HANDBOOKS IN ECONOMICS 22

HANDBOOK OF ECONOMIC GROWTH

VOLUME 1A

Editors:
Philippe Aghion
Steven N. Durlauf

NORTH-HOLLAND

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22

Series Editors

KENNETH J. ARROW
MICHAEL D. INTRILIGATOR

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Edited by

PHILIPPE AGHION
Harvard University

and

STEVEN N. DURLAUF
University of Wisconsin at Madison

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Radarweg 29
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ELSEVIER Inc.
525 B Street, Suite 1900
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USA

ELSEVIER Ltd
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INTRODUCTION TO THE SERIES

The aim of the *Handbooks in Economics* series is to produce Handbooks for various branches of economics, each of which is a definitive source, reference, and teaching supplement for use by professional researchers and advanced graduate students. Each Handbook provides self-contained surveys of the current state of a branch of economics in the form of chapters prepared by leading specialists on various aspects of this branch of economics. These surveys summarize not only received results but also newer developments, from recent journal articles and discussion papers. Some original material is also included, but the main goal is to provide comprehensive and accessible surveys. The Handbooks are intended to provide not only useful reference volumes for professional collections but also possible supplementary readings for advanced courses for graduate students in economics.

KENNETH J. ARROW and MICHAEL D. INTRILIGATOR

PUBLISHER'S NOTE

For a complete overview of the Handbooks in Economics Series, please refer to the listing at the end of this volume.

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VOLUME 1A

PREFACE TO THE HANDBOOK OF ECONOMIC GROWTH

> The progress which is to be expected in the physical sciences and arts, combined with the greater security of property, and greater security in disposing of it, which are obvious features in the civilization of modern nations, and with the more extensive and skillful employment of the joint-stock principle, afford space and scope for an indefinite increase of capital and production, and for the increase of population that is its ordinary accompaniment.
>
> John Stuart Mill, *Principles of Political Economy*, 1848

Interest is economic growth has been an integral part of economics since its inception as a scholarly discipline. Remarkably, this ancient lineage is consistent with growth economics representing one of the most active areas of research in economics in the last two decades. Perhaps more surprising, this activity followed a relatively long period of calm in the aftermath of the seminal theoretical and empirical work by Robert Solow on the neoclassical growth model [Solow (1956, 1957)]. Solow's research set the growth research agenda for over 25 years. In terms of economic theory, much of the work of the 1960's consisted of translating the Solow framework into an explicit intertemporal optimizing framework; this translation, enshrined in economics as the Cass–Koopmans model [David Cass (1965), Tjalling Koopmans (1965)] has been of great importance in much of the new growth theory as well. In terms of empirical work, Solow's accounting framework stimulated many studies [a style of work well summarized in Edward Denison (1974)] which attempted more elaborate decompositions of growth patterns into components due to human and physical capital accumulation and a technology residual. Indeed, from the perspective of 1980, growth economics might have itself appeared to have achieved a steady state.

This apparent steady state was shattered on both the theoretical and empirical levels in the late 1980's and the 1990's. In terms of theory, new models of endogenous growth[1] questioned the neoclassical emphasis on capital accumulation as the main engine of growth, focusing instead on the Schumpeterian idea that growth is primarily driven by innovations that are themselves the result of profit-motivated research activities and create a conflict between the old and the new by making old technologies become obsolete. On the empirical side, Robert Barro (1991) and N. Gregory Mankiw,

[1] Also based on capital accumulation are the so-called AK models of endogenous growth [Frankel (1962), Romer (1986), Lucas (1988)], in which capital accumulation generates knowledge accumulation. See the books by Grossman and Helpman (1991), Jones (2002), Barro and Sala-i-Martin (2003) or Aghion and Howitt (1998), for other references.

David Romer, and David Weil (1992) launched the use of cross-country growth regressions to explore growth differences across countries; a cross-section that is far more extensive and covers much more of the world than occurred in earlier growth studies. These two parallel developments themselves gave birth to a whole range of new theoretical and empirical explorations of the determinants of growth and convergence – in particular the economic organizations and policies and the political institutions that are growth-enhancing at different stages of development. At the same time, new empirical methods were developed to reexamine issues of growth accounting on one end and which have begun to employ sophisticated statistical methods to uncover heterogeneities and nonlinearities on the other.

