

$$-\Sigma_j(\tau_j/p_j)(\partial\ln\tau x_i/\partial\ln p_j)_U=\rho\Phi_i+\chi, \tag{20}$$

where $\Phi_i = -[(L^{t+1}/(1+\tau_i)s_i^t L^t]\ \Sigma_k\{s_k^{t+1}\ \Sigma_j h_j^k[\partial(\ln x_j^t)/\partial(\ln p_i)]_U\}$ is the total net marginal learning benefit from encouraging the consumption (equals the production in a closed economy) of sector j, taking into account potential effects on other sectors, both through induced learning in other sectors (as a result of cross elasticities of demand) and as a result of learning spillovers. The double sums reflect this. An increase in the subsidy on product i leads to an increase in consumption of i, which affects learning in i, but also in other sectors (hence the terms H_i^k); but through cross-elasticity effects, it also affects production in sector j, and this affects learning in that sector and every other sector.

$\Sigma_j h_j^k[\partial(\ln x_j^t)/\partial(\ln p_i)]_U$ reflects the total impact of a change in the price of good i on learning in sector k, taking both of these effects into account. Φ_i weights these learning effects by the relative share of these goods in the second-period

[38] To derive 18(a), we make use of the Slutsky relationship $\partial x_i^t/\partial p_j = (\partial x_i^t/\partial p_j)_U - x_j\partial x_i/\partial I$.

[39] To derive (20), we make use of the symmetry of Slutsky terms.

consumption bundle. Φ_i also reflects the relative scale of the economy in the two periods—if L^{t+1}/L^t is large, Φ_i is large, reflecting the greater value of learning. Finally, we take into account the relative size of sector i. If it is small, the cost of the distortion will be small relative to the society-wide benefits.

Equation (20) can be interpreted similarly to the analogous expression in optimal tax theory: in the absence of learning (where $\Phi_i = 0$ for all i), the percentage deviation of consumption of good i (along the compensated demand curves) should be the same for all goods. Of course, since the only reason for imposing taxes and subsidies is learning, $\tau_i = 0$ for all i. Now we will make an adjustment: the percentage deviation should be larger for those sectors with larger marginal learning benefits, but those marginal learning benefits include not just the direct learning benefits but the spillovers to other sectors.

Qualitatively, we can see what is implied by considering the case of separable demand functions with no spillovers:[40]

$$\tau_i = \rho h_i^i \zeta_i, \tag{21}$$

where $h_i^i = \partial(\ln H^i)/\partial(\ln L_i)$, the (own) elasticity of the learning curve; and

$$\zeta_i = s_i^{t+1} L_i^{t+1} / \left(s_i^t L_i^t\right),$$

the ratio in sector i of labor input the second period to that in the first period.[41] ζ_i is itself a function of τ_i. We can use techniques similar to that employed earlier to show that the optimal subsidy increases with the learning elasticity and the elasticity of labor supply, and obviously decreases with the intertemporal price.

(a) A two-sector case

Now let us assume, as before, two sectors: one (denoted by o) that has no learning spillover to the other sector and another (denoted by s) that has a full learning spillover.

If the two sectors have the same learning elasticity and demand elasticity, we will subsidize (expand) sector s (with the spillover), more than sector 0 (without).[42] Similarly, even if sector j has a lower learning elasticity,

[40] One must take care in interpreting this and other optimal tax/subsidy formulas in this chapter, because the variables on the right-hand side are typically not constants but functions of the subsidy rate itself. Still, they provide insights into the determinants of the appropriate subsidies for optimally designed subsidies.

[41] With a positive wage elasticity, ζ_j can be shown to be greater than unity, using the technique of footnote 34.

[42] For a fuller analysis, see Greenwald and Stiglitz (2014).

we may wish to subsidize it more. The extent of spillovers is of first order importance.

(b) Symmetric equilibrium

We can simplify further in the special case of symmetry, discussed above. From symmetry, we know that all will face the same price, so we can write our optimization problem as (using the obvious notation)

$$\text{Max } V^t((1-\tau_i),\ldots\ldots,-n\tau_i x_i) + \delta V^{t+1}(c_i(\tau_{i,}\tau_{j\neq i}),0), \tag{22}$$

where c is the cost of production, that is, $c_i = 1/H_i$, implying

$$-V_I^t(\tau dx_i^t/d\tau) - \delta V_I^{t+1}\Sigma_i\left[(n-1)x_j^{t+1}\partial c_i(\tau_{i,}\tau_{j\neq i})/\partial\tau_{j\neq i} + x_i^{t+1}\partial c_i(\tau_{i,}\tau_{j\neq i})/\partial\tau_i\right] = 0 \tag{23}$$

or

$$\{-V_I^t(\tau/p) + \delta V_I^{t+1}\left(L_j^{t+1}/L_j^t\right)\left[(n-1)h_j^i + h_j^j\right]\}\{d\ln x_i^t/d\ln\tau\} = 0, \tag{24}$$

where

$$d\ln c_i(\tau_{i,}\tau_{j\neq i})/d\ln\tau = -[(n-1)(\partial\ln c_i/\partial\ln x_j)_{j\neq i} + \partial\ln c_i/\partial\ln x_i]d\ln x_i^\tau/d\ln\tau x_i^t.$$

There are direct benefits of learning (and $h_j^i = -\dfrac{\partial\ln c_i}{\partial\ln x_j^t}$, the own elasticity of the learning curve) and indirect benefits (and $h_j^j = -\dfrac{\partial\ln c_j}{\partial\ln x_j^t}$, the learning spillovers).

There are two solutions. If $d\ln L^t/d\ln\tau = 0$, then (as we argued earlier) there is no reason to interfere with the market. But in the more general case,

$$\tau/1-\tau = \rho\,\zeta\,[(n-1)h_j^i + h_j^j] \tag{25}$$

As before, the higher the learning and the more learning spillovers, the higher the subsidy. If labor supply is very elastic and there is substantial learning, then $L^{t+1}/L^t >>> 1$, so, again, the higher the subsidy. If there are significant spillovers and many sectors, it is the magnitude of the spillovers that really matters.

2.3.2.5 No Lump Sum Taxes

When government cannot impose lump sum taxes, there may still be room for industrial policies. One sector may have more learning benefits, so that a tax on the other sector to finance a subsidy on the learning sector migbt be desirable.

Consider the following polar model (which will be expanded on in later sections).[43] There is no learning in sector A (the agricultural sector), but sector M (manufacturing) has a learning function $c(L_M)$, and there are full spillovers to sector A. (Greenwald and Stiglitz [2004] argue that it is plausible that not only does manufacturing have a higher learning elasticity ($h^A << h^M$) but that there are larger cross-sector learning spillovers from manufacturing to agricultural than vice versa.) Thus, continuing within the optimal tax framework of the previous section, we seek to

$$\underset{\{\tau_M,\, t_A\}}{\text{Max}}\, V^t((1-\tau_M),(1+t_A),0)+\delta V^{t+1}\left(c(L_M),c(L_M),0\right) \tag{26}$$

where $\tau_M x_M = t_A x_A$, $dt_A / d\tau_M = (x_M / x_A) + \tau_M d(x_M / x_A)/d\tau_M$ where, as before, τ_M is the subsidy on manufacturing and t_A is the tax that must be levied on agriculture to pay for the subsidy. This implies that

$$V_I^t[x_M^t - x_A^t\,(dt_A / d\tau_M)] = -\delta V_I^{t+1} c'(L_M)\left(x_M^{t+1} + x_A^{t+1}\right) dx^t{}_M / d\tau_M . \tag{27}$$

The LHS of (27) is the cost of the subsidy/tax—the distortion in consumption patterns—while the RHS is the learning benefit. Optimality requires that the (static) marginal cost of a subsidy equal the (dynamic) marginal benefit.