This renaissance of growth economics reflects several factors. On the theory side, much of the work has been stimulated by modeling techniques imported in the 1970s from the new theory of international trade[2] or the new theory of industrial organization,[3] which made it possible to introduce imperfect competition and innovations in simple general equilibrium settings. Empirical work has been facilitated by the construction of new data sets, of which Alan Heston and Robert Summers [see Heston, Summers and Aten (2002) for the latest incarnation] has been especially influential. More recent work has made increasing use of new micro data, whether cross-industry, or cross-firm, or plant level. The availability of these new data sets, in turn has initiated a new phase in growth economics in which theory and empirics go hand in hand as the development of new growth theories generates or is itself prompted by the introduction of new statistical tools and empirical exercises. This phase is particularly exciting as one can more directly analyze the impact of specific institutional reforms or macroeconomic policies on economic growth across different types of countries.

The *Handbook of Economic Growth* is designed to communicate the state of modern growth research. However, in contrast to other handbook volumes, we looked for chapters by active growth researchers. We then asked these authors to primarily convey the frontier ideas they are currently working on, anticipating that in order to put the reader up to speed with their current research agendas, the authors would also have to provide introductory surveys of contributions in their fields. As our readers will see, some chapters contain overlaps with other chapters and in a number of cases they partly disagree with one another. This only shows that growth economics is a lively field, with professional disagreements, alternative perspectives and outstanding controversies, but at the same time there exists a common eagerness to better understand the mechanics of economic development.

The Handbook consists of 28 chapters and is divided into six parts.

Part I lays out the theoretical foundations. The first chapter surveys the neo-classical and AK models of growth. The second chapter develops the Schumpeterian growth

[2] See the product variety models of Romer (1990) and Grossman and Helpman (1990) and the whole literature that builds upon this approach, surveyed in Chapter 3 below.

[3] The Schumpeterian models with quality-improving innovations, starting with Segerstrom, Anant and Dinopoulos (1990) and Aghion and Howitt (1992), belong to this second category.

model with quality-improving innovations and confronts it with new empirical evidence. The third chapter surveys the literature that built upon Paul Romer's product-variety model. The fourth chapter looks at growth in the very long run and analyzes the interplay between technical change and demographic transitions, and explores the issue of transitions between different growth regimes. The next chapter analyzes the central role of economic and political institutions, and describes the mechanisms whereby the dynamics of political institutions interacts with the dynamics of economic institutions and that of income inequality. The following chapter focuses on the emergence and existence of poverty traps, a question of particular importance in development contexts. The final chapter further explores the interplay of growth economics and development economics, with particular attention to how factors such as credit market constraints and intersectoral heterogeneity can explain outstanding puzzles concerning capital flows and interest rates, which are major elements of the growth process.

Part II examines the empirics of growth. An important aspect of these chapters is the diversity of approaches that have been taken to link growth theory to data. Growth accounting continues to play an important role in growth economics, both in terms of organizing facts and in terms of identifying the domain in which new growth theories can supplement neoclassical explanations. Growth economics has at the same time stimulated the development of new econometrics tools to address the specific data implications of various growth theories, implications in some cases challenge the assumptions that underlie conventional econometric tools. One theme of the work in this Part of the Handbook is that there exist limits to what may be learned about the structural elements of the growth process from formal statistical models. At the same time, empirical growth work plays a key role in identifying the stylized facts that growth theories need to address.

Part III of the Handbook examines a range of growth mechanisms. Some of these mechanisms have to do with the microeconomics of technology and education. Other mechanisms lie outside the domain of the neoclassical model and have to do with issues of political and economic institutions and social structure. Another theme that is developed here concerns the links between inequality and growth, which naturally raises issues of equity/efficiency tradeoffs. Finally, the role of government policy in affecting long run growth is studied. Much of the exciting work on growth has consisted of efforts to understand how factors beyond capital accumulation and technological change can affect growth; this very broad conception of the growth process is reflected in this section.