As expected, if $c' = 0$, the solution to (27) entails $\tau_M = t_A = 0$: there is no scope for distortionary taxation. But if the RHS of (27) is positive, it is optimal to tax A (agriculture) to expand M (manufacturing), provided $(\beta_M + \beta_A) > 0$:

$$\tau_M = -\,h\rho\left(L^{t+1} / L_A{}^t\right)\beta_M / (\beta_M + \beta_A) \geq 0 \tag{28}$$

where, as before, $\rho = \delta\ V_I^{t+1}/V_I^t$, the discount rate for future income, reflecting both the pure discount factor δ and the normally lower marginal utility of income at $t + 1$ relative to t as a result of growth, and where[44]

[43] This model is, in fact, the limiting case of the two-sector model discussed earlier (with a sector 0 with no spillovers and a sector s with full spillovers), under the special case that $h_0 = 0$: there is no learning in the nonspillover sector. It is straightforward to generalize the results to the case in which there is some learning in the nonspillover sector. In this special case, we relabel the sectors, so $s = M$ (for manufacturing) and $0 = A$ (for agriculture).

[44] Alternatively, we can write $\beta_M = (d\ln x_M/d \ln (p_M/p_A))(d\ln (p_M/p_A)/d\ln \tau_M)$, where $d\ln (p_M/p_A)/d\ln \tau_M$ can be calculated in a straightforward way. Similarly for β_A.

$$\beta_M = d\ln x_M / d\ln\tau_M \geq 0, \quad \text{and}$$
$$\beta_A = -d\ln x_A / d\ln\tau_M \geq 0 .$$

These are total derivatives, taking into account the indirect effect of the increased price of agricultural goods. Thus, normally we expect the subsidy to increase consumption of manufacturing and reduce the consumption of agricultural goods. It follows that

$$d\ln\left(x_M / x_A\right) / d\ln\tau_M = \beta_M + \beta_A .$$

This is the total change in relative consumption of the two goods as a result of the imposition of the subsidy on M paid for by a tax on A, the magnitude of which depends on the elasticity of substitution. If the elasticity of substitution is zero, then $\beta_M + \beta_A = 0$.[45]

When the elasticity of substitution is zero, there are neither benefits nor costs associated with the imposition of the subsidy/tax scheme. If the elasticity of substitutions is greater than zero, the size of the subsidy τ_M decreases with the share of manufacturers in consumption.

Again, we obtain the result that the larger the learning elasticity (h) the larger the subsidy.

Alternatively, the government may be able to borrow, even if private individuals cannot. It can impose taxes in the second period to repay the cost of first-period subsidies. Take the symmetric case. The government seeks to maximize

$$\text{Max } V^t((1-\tau_i),\ldots\ldots,0)+\delta V^{t+1}((1+t_i)c_i(\tau_{i,}\tau_{j\neq i}),\ldots\ldots,0)$$
$$\text{s.t.}\, \Sigma\tau_i x^t (1+r) = \Sigma t_i x_i^{t+1},$$

where r is the interest rate the government has to pay. In the symmetric case, we can, without loss of generality, simplify by assuming only one commodity; dropping the subscripts, we have $\tau x^t (1 + r) = t\, x^{t+1}$ and $c\,(x^t)$.

The first order condition is

$$\tau[V_I^t x^t - \delta(1+r)V_I^{t+1} x^t(1+\beta^t+\beta^{t+1})] + \delta V_I^{t+1} x^{t+1} c' x^t \beta^t (1+t) = 0,$$

where, in the obvious notation,[46]

$$\beta^t = d\ln\, x^t / d\ln\, \tau > 0$$

[45] Relative consumptions x_M/x_A is just a function of relative prices $(1 - \tau_M)/(1 + t_A) : x_M/x_A = Q((1 - \tau_M)/(1 + t_A))$. The elasticity of substitution is defined as $d\ln(x_M/x_A)/d\ln(1-\tau_M)/(1+t_A))$, where $dt_A/d\tau_M = (x_M/x_A) + \tau_M d(x_M/x_A)/d\tau_M$.

[46] Both of these are total derivatives, taking into account the direct effect of the change in τ and the indirect effect on the tax in the next period (t).

and

$$\beta^{t+1} = -d \ln x^{t+1}/d \ln \tau,$$

or simplifying

$$\tau\left[1-\rho(1+r)\left[1+\beta^{t}+\beta^{t+1}\right]\right]+\rho\left(L^{t+1}/L^{t}\right)h\beta^{t}=0.$$

$[1 - \rho(1 + r)(1 + \beta^t + \beta^{t+1})]$ is the benefit of borrowing money this period to be paid back next period. It is negative if r is high or ρ is high. We focus on the case where, in the absence of learning benefits, it would not be beneficial to borrow, that is,

$$\rho(1+r)\left(1+\beta^{t}+\beta^{t+1}\right)>1.$$

In that case, if there is learning, there is an optimal subsidy (financed by borrowing), given by (for small h)

$$\tau^{*} \approx \rho(L^{t+1}/L^{t})h\beta^{t}/[\rho(1+r)\left(1+\beta^{t}+\beta^{t+1}\right)-1]>0.$$

The subsidy is higher the higher the learning elasticity h; the lower the interest rate; and the more sensitive first period consumption (production) is to the subsidy (i.e., the higher β^t is for given β^{t+1}).

2.3.3 Part 2: Long-term Growth

Finite period models have gone out of fashion in economics in favor of infinite period models. To make such models tractable, however, requires much more special parameterizations, so that in practice neither model is really more general than the other. If there is to be a steady state with learning, since the output per unit of labor is increasing steadily, for the labor supply to any sector to be constant, either (a) the labor supply must be inelastic and relative prices must be constant or (b) utility of consumption must be logarithmic. Logarithmic utility functions have the unattractive property that the share of expenditure on each commodity is fixed. Normally, relative prices will be constant only with full spillovers (one of the cases we focus on, but clearly not general). Alternatively, we can focus on asymptotic behavior; for instance, where the fraction of a person's (society's) time spent working in any particular sector approaches some bound. But again, these asymptotes are often of limited interest in the short run (and we are always in the short run), especially since, in the general case of these models, asymptotic allocations of labor to certain sectors go to zero.

The problems posed by learning models are even more complicated in the case of, say, an exponentially growing population. Of course, with a finite earth, such models face a problem of asymptotically infinite density, which is, to say the least, uncomfortable. But more formally, if learning depends on labor input and labor input is always growing, then growth is always increasing, unless there is magically just the right amount of offsetting diminishing returns. One can find parameterizations in which this occurs, but we should not be fooled—they are very special.

Indeed, there is no theoretical reason to expect the episodic large innovations that have transformed our economy—electricity, computers, the automobile—to occur with regular periodicity and appropriate magnitude to sustain anything approximating a steady state.

In our own lifetime, we have seen dramatic transitions in the rate of population growth, to the point where it is even declining in many advanced industrial countries. There is a general consensus that the global population will level off (will *have* to level off) at around nine billion.

In short, we shouldn't take steady-state models excessively seriously. They are meant to help us think through trade-offs. In some cases—for instance, when we are focusing on issues of the demographic transition—more insight might be obtained from looking at N period models, where population is expanding in earlier periods and stationary in later periods. On the other hand, with a high enough discount, the distant future is of little moment, and a model focusing on the short run may provide a good approximation.

In the paragraphs below, we briefly explore special cases in which a steady state exists. We structure the cases so that whatever is optimal at time t is optimal at time $t + 1$; in that case, policy is directed at choosing the optimum steady state. In all the cases, the central result is that it is optimal to permanently impose distorting taxes to encourage production in the learning sector.

In the previous sections, we have explored models in which the government directly controls outputs (inputs), in which it has indirect control through taxes but can impose lump sum taxes, and in which it cannot impose lump sum taxes. We have also explored models in which learning is symmetric or asymmetric. In this section, we investigate only two cases; the results can easily be generalized to the other contexts.

2.3.3.1 Logarithmic Utility Functions

We first assume a logarithmic utility function

$$u^{t} = \Sigma\alpha_{i} \ln x^{t}_{i}, \Sigma\alpha_{i} = 1$$

and

$$W^t = u^t - v(L^t),$$

which at each moment of time implies (in static maximization)

$$\alpha_i / x^t_i = p_i v'(L^t),$$

which in turn implies that

$$x^t_i p_i = \alpha_i / v'(L^t).$$

Expenditure shares are equal to α_i and don't depend at all on costs. We focus on the direct control problem where the government sets $\{v, L\}$, where v_i is the share of total labor allocated to the production of good i. In the short run, as before, we assume the cost of each good is unity. Then

$$W^t = \Sigma_i \alpha_i \ln \upsilon^t_i + \ln L - v(L) \equiv W_o,$$

from which it follows that static optimization entails $v^t_i = \alpha_i$, and $1 = v'(L^*)L^*$. Note that the short-run optimum L does not depend on productivity.