Part IV explores a range of aspects concerning technology. The discussion starts with a chapter that reviews the history of technology from a growth perspective. This discussion is a valuable complement to the formal statistical analyses studied in Part II. The analysis then turns to alternative theories by which technology evolves and diffuses in an economy. General purpose technologies are studied as an engine of growth. The consequences of technological diffusion for economic transformations are described and the inequality consequences of technological change are considered. Finally, the role of technology barriers in producing persistent international inequality is examined.

Part V considers the relationship between trade and geography. The discussion explores how trade and geographic agglomeration can affect growth trajectories as well as how growth interacts with geography to produce national boundaries.

Further, some of the consequences of economic growth for a range of macroeconomic phenomena are explored in Part VI. Different chapters explore how growth affects inequality, sociological outcomes, and the environment.

Finally, we are honored that Robert Solow has contributed a set of reflections on the state of growth economics to complete the Handbook. While growth economics has made immense strides in the last two decades, it is of course the case that the field "stands on the shoulders of giants". And in this regard, Solow's contributions are not alone. One can see the intertemporal optimization methodology that underlies the current theoretical analyses in the work of Frank Ramsey [Ramsey (1928)] and the ideas of social increasing returns in an early paper by Kenneth Arrow (1962). Such observations do not diminish the new growth economics, but rather speak well to the nature of progress in economics.

We would like to thank Kenneth Arrow and Michael Intriligator for their support in initiating this project as well as in providing invaluable guidance throughout the process. Valerie Teng of North-Holland, Lauren LaRosa at Harvard and Alisenne Sumwalt at Wisconsin have provided terrific administrative assistance at various stages of this project. And of course, we are deeply grateful to the authors for their work. If nothing else, their contributions reinforce our view that the human capital contribution to production takes pride of place, at least when the growth of knowledge is concerned.

Philippe Aghion and Steven Durlauf

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PART II: EMPIRICS OF ECONOMIC GROWTH

INTRODUCTION

GROWTH IN RETROSPECT AND PROSPECT

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REFLECTIONS ON GROWTH THEORY

ROBERT M. SOLOW

Abstract

This note contains some general and idiosyncratic reflections on the current state of neoclassical growth theory. It expresses some surprise at the lack of attention both to multi-sector growth models and to multi-country models with trade and capital flows. It also suggests that there might be value in further analysis of some old topics like capital–labor substitution with an expanded definition of capital, and the interaction of growth and medium-run phenomena (or, to put it differently, the interaction of demand-side and supply-side variations).

Keywords

economic growth, neoclassical growth model

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I cannot remember what words Charles Dickens put in the mouth of The Ghost of Christmas Past. This is not the Cratchit family dinner anyway, and there is no one to play the role of Scrooge. But there is no doubt that I am here in roughly the capacity of the Ghost. So I will make up something for him to say.

We are nearing the 50th anniversary of the neoclassical model of growth; astonishingly, it is still alive and well. There is not really any competing model. In the broad sense in which I use the term, the "endogenous growth" models of Romer and Lucas and their many successors are entirely neoclassical. So the *basic* model has survived for 50 years. I emphasize "basic" because progress, in theory and in practical analysis, has come mainly from extending the basic model at the edges. The territory of growth theory has expanded to include more topics in what used to be border areas. This is not necessarily exactly the same thing as "endogenizing" these borderline topics. There is a lot in the *Handbook* about the influence of background forces like "institutions" on the evolution of technology or total factor productivity. Some of it is in the mood of the "New Growth Theory" but not all of it. Much of it just wants to be explicit about background forces without trying to absorb them into the model.

I will come back to some of the extensions of growth theory; but it is also interesting to contemplate a few of the territories into which the theory has not expanded. For example, I suspect that early on one would have expected much more work on multi-sector growth models than there has been. Not that there has been none: Leif Johansen had an early book, oriented toward planning. Luigi Pasinetti has written extensively on the sorts of structural changes to be expected along a trajectory, arising from such inevitable factors as differing income elasticities of demand for different goods. In a very different vein, there was a whole literature stemming from the von Neumann model, which now seems to have gone out of favor. Xavier Sala-i-Martin's chapter in the *Handbook* reviews some worthwhile developments and promises others.