We assume that, as before, productivity at time $t + 1$ is related to productivity at time t by a learning function, which we now write as

$$P^{t+1}_i = P^t_i H^t_i (\upsilon L),$$

where P^t_i is output per unit labor at time t and $\boldsymbol{vL}$ is the vector of labor inputs. If L and v are the same at t and $t + 1$, then

$$u^{t+1} = u^t + \Sigma\alpha_i \ln H^t_i (\upsilon L) = u^t + g\ (\upsilon L).$$

g ($\boldsymbol{vL}$) is the overall rate of productivity increase (measured here in terms of utility). It should be clear that, given the structure of the model, if $\boldsymbol{vL}$ is optimal for time t, it is optimal for time $t + 1$. We can write discounted utility[47]

$$\mathcal{W} = \Sigma\ W^t \delta^t = [W_o + \delta\, g/(1 - \delta)]/(1 - \delta),$$

from which it follows that $\mathcal{W}$ is maximized when

$$\partial W_o / \partial \upsilon_i + [\delta / (1-\delta)] \partial g / \partial \upsilon_i = 0$$

47 $u^{t+n} = U_o + n\,g . \Sigma n\, g\, \delta^n = \Sigma \delta\, g\, \delta^n / 1 - \delta = \delta\, g / (1 - \delta)^2$

$$\partial W_o / \partial L + [\delta / (1-\delta)] \partial g / \partial L = 0,$$

from which it follows that we expand production beyond short-run utility maximization the most in sectors that increase g the most; in this model, industrial policy is a permanent feature of the economy. Moreover, we increase work (labor supply) beyond the level of short-run utility maximization.

It is easy to derive the implications for some special cases. Assume that there are two sectors, A and M, and there is learning only in the M sector. Then

$$g = \alpha_M \ln H(\upsilon_M L)$$

and the optimum value of

$$\upsilon_M = \alpha_M [1 + h\delta / (1-\delta)] / [1 + \alpha_M h\delta / (1-\delta)],$$

where $h = (d\ln H/d\ln v_M L)$.

The greater h, the larger the larger the fraction of labor allocated to manufacturing. When $h = 0$, as expected, $v_M = \alpha_M$. By the same token, work at each date is expanded beyond the static level, to the point where

$$1/L - v' = -h\delta\ \alpha_M / (1-\delta)L < 0,$$

(the static marginal disutility of work exceeds the value of the marginal output), or L^{**} now satisfies

$$Lv' = 1 + h\delta\ \alpha_M / (1-\delta)$$

2.3.3.2 *Fixed Labor Supply, No Lump Sum Taxation*

In the second case, the labor supply is fixed and lump sum taxes are not allowed. There are two sectors, denoted A and M. Here, we have an additional problem in steady-state analysis. If there is differential growth in labor productivity in the two sectors, one sector gets a smaller, with a diminishing share of overall expenditures, except in the special case of unitary elasticity of substitution (the logarithmic utility case just analyzed). Accordingly, we focus on the case with full spillover, so that relative prices remain unchanged, and with homotheticity, so do relative shares. We assume a homothetic utility function of the form

$$U = U(x_M, x_A) = x_A^{-\eta+1} u(x_M / x_A), 0 < \eta < 1,$$

where, as before, η is the elasticity of marginal utility. As before, we impose a subsidy at the rate τ on manufacturing paid for by a tax at rate t on agriculture. We can write the indirect utility function then as $V(1 - \tau, 1 + t, I)$. Static utility maximization entails maximizing V with respect to τ:

$$\begin{aligned} dV/d\tau &= -x_A \tau \left[d(x_M / x_A)/d\tau \right] V_I \\ &= -x_M \left[d\ln(x_M / x_A)/d\ln\tau \right] V_I \\ &= -x_M (\beta_M + \beta_A) V_I \end{aligned}$$

Static efficiency entails, as before, $\tau = 0$.[48] But now assume that there is learning only in the manufacturing sector but perfect spillover to the agricultural sector. Productivity growth is thus $H(x_M)$. Again, we have structured the model so that the optimal subsidy at time t is the optimal subsidy at $t + 1$, and the present discounted value of utility is given by

$$U_o / (1 - \delta H^{-\eta+1}),$$

where U_0 and H are both functions of τ.

The optimal subsidy rate is as before.

2.3.3.3 *Cumulative Experience*

We now take a somewhat different approach in which changes in productivity are based not directly on current production but on the change in cumulative experience. (Effectively, Arrow's original model was of this form.) That is, we write, in the absence of spillovers,

$$Q^k(t) = H^k(t) L^k(t),$$

where now, say, productivity depends on discounted cumulative experience E according to the function

$$H^k(t) = [E]^{b^k}$$

[48] Recall the definitions of β_M and β_A in section 2.3.2.5.

where b^k is the elasticity of productivity with respect to experience in sector k, and where experience E is defined by[49]

$$E = \left[\int_0^t L^k(x) e^{-z(t-x)} dx \right],$$

capturing the notion that experiences a long time ago have limited relevance for productivity today. In steady state, it is obvious that

$$g^k = d\ln\ Q^k/dt = (b^k + 1)n,$$

where n is the rate of growth of population. Even though learning is endogenous, we obtain the standard Solow result that the long-term sectoral growth rate is determined by the rate of growth of population. The fact that learning is affected by experience is still important, because the aggregate growth rate is affected by the allocation of resources. Assume, for instance, individual logarithmic utility function

$$\mathcal{W}^t = \Sigma(x_j^t)\alpha_i - v(L^t), \quad \Sigma\alpha_i = 1,$$

exponential labor force growth at the rate n, and a social welfare function of the form

$$\mathcal{W} = \int \exp(-r+n) W^t,$$

where r is the discount rate, $r > n + g$, where g is the rate of growth of utility (output, if U has constant returns to scale). In steady state,

$$\mathcal{W} = W^*/(n+g-r).$$

With learning, in steady state, W is increasing at the rate

$$g = \Sigma\alpha^k (b^k + 1)n.$$

Clearly, allocating more labor to sectors with higher learning elasticities will lead to higher rates of growth of utility. As before, let v_i be the fraction of the

[49] For convenience, we switch to continuous time. Analogous results hold in the discrete time version.

labor supply allocated to sector i. For simplicity, we can express W^* (in steady state) as a function of $\{L, v\}$. Then, we want to choose the allocation that

$$\text{maximizes } W^*\{L, v\}/n + g(L, v) - r$$

implying that we distort the allocation of $\{L, v\}$, relative to static utility maximization, to increase long-run growth.[50] The optimum balances the two effects. Because increasing L increases cumulative experience, it increases productivity, and long-term social welfare maximization takes this into account. Like an increase in the savings rate in the standard Solow growth model, an increase in L does not, however, have any effect on long-term growth rates. The allocation of labor does.

2.3.3.4 *Asymmetric Equilibria and the Advantages of Specialization*

Learning, as we have noted, introduces nonconvexities, which may make it desirable for countries to specialize. The learning curves introduced in the previous section suffer from diminishing returns and therefore don't capture this effect. If, for instance, there were two commodities, with $\alpha = ½$, then, $v^* = ½$.

Assume that

$$H^k(t) = \left[\int_0^t L^k(x) e^{-z(t-x)} dx\right]^b \text{ if } E \geq E^*$$

$$= \hat{H} \text{ if } E < E^*$$

and $\hat{H}(E)$ is a convex function, such that $\hat{H}(0) = 1$, $\hat{H}(E^*) = E^{*b}$.[51]

Assume further that

$$u^k = \log x^k \textit{ if } x^k \geq 1$$
$$= 0 \text{ otherwise}$$

[50] The full intertemporal maximization problem is somewhat more complicated and can be analyzed using standard techniques.

[51] The simplest form is $\hat{H} = 1$ for $E < E^*$; that is, there is no learning. There is then a discontinuity at E^*.

where now x^k represents individual consumption. (We introduce this assumption because otherwise, as x^k goes to zero, the marginal utility of consumption goes to infinity, and we always produce both goods.)

It follows that if L is small enough, then optimality may require, say, $v_1 = 1$, $v_2 = 0$. The economy specializes in one of the two commodities. As we specialize in commodity 2, H^2/H^1 becomes small (there is no cumulative experience in producing good 2), so it becomes optimal both statically and dynamically not to produce good 1.

2.3.3.5 *Cumulative Learning from Output*

A slight variant of the previous model focuses on output rather than input. The difference arises from that fact that with learning, output grows more rapidly than input.[52] Assume now that the relevant measure of "experience" is

$$E = \left[\int_0^t Q^k(x) e^{-z(t-x)} dx\right]$$

$$H^k(t) = \left[\int_0^t Q^k(x) e^{-z(t-x)} dx\right]^b,$$

so in *steady* state (where the same fraction of labor is allocated to any sector every year)

$$g^k = bg^k + n = n/(1-b),$$

where it will be remembered that $b < 1$. If $b > 1$, faster growth begets faster growth of experience, which begets even faster growth of output. The economy is unstable, with potentially super-exponential growth. While the steady states of this model look very much like those of the earlier models, in which experience is based on labor input, more general versions of this model can give rise to multiple short-run equilibria. Assume that $H^k(E)$ does not have constant elasticity.[53] Then, assuming that at each date, L is fixed,

[52] As we noted in section 2.3.2.1, Arrow's original model focused on learning through investment. But with the capital output ratio fixed, cumulative investment grows with output.

[53] Long-run steady states require asymptotically constant elasticities.

$$g^k = h(E)\,d\ln E/dt + n + d\ln \upsilon^k/dt.$$

Since E and $d\ln E/dt$ depend on g^k, there can be short/medium rate high-growth scenarios: a high level of expansion of a sector can lead to a higher elasticity of learning (e.g., if there is learning by learning), which supports the higher expansion of the sector. The implications for optimal policy are similar to those discussed earlier: even if two sectors initially appear symmetric, it may be optimal to focus on one of the two sectors to increase learning; but now it is possible that the increased growth induced by the faster learning is further reinforced by a higher learning elasticity.

2.4 MONOPOLISTIC COMPETITION

A similar analysis applies to a model with monopolistic competition. In the previous models, there was competition and learning was external to the firm, so that each firm put no value on the learning generated by its production activities. In this model, there is only one firm in each sector, but there are a sufficiently large number of products that each firm can take the wages and prices of other firms as given. As before, industrial policy depends on the set of instruments available to the government; for example, whether it can undo the effects of monopoly and whether it can impose lump sum taxes. Here, we assume that the government can do nothing about the monopoly power of each firm but that in setting, say, a subsidy for any product, it takes into account that markets are distorted as a result of monopolistic competition.

The major difference between this case and those analyzed in the previous section is that if there are no cross-sector learning externalities, the monopolistically competitive firm internalizes the learning externality. However, the firm still does not internalize cross-sector demand effects. We begin the analysis, however, by focusing on the case in which these can be ignored. The firm sets

$$\left(p_i^t + x_i^t dp_i^t / dx_i^t\right) = 1 - \delta x_i^{t+1} H_i^i / \left(H^i\right)^2 \tag{29}$$

or

$$p_i^t\,(1 - 1/\acute{\eta}_i) = 1 - \delta\zeta_i h_i$$

or

$$p^t{}_i = [1 - \delta\zeta_i h_i]/(1 - 1/\acute{\eta}_i) \tag{30}$$

where (as before) $\zeta_i = L_i^{t+1}/L_i^t$, the ratio of the input into sector j at time t to that at $t+1$, $h_i = d\ln H^t/d\ln L_i^t$, the (own) elasticity of productivity with respect to labor input (the learning coefficient) and $1/\acute{\eta}_i = -d\ln p_i/d\ln x_i$, the elasticity of demand.

The monopolist obviously doesn't take into account the consequences of his production/pricing decisions on the learning of other firms—either through spillover effects or through market effects. The latter can be important in the case of a nonseparable demand function. But he does take into account his own learning, and so sets a price lower than he would if there were no learning. Firms with more elastic demand functions charge a lower price (and produce more the first period); but firms with a more inelastic demand show a greater sensitivity to learning (i.e., all firms lower their price as h increases, but those with a higher markup—lower price elasticity—lower their price more. They have to, in order to expand output.)

The nature of the overall market distortion is, however, complex. For instance, in the second period, because of the exercise of monopoly power, the benefits of learning will be smaller. But, given the lower level of output in the second period, ignoring spillovers, the firm appropriately values the benefits of learning, which it sees, at the margin, as saving labor.[54]

There can be distortions in both total labor supply in the first period and in its allocation. Consider, for instance, a symmetric equilibrium in which all firms have the same demand and learning elasticities. The effect of monopolistic competition is to change real wages in the first period. If first-period labor supply elasticity is zero, this has no effect on learning. An awareness of the learning benefits drives up the real wage, but that is all that happens. First- and second-period output is unchanged. But if there is a positive elasticity of labor supply, the analysis becomes more interesting. In the case of myopic monopolistic competition (where no weight is given to the value of future learning), first period real wages are lowered as a result of monopoly power, labor supply is lowered, output is lowered, and learning is thereby lowered. *With myopic monopolies, monopoly is unambiguously worse than competition; even though neither takes into account the benefits of learning, growth is higher with competition than with monopoly.*

With nonmyopic monopoly, whether learning (growth) is higher with monopoly depends on whether

$$[1 - \delta\zeta_i h_i]/(1 - 1/\acute{\eta}_i) < \text{or} > 1, \tag{31}$$

[54] In particular, the value of ζ_i is sensitive to the elasticity of demand, the amount of learning in this sector, the elasticity of labor supply, what happens in other sectors, and so on. As we have noted, $p_i^t = (1 - \delta\,\zeta_i\,h_i)/(1 - 1/\acute{\eta}_i)$. On the other hand, $p_i^{t+1} = 1/H^t(1 - 1/\acute{\eta}_i)$. If $H^t = 1/(1 - \delta\,\zeta_i\,h_i)$, the price would be the same both periods. The smaller the elasticity of demand, the higher the mark-up, so the larger the sensitivity of price to any differences between H^i and $1/(1 - \delta\,\zeta_i\,h_i)$.

that is, on whether

$$\delta\zeta_i h_i > \text{or} < 1/\acute{\eta}_i . \tag{32}$$

If the elasticity of demand is low, the elasticity of learning is small, or the rate of discount is high, then monopoly is worse than competition, even though the benefits of learning have been internalized.

The general principles of government intervention should be clear. Government has to correct two market failures and must be careful that in correcting one, it does not exacerbate the other. Focusing only on learning, optimal policy entails encouraging production in the first period by a production subsidy financed (if possible) by a lump sum tax. If a lump sum tax is not possible but the country can borrow, it pays to finance the first-period subsidy with a second-period tax.

Precise prescriptions for the design of optimal intervention depend on what the government can do. For instance, if the government can impose a nondistortionary profits tax and use it to subsidize production in the first and second periods, it can presumably fully undo the effects of monopoly. If it can undo the effects of second-period monopoly, the formulas derived earlier can be used.

If it can only, say, impose a lump sum tax to finance a commodity subsidy in the first period, then it seeks to

$$\underset{\{\tau\}}{\text{Max}}\, V^t(p^t, -\Sigma \tau_i x_i) + \delta V^{t+1}(p_i^{t+1}, 0) \tag{33}$$

where

$$p_i^t = \kappa_i(1-\tau_i) \tag{34}$$

$$p_i^{t+1} = \kappa_i / H^i \tag{35}$$

where

$$\kappa_i = 1/(1-1/\acute{\eta}_i), \tag{36}$$

the monopoly markup over marginal cost. When we introduce a subsidy, we undo the first-period monopoly distortion and correct the underinvestment in production/learning distortion.[55] If we could impose similar corrective taxation in the second period, we could achieve precisely the equilibrium

[55] For instance, in the absence of learning, by setting $\kappa_i (1-\tau_i) = 1$, or $(1-\tau_i) = 1/\kappa_i$ or $\tau = 1 - 1/\kappa_i = 1/\acute{\eta}_i$, we can correct the monopoly distortion.

described earlier for the competition case. If not, we have to take into account the fact that the benefits of learning are lower, because future production is lower. Hence, in general, optimal subsidies will be lower.

The more interesting case is that in which there are two sectors, one (manufacturing) with a full learning spillover and the other (agriculture) with no learning. In this case, it can be shown that not only is a subsidy on manufacturing desirable, there is even some presumption that it should be larger with monopoly than with competition.

We now have

$$\underset{\{\tau_M\}}{\text{Max}}\, V^t(\kappa_M(1-\tau_M), \kappa_A(1+t_A), 0) + \delta V^{t+1}(\kappa_M c(L_M), \kappa_A c(L_M), 0), \tag{37}$$

where, as before, the subsidy to manufacturing is financed by a tax on agriculture.

$$\begin{aligned} &V_I^t\left[(\kappa_M - \kappa_A)\, x_M - \kappa_A x_A \tau_M d(x_M / x_A)/d\tau_M)\right] \\ &= -\delta V_I^{t+1} c'(L_M)(\kappa_M x_M^{t+1} + \kappa_A x_A^{t+1})dx_M^t / d\tau_M, \end{aligned} \tag{38}$$

where, it will be recalled,

$$dt_A / d\tau_M = (x_M / x_A) + \tau_M d(x_M / x_A)/d\tau_M .$$

The following differences from the earlier equation (27) are apparent:

(a) The change in relative prices may correct or exacerbate a distortion in relative consumption caused by differences in demand elasticities. In the case where demand elasticities are the same, the LHS of (38) simplifies to

$$-\tau_M(d(x_M / x_A)/d\tau_M)\kappa_A x_A,$$

which is negative.

(b) Lowering costs has a multiplicative effect on prices in the next period, so the benefits of learning are enhanced. In the case where demand elasticities are the same, the benefits are multiplied by a factor $\kappa_M = \kappa_A$ (as are the costs). Moreover, an increase in the subsidy leads to a decrease in the price by a multiple (and an increase in the price of the agricultural good by a corresponding multiple), so that with monopoly, $dx_M^t/d\tau_M$ is much larger than with competition (as is $dx_M^t/x_A^t)/d\tau$). Moreover, under normal assumptions, c' with monopoly is higher but $x_M^{t+1} + x_A^{t+1}$ is smaller, because real wages are smaller and productivity is lower.

2.5 OPEN ECONOMY

The most interesting context for analyzing government intervention is that of a small, open, developing economy. The question is, should it use trade policy (tariffs or foreign exchange intervention)? Such policies change the structure of the economy. Can it do so in ways that will enhance learning and promote welfare? And even if it can, are these the best instruments available?

2.5.1 Two-sector Economy

First, consider a two-sector economy, comprising agriculture and manufacturing, in a Ricardian world in which labor is the only input to production. In the simplest version of this model, the country can produce both goods and exchange some of the tradable goods for imports.

The developing country is small relative to the global economy and is assumed initially to have a comparative advantage in the agricultural good. The agricultural good has no direct learning potential but industrial production has considerable learning potential, and the benefits of learning spill over perfectly to the agricultural sector. This is important, because it means that the relative price of agriculture and industrial goods remains fixed.

In the absence of protection (or some other industrial policy), the small developing country specializes in agriculture and hence has no growth. It stagnates, while the large developed country continues to grow. The gap between the two increases over time.[56]

With protection—say, in the form of quotas—the country produces some of the industrial good, generating some learning, which spills over to the rest of the economy. There is a static inefficiency, but so long as the learning is sufficiently great, the static inefficiency is more than offset by the dynamic benefits.

Assume, for instance, that the labor supply is (in the absence of intervention) fixed at unity (this is just a normalization);[57] that a fraction of the labor force π is assigned to the industrial sector; that the short-term productivity in the industrial sector relative to that in the advanced industrial country is $\gamma < 1$ (where we have normalized productivity abroad at unity); and that a proportion of the production of the agricultural sector λ is traded for industrial goods from the developed country (at a price of unity). Then, at any moment in time,

$$\begin{aligned} U &= \alpha_M \ln M + (1-\alpha_M)\ln A \\ &= \alpha_M \ln(\pi\gamma + (1-\pi)\lambda) + (1-\alpha_M)\ln((1-\lambda)(1-\pi)) = U^*. \end{aligned} \tag{39}$$

[56] It is easy to modify our model to allow a steady-state degree of disparity: all we have to assume is that knowledge diffuses freely from the developed to the less developed country with a lag of N years.

[57] As we noted in section 2.3.3.2, the assumption of a fixed labor supply is, however, not innocuous.

It is easy to show that U is maximized at $\pi = 0$; that is, the country specializes in the production of agricultural goods. This is the conventional static result.[58]

But now we assume that the country's rate of productivity increase is $g(\pi)$, $g' > 0$; that is, the rate of productivity growth increases with the size of the industrial sector. There is full spillover from the industrial sector to the agricultural sector. Because of this assumption (and a similar assumption in the global market), the country's comparative advantage remains with agriculture. The problem facing the country in the next period is essentially the same problem facing the country this year. If consumption of both goods at $t + 1$ is $(1 + g)$ times consumption at t, $U^{t+1} = U^t + \ln(1 + g)$. Hence, if δ is the discount rate, the present discount value of utility is[59]

$$\mathcal{W} \equiv \{U^* + \delta[\ln(1+g)/(1-\delta)]\}/(1-\delta). \tag{40}$$

And it is no longer the case that maximizing social welfare ($\mathcal{W}$) entails $\pi = 0$. It immediately follows that

$$\partial U^*/\partial \ln \pi + G\,[g/(1+g)]\,[\delta/(1-\delta)] = 0, \tag{41}$$

where $G = d\ln g/d\ln \pi$, which implies that, so long as $G > 0$ (there is a marginal benefit to learning) optimality requires that $\pi > 0$: the dynamic benefits of learning exceed the static costs. Industrial policies pay off. The greater the learning elasticity and the higher δ (the lower the discount factor), the higher π; that is, the higher the optimal static distortion.

This framework requires industrial policies that allow for a limited industrial sector, even though the country has a comparative disadvantage in that sector in the short run and, in this model, even in the long run. That is, in our Ricardian model, with full spillovers, technological change does not change

[58] $$\begin{aligned} &d\,\alpha_M \ln(\pi\gamma + (1-\pi)\lambda) + (1-\alpha_M)\ln((1-\lambda)(1-\pi))/d\pi \\ &= \alpha_M(\gamma-\lambda)/(\pi\gamma + (1-\pi)l) - (1-\alpha_M)/(1-\pi) \end{aligned}$$

$\alpha_M(\gamma-\lambda)/(\pi\gamma+(1-\pi)\lambda) - (1-\alpha_M)/(1-\pi) \le 0$ for $\pi \ge 0$ (provided $\gamma < 1$), at $\lambda = \lambda^*$, where λ^* is the solution to

$$\begin{aligned} &d\,\alpha_M \ln(\pi\gamma + (1-\pi)\lambda) + (1-\alpha_M)\ln((1-\lambda)(1-\pi))/d\lambda \\ &= \alpha_M(1-\pi)/(\pi\gamma + (1-\pi)\lambda) - (1-\alpha_M)/(1-\lambda) = 0 \end{aligned}$$

[59] $U^{t+1} = U^t + \ln(1 + g)$, and, using the same techniques employed earlier, $\mathcal{W} = \Sigma\, U^*[(1 + t(\ln(1 + g)))]\delta t$, from which (40) follows directly. If U is not logarithmic but exhibits constant elasticity with respect to the scale of consumption (as before), with the elasticity of marginal utility of η, there is a parallel analysis.

the country's comparative advantage. The fact that the country's industrial sector never becomes competitive (the infant never grows up) is not necessarily an argument against industrial policies, when the learning spillovers are great enough.

In this model with a linear technology, the easiest way to implement the desired level of domestic production is through a quota, which ensures that at the equilibrium price, the desired amount of manufactured goods are produced at home. With increasing costs, there exists an optimal tariff, which would result in the desired level of domestic production.

2.5.2 Nontraded Sector

Finally, we consider a variant of the canonical Ricardian model in which there are three goods: exports, imports, and a nontradable good. Government intervention can affect either the price of tradables relative to nontradables or the price of imports relative to exports.

A slight variant of the previous model yields precisely the same results. Let us assume a more general homothetic utility function, with the obvious notation

$$\begin{aligned} U^* &= U(M, A, NT) \\ &= U((\pi\gamma + (1-\pi-\theta)\lambda), (1-\pi-\theta)(1-\lambda), \theta), \end{aligned}$$

where now θ is the fraction of the labor force allocated to the nontraded sector.

We again get the result that U^* is optimized at $\pi = 0$. But again, if the rate of learning is a function of the size of the industrial sector π, the economy should produce industrial goods even though those are not its comparative advantage.

We now consider what happens when international trade agreements restrict the use of industrial policies. The only instrument left is the exchange rate. Lowering the exchange rate simultaneously decreases the price of exports in foreign currency, leading to an increase in the demand for exports, and increases the price of imports (in domestic currency, relative to the price of nontraded goods). It thus encourages substitution away from imported consumption goods. Increased exports and reduced imports lead to a trade surplus.

In a two-period model, this means that the country consumes less than it could in the initial period, offset by increased consumption in the later period.[60]

[60] In our simple model, we assume individuals cannot borrow or lend, and simply solve a period-by-period static utility maximization problem, determining the allocation of current income among the three commodities. But it would be easy in principle (complicated in practice) to generalize the results to cases that include individual borrowing and lending, with precise effects depending on the structure of preferences (e.g., on separability of utility functions.)

As in the earlier models without trade, the static distortion (consuming less than what would normally maximize utility, based on the equality of the marginal rate of substitution and the interest rate) is justified by the dynamic benefits—producing more of the export good, say, leads to more learning, which generates a higher level of consumption in the second period than would otherwise be possible. This is true even though the range of instruments has now been restricted so the social cost of intervention is higher.

But if the learning effects are strong enough, even in an infinite period model, the benefits of expanding exports are sufficiently great that it may be possible that optimal policy requires the country to build up reserves forever, never to use them (essentially like throwing money away). We construct a model in which each period the world looks as it did the previous period, so that if it is desirable to have a surplus at time t, it is desirable to have a trade surplus at time $t + 1$. (Of course, in a more general dynamic model, it may be desirable to have trade surpluses initially, to be spent at later dates.)

Denote the exchange rate by e. Taking labor as our numeraire, and noting that by our choice of units the price of the nontraded goods is also unity (in the absence of taxes and subsidies, which, by assumption, are precluded), the price (and therefore the level of consumption) of the industrial and agriculture good are simply a function of e.

Hence, we obtain

$$U^* = U\left[M(e), A(e), NT(e)\right], \tag{42}$$

where consumption of agricultural goods is equal to production minus exports:

$$A(e) = (1-\pi-\theta)(1-\lambda), \tag{43}$$

where, it will be recalled, λ is the share of production exported, and where consumption of the industrial goods is production plus imports, m,

$$M(e) = \pi\gamma + m \tag{44}$$

Static utility maximization requires

$$(1-\pi-\theta)\lambda - m = S \geq 0, \tag{45}$$

where S is the balance of payments surplus. (Equation (45) is the balance of payments constraint.)

In a static model, U^* is maximized, subject to (45) (the balance of payments constraint), $1 \geq \lambda \geq 0$, $1 \geq \pi \geq 0$, and $1 \geq \theta \geq 0$. It is easy to show in the static model (i.e., with no learning) that free trade is optimal and the balance of payments constraint is binding:

$$\pi=0,\ S=0,\ \lambda>0. \quad (46)$$

The equilibrium exchange rate can easily be calculated. In equilibrium, full income is

$$y=\theta+e(1-\theta)=y(e,\theta).$$

$$NT(e,y(e,\theta))=\theta \quad (47a)$$

$$X=1-\theta-A(e,y(e,\theta)) \quad (47b)$$

$$m=M(e,y(e,\theta)) \quad (47c)$$

$$X=m \quad (47d)$$

where X = exports, and where $NT(e,y(e,\theta))$, $A(e,y(e,\theta))$ and $M(e,y(e,\theta))$ are, respectively the demand for nontraded goods, agricultural goods, and industrial goods, and where, because of the lack of comparative advantage in manufacturing, in the absence of government intervention, the country imports all manufactured goods. Equations (47b) to (47d) can be re-expressed as a function relating e and θ:

$$1-\theta-A(e,\ y(e,\theta))=M(e,\ y(e,\theta))$$

or

$$1-\theta=A(e,y(e,\theta))+M(e,\ y(e,\theta)). \quad (48)$$

Equations (48) and (47a) can be solved simultaneously for e and θ. Equations (47a) through (47d) can then be solved simultaneously for the full equilibrium. We assume the government controls e, and that the rate of growth depends on Q_M, the output of manufacturing goods, which in turn depends on e.

In the dynamic model, we can write again

$$W\equiv\left[U^*+\delta\ln(1+g)/(1-\delta)\right]/(1-\delta). \quad (49)$$

We now maximize $\mathcal{W}$ with respect to e (recognizing the effect of e on Q_M) to obtain an equation parallel to (41):

$$\partial\ln U^*/\partial\ln e+G\,g\,\delta\left(d\ln Q_M/d\ln e\right)/(1-\delta)(1+g)=0. \quad (50)$$

If $\delta g G(d\ln Q_M(e)/d\ln e)>0$, it means that at the optimum e, $\partial U^*/\partial\ln e<0$.

Once learning is taken into account, it may pay to have a lower exchange rate than the equilibrium exchange rate described earlier. A lower exchange rate will mean that exports will increase and imports decrease, and (with the usual restrictions on demand functions) there is a trade surplus. It pays to perpetually accumulate reserves—to run a surplus—because of the learning benefits. (To repeat: this requires that no other instruments are available to promote learning; e.g., through exports.)

In our Ricardian model, with constant returns to scale, small changes in the exchange rate have no effect on production of the industrial good, given the developing country's comparative and absolute disadvantage in its production. But lowering the (real and nominal) exchange rate enough makes the industrial good competitive. Define e^{**} as the exchange rate at which firms are just indifferent between producing industrial goods and importing them. Assume that at e^{**} the government can choose a level of industrial output, $Q_M^{**}>0$. Then we can solve for the equilibrium allocation of labor to the nontraded sector:

$$NT(e^{**},\ y(e^{**},\theta^{**}))\ =\theta^{**}.$$

The equilibrium level of exports is[61]

$$X=1-\theta^{**}-A(e^{**},\ y(e^{**},\theta^{**}))-O_M^{**}/\Upsilon),$$

while the level of imports is

$$m\ =M(e^{**},\ y(e^{**},\theta^{**}))-Q_M^{**}.$$

At every value of Q_M^{**}, we can calculate S:

$$S=X-m.$$

Then the optimal level of Q_M^{**}[62] solves

$$W^{**}=\underset{\{M^{**}\}}{\mathrm{Max}}\left[U\left(M\left(e^{**}\right),\ A\left(e^{**}\right),\ NT\left(e^{**}\right)\right)+\delta\ln\ (1+g)/(1-\delta)\right]\Big/(1-\delta) \quad (51)$$

subject to

$$S\geq 0$$

In general, the constraint will not be binding.

61 Because of the inefficiency in the production, it takes, in effect, $1/\gamma$ units of domestic labor to produce 1 unit of industrial good. Hence, exports are the output of agricultural goods minus the consumption of agricultural goods, where the output of agricultural goods is total labor supply, less the input into nontraded goods and into the industrial sector.

62 In effect, the supply curve is effectively horizontal at e^{**}.

If $\mathcal{W}^{**} > \mathcal{W}(e^*)$, it pays to lower the exchange rate to e^{**}. The country should run a surplus.

We should emphasize the sensitivity of this analysis to the assumptions that we have imposed to allow for a steady-state analysis. A fuller analysis would take into account the fact that as the country closes the knowledge gap between itself and the advanced industrial countries, learning benefits may decrease, perhaps to the point at which the cost of running a surplus—the lost utility from the foregone consumption—exceeds the learning benefit. The country might then want (as in our two-period model) to consume its accumulated surplus. Other factors would also affect the country's desired level of surplus. A country with an aging population might want to put aside savings and then, as the aging population enters into retirement, reduce that surplus. Such demographic transitions are not analyzed well in steady-state models.[63]

Some countries have been criticized for contributing to global imbalances by accumulating excessive reserves. In static models, it has seemed irrational for developing countries—suffering from capital shortages and with constrained consumption—to do so; just as it has seemed peculiar that the United States, with an aging population, is running long-term deficits. This chapter shows, however, that once dynamic learning benefits are taken into account, with sufficient constraints on industrial policies (such as those imposed by the World Trade Organization), the accumulation of reserves by a developing country (beyond a level required for precautionary reasons to manage global volatility) may be reasonable if the learning benefits are large enough. Interestingly, while this policy leads to a lower level of imports initially because of the induced growth, over the longer run, the country's level of imports is actually increased.[64]

2.6 CONCLUDING COMMENTS

I have argued here that what matters for development is *learning* and, more broadly, technical progress and a developmental transformation. I have

[63] One other interesting aspect characterizes the optimum pattern of reserve accumulation. If, in the earlier stages of development, learning benefits are sufficiently large that the country accumulates a surplus, using the indirect utility function, at the margin, an increase in the price of tradables (a further reduction in the price of nontradables) has a positive effect—it receives more for what it sells; while in later periods, when the country has a trade deficit (using up its surplus), a decrease in the exchange rate (the price the country has to pay for the goods it buys) has a negative effect. This provides further impetus for lowering exchange rates (further below equilibrium levels that would prevail in the absence of intertemporal effects) in earlier stages and increasing them later—exacerbating patterns of "global imbalances."

[64] An analysis of the full global general equilibrium effects of such policies, if pursued by enough developing countries to have systemic effects, is beyond the scope of this chapter.

focused on a simple model of learning, but even within that simple model we have seen how much of recent conventional wisdom about development strategies is overturned. The standard paradigm has focused on eliminating market distortions—ensuring that the economy is on its static production (or, more generally, utility)[65] possibilities curve, based on a given level of knowledge. More important in the long run, however, is moving the possibilities curve outward—for advanced industrial economies by advances in technology; for developing countries by closing the knowledge gap between advanced industrial countries and developing countries; and for all countries by ensuring that all firms are employing best practices[66] as rapidly as possible. Moving toward the frontier (for instance, by eliminating all tariffs and quotas) might entail slowing down the pace of outward movement of the frontier—and slower long-run growth, with the benefit of but a one-time gain.

A full analysis of what makes for a learning economy would take us beyond this short chapter. We can *learn to learn* (Stiglitz 1987c)—we can enhance our learning capacities. Just as what we produce may affect how much we learn, it may affect how we learn to learn. Just as "roundabout means of production" (to use Böhm-Bawerk's terminology) may be more efficient, roundabout means of learning may be more efficient. We can learn more efficiently if we first learn how to learn.[67]

Once one recognizes the importance of learning and developmental transformation (Stiglitz 1998), analysis must go beyond economics. Education can either reinforce norms of *statis* or persuade young people that change is possible and give them tools with which to bring about and cope with change. A variety of institutions and institutional arrangements can either promote or prevent the development of a culture of change.[68]

In this chapter, we have focused on the economics of learning. From the earliest literature on endogenous technological change—when the public-good

[65] The utility possibilities curve gives the maximum level of utility for an individual given the level of utility of others.

[66] As Greenwald and Stiglitz (2014) point out, even in advanced industrial countries, most firms operate well below best practices.

[67] Operationally, we can think of dividing the learning period into two subperiods. In the first, we devote ourselves to improving our learning skills; in the second, we use those learning skills to learn about the subject at hand. (Here, we ignore the problem posed by the possibility of infinite regress: we can learn how to learn how to learn. . . .)

[68] Sah and Stiglitz (1989a, 1989b), Stiglitz (1995b), and Hoff and Stiglitz (2001) show that there can, in fact, be multiple societal equilibria. Hoff and Stiglitz (2010) use recent results in psychology to underpin an analysis of the interactions between prior beliefs and societal change, explaining how some societies can become trapped in a seemingly dysfunctional equilibrium for an extended period, while other societies seem to evolve more smoothly. Politics and economics also interact: repressive and authoritarian societies are, in a fundamental sense, incompatible with the kind of questioning of authority that is associated with a dynamic learning society. See Stiglitz (2010b).

nature of knowledge, the problems of appropriability, and the pervasiveness of spillovers were recognized—it was apparent that markets on their own were not likely to be efficient and that the overall efficiency of the market would depend on market structure in rather complex ways—with monopolies restricting output but internalizing the benefits of learning. Schumpeter recognized that this was a problem in the second best.[69] He tried to defend monopoly on the grounds (in modern language) that it partially solved the appropriability problem and the problems posed by imperfect capital markets. While the question is in some sense not appropriately posed (market structure should be viewed as endogenous, and in the absence of full spillovers, competitive markets may be hard to sustain), this chapter shows that even though monopolists internalize their own learning benefits, the distortion associated with underproduction (monopoly pricing) may lead to less learning than in a competitive market with optimal intervention.

Previously, most of the growth literature has focused on aggregate models in which the scope for allocative decisions was very limited (e.g., sectoral allocations played little role in aggregate growth rates). Insufficient attention has been paid to the design of policy interventions (and the parameters on which they should depend) to correct systemic market failures, especially in the presence of cross-sectoral spillovers. This chapter has provided a simple context in which market distortions—on both the aggregate supply of labor and its allocation—can be analyzed and the kinds of interventions (typically second- or third-best interventions, predicated on the existence of certain restrictions on the set of admissible policies) that might address them.

The chapter thus provides both a case for industrial policies and the beginning of an analysis of the optimal design of such policies. Many of the results are not surprising, though the simplicity of the forms of intervention (at least in some limiting cases) is striking. Simple formulas akin to those arising in the theory of optimal taxation are derived. The size of the static distortions (reflected in subsidies) increases, as expected, with learning elasticities and knowledge spillovers—with the latter taking on a particularly prominent role. Patterns of subsidies are affected, too, in easily understandable ways by patterns of demand interdependence. Intertemporal trade-offs are captured by the pure rate of discount as well as the rate at which marginal utility of income diminishes as a result of increasing productivity (which, in turn, depends on the elasticity of marginal utility and the rate of progress), with the intuitive result that the smaller the value at the margin of future consumption, the less distortion (the smaller the subsidy) to induce

[69] Before the term "second best" had come into fashion through the work of Meade (1955) and Lipsey and Lancaster (1956–7).

learning. But now the intertemporal trade-off is partly endogenous and other factors come to play a role, especially the elasticity of labor supply and a scale parameter reflecting the size of the economy at $t + 1$ relative to time t. Indeed, in the limiting case of symmetric learning and demand functions, we have shown that regardless of the learning elasticity, if the elasticity of labor supply is zero, the market equilibrium may be Pareto efficient. More generally, the magnitude of interventions also depends on labor supply elasticities. A particular complicating factor which we have noted is that, given the nonconvexities naturally associated with learning, optimal intervention may lead to asymmetric equilibria, even when all demand and learning functions are symmetric.

We noted that one of the standard objections to industrial policies in the past has been political: the potential for misuse. This poses an important trade-off. Broad-based measures such as exchange rate interventions require only that the government ascertain that the sectors that would be encouraged by such interventions have more societal learning benefits than the sectors that would be discouraged—and there is ample evidence that that is the case (evidenced by the success of export-led growth strategies). Firms and sectors within the economy self-select, and the expansion of firms and sectors with greater learning enhances the dynamism of the economy. On the other hand, more targeted interventions can lead to even more learning and faster rates of growth. No intervention completely "solves" the political economy problem. Sectors that benefit from exchange rate intervention may lobby for the maintenance of that intervention even in the absence of learning benefits. And some countries have shown that they can manage the political economy problems of more targeted interventions. The East Asian countries did so by using rule-based systems in which interventions were linked to past export success.

In any case, no government can completely absolve itself of the necessity of addressing the issues with which we have been concerned. For while we have focused on the use of taxes and subsidies to alter the structure of production and encourage more learning, different government investments in infrastructure, technology, and education affect different industries differently. In making such decisions, we argue that the government should take into account impacts on societal learning that will shape the country's dynamic comparative advantage.

We have focused on a model with a single factor of production: labor. The early learning literature[70] focused on learning through investment. Obviously, if countries learn through investment, there is an argument for

[70] See, in particular, Arrow (1962a). See also Solow (1997).

encouraging investment, especially in sectors that have a greater learning elasticity and greater spillovers. Standard international trade arguments demonstrate that taxes on imports, if imports are labor-intensive, will drive up wages and lower interest rates, thus encouraging more investment (Korinek and Servén 2010).

We have emphasized the importance of developing policies that maximize effective learning. In our simple model, we have assumed that different sectors have different learning curves, with different spillovers to other sectors. Identifying these learning functions is necessary to design appropriate government policies. Elsewhere, Greenwald and Stiglitz (2014) have discussed some of the factors that contribute to greater learning and greater spillovers. They argue that the manufacturing sector may have both greater learning potential and greater spillovers. Different countries may have different learning elasticities. Countries that are too distant in technology may have more difficulty closing the gap than countries that are somewhat closer, while for some countries there is little gap to close. Hence, learning elasticities (at least in some sectors) may be low for both the least developed countries and those that are near best practices.

Our simplified model also circumvents a central question: learning toward what end? Much of technological change in advanced developed countries has been directed toward saving labor, which is viewed as the "scarce factor." In developing countries, however, labor is in abundance—levels of unemployment are often high. A reduced demand for labor exacerbates the problem of unemployment. To put it another way, in these situations, the shadow wage and the market wage may differ. Innovation responds to market wages; innovation in the advanced industrial countries responds to the high market wages there.

It has long been recognized that technologies that are appropriate for developed countries may be less appropriate for developing countries. This means that developing countries may have less to learn from developed countries than is sometimes supposed;[71] their learning and research should be directed not so much at saving labor (the shadow price of which may be very low) as at saving capital and natural resources, and protecting the environment.[72]

[71] There is an old (and largely forgotten) literature on the determinants of the factor bias of technological change. For a more recent attempt to develop a general theory of the endogenous determination of the factor bias and the equilibrium level of unemployment, using a variant of the efficiency wage model, see Stiglitz (2006a).

[72] Some might argue that with globalization, the price of capital has become the same everywhere in the world. But this view ignores the importance of information and other market imperfections, the effect of which is to make the effective price of capital higher in some countries than in others. See, for example, Greenwald and Stiglitz (2003).

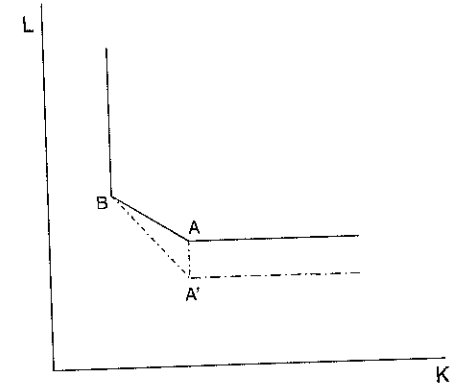

Figure 2.1 An isoquant with two technologies, one (A) appropriate to a high-wage economy, the other (B) appropriate to a low-wage economy

Four decades ago, when we were thinking about these issues at Cambridge, Tony Atkinson and I introduced the concept of "localized technological change" (Atkinson and Stiglitz 1969). Technological change affected only certain production processes. An innovation could improve, for instance, some very advanced technologies but leave traditional technologies largely unaffected. Indeed, as noted earlier in this chapter, the spillovers might be greater to advanced technologies in other sectors than to simple (say, nonautomatic) processes in the same sector.[73] This has an important implication. If developing countries resort to learning and adapting technologies created for circumstances prevalent in developed countries, the advances may be of limited value to their own economies. Emerging markets and developing countries need to develop their own research and learning capacities so they can improve the technologies that are appropriate to their economic circumstances. Thus, the point of industrial policies is not just to catch up to the advanced industrial countries, but to promote advances in technology that are appropriate to their circumstances and enhance their ability to make additional advances in these technologies.

Figure 2.1 illustrates an isoquant with two technologies, one (A) appropriate to a high-wage economy, the other (B) appropriate to a low-wage economy. Advances in technology in the advanced industrial economy move A downward (lower labor requirements per unit of output) but leave B unchanged. If the developing country simply borrows (say, with a lag)

[73] Indeed, that is one of the reasons we have emphasized cross-sector learning spillovers in this chapter.

technology from the advanced industrial country, it initially gets no benefit (if it produces the good at all, it continues to use the unchanged technology B) until the cost savings from lower labor costs are so overwhelming that the country switches to A.

The fact that the country's technology remains unchanged implies that if it did not initially have a comparative advantage in the good (say, the industrial product), its comparative disadvantage may increase over time. But even if the country does not have a comparative advantage in the good and never will, the nontraded sector (or the agriculture sector) might benefit from spillovers.

If, however, the country is able to develop its own learning capacities (e.g., through industrial policies, which might seem inefficient in the short run), it can start improving technology B. Moreover, with capital scarce, the improvements will be directed at saving capital, not labor. Indeed, the improvements in its technology, if rapid enough, could change its comparative advantage. But even if that did not happen, the spillovers to the other sectors—reducing, say, capital but leaving labor inputs unchanged—would have far greater benefits than those generated from borrowing technology from the advanced industrial country.

The distortions in the bias of innovation are even greater when it comes to saving on environmental resources because of the massive mispricing of these resources. With no costs associated with carbon emissions, why would there be any incentive to reduce them? Social costs associated with the macroeconomic variability linked to dependence on imported resources whose prices are highly variable may be far greater than the private costs. This provides another rationale for government policies designed to encourage less dependence on such inputs—and another rationale for industrial policies.[74]

These environmental impacts are important for all countries but especially for developing countries, as Dasgupta's work repeatedly emphasizes.

This brings me back to one of the themes I raised earlier, a theme central to Dasgupta's work. What matters is not GDP but quality of life, well-being, and sustainability.[75] What that entails—and how it can be increased—should and can be the subject of rational inquiry. Dasgupta has led the way in showing us how that can be done. For that, and for all his other contributions, we are grateful.

[74] This is a lesson Europe learned at some cost: it might have been privately profitable to become dependent on Russian oil, but it was socially costly.

[75] This was, of course, the thrust of the *Report of the International Commission on the Measurement of Economic Performance and Social Progress*. See Fitoussi et al. (2010).

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3

Some Perspectives on Linked Ecosystems and Socioeconomic Systems

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3.1 INTRODUCTION: ECOLOGY, ECONOMICS, SOCIETIES, AND COMPLEX SYSTEMS

Partha Dasgupta has been a pioneer in bridging the gap between two scholarly foci: on the one hand, the human socioeconomic system and its development, and, on the other, the ecosystems on which the former are utterly dependent (Dasgupta 2001; Dasgupta 2003; Dasgupta et al. 2005). In his brilliant book, *Economics: A Very Short Introduction*, Dasgupta summarized the significance of ecosystems (which he categorizes in terms of types of capital assets) as follows: "The services they produce include maintaining a genetic library, preserving and regenerating soil, fixing nitrogen and carbon, recycling nutrients, controlling floods, filtering pollutants, operating the hydrological cycle, and maintaining the gaseous composition of the atmosphere" (Dasgupta 2007: 119). These and many other ecosystem services (Holdren and Ehrlich 1974), such as controlling crop pests, supplying fish from the seas and freshwater sources, and providing cultural, intellectual, spiritual, and aesthetic inspiration, indicate how deeply intertwined are the problems of improving the welfare of humanity, especially the half in need of "development" (basically increased capacity to command consumption), and the problems of maintaining these crucial services.

The importance of natural capital is reinforced by recognition of the accelerating pressures caused by increasing human influence on Earth's ecological systems—the use of land, forests, and animal resources for food and fuel and for space for living, sequestering of "wastes" such as CO2 and other human purposes.