In the early stages there was active exploration of two-sector models, culminating in the book by Duncan Foley and Miguel Sidrauski, but it petered out fairly soon. The reason was probably internal-intellectual rather than any feeling that the applications were unimportant. The usual, perfectly reasonable, choice was to distinguish between a consumer-good-producing sector and an investment-good sector. (Agriculture and Industry was another possible split, but mainly in the development context.) I have the feeling that too much in those models turned out to depend on differences in factor-intensity between the sectors. We have very little in the way of facts or intuition about that issue, and there was no reason to expect or postulate any systematic pattern that could lead to exciting results.

It is also a little odd that there was not more in the way of open-economy growth modelling. There was of course the well-known book by Gene Grossman and Elhanan Helpman; it attracted attention more for its analysis of endogenous technology and quality ladders than for trade and capital flows. Jaume Ventura's chapter in the *Handbook* records the current state of play. I can only say that 40 years ago I would have been expecting to see more research in these areas than actually turned up.

These undercultivated subfields would have had, could still have, important practical applications. I will just mention three examples.

(a) The creation and enlargement of the European Union have been modelled in several places; but I do not think that we have had the insights that could come from embedding this question in a formal multi-sector, multi-country growth model. (How much does it matter where the R&D is done? Are there potential gains from more migration within the EU? And so on.)

(b) Is there anything deeper to be learned from the fact that, after a couple of decades of catch-up to the U.S. in productivity and TFP, the large European economies seem recently to have stagnated relatively or even fallen back a bit?

(c) If the U.S. (and the EU) were to impose their own local environmental standards on their poor-country trading partners, what could be expected to happen to factor prices, real income levels and growth rates in the poor countries? All these things have been thought about, of course, but something might have been gained had appropriate growth models been easily available.

A slightly larger and slightly different question has to do with China: How should growth theory be applied to such a large, diverse, almost dual economy, especially in a world of rapidly increasing trade and international investment? Certainly the many-industry, many-country aspects must matter, but sheer geographical size and regional diversity may require special treatment. Chinese economists have already started applying modern growth theory to their problems; but some departures from the usual might be in order.

While the Ghost is going on about might-have-beens, I will allow him a couple of paragraphs on a topic that he has grumbled about before. Neoclassical growth theory is about the evolution of potential output. In other words, the model takes it for granted that aggregate output is limited on the supply side, not by shortages (or excesses) of effective demand. Short-run macroeconomics, on the other hand, is mostly about the gap between potential and actual output. (There is an important modern school of macroeconomics that assumes this distinction away, and makes the growth model explain short-run fluctuations too. It would be a digression to discuss that issue here.) On the older view – this is after all the Ghost talking – some sort of endogenous knitting-together of the fluctuations and growth contexts is needed, and not only for the sake of neatness: the short run and its uncertainties affect the long run through the volume of investment and research expenditure, for instance, and the growth forces in the economy probably influence the frequency and amplitude of short-run fluctuations. This terrain is sometimes described as the economics of the medium run.

It too has been undercultivated by growth theory. It has not been entirely ignored; but I have the impression that growth theorists simply write this off as a trivial perturbation that can not be allowed to deflect their own preoccupation with steady-state growth. For example, the work of Robert Coen and Bert Hickman, who actually do try to embed a serious demand side in a serious growth-model framework, and implement the result econometrically, is generally ignored by growth theory. There must be other scattered forays in this direction; I have taken a casual step or two myself. It should be a more central part of growth theory proper. To put it differently, it would be a good thing if there were a unified macroeconomics capable of dealing with trend and fluctuations, rather than a short-run branch and a long-run branch operating under quite different rules. My quarrel with the real business cycle and related schools is not about that; it is about whether they have chosen an utterly implausible unifying device.

I can now turn from the things that growth theory has not accomplished to the things that it has done, in particular the way it has expanded outside the confines of a narrow model. The main effort has quite properly gone into the endogenization of changes in technology (or more broadly TFP, though usually with technology in mind) and changes in the stock of human capital. In both cases the popular early theoretical models had features that I personally found unappealing and, in policy terms, misleading for reasons that I have pursued elsewhere, and do not intend to repeat now. On the whole, better ideas have driven out worse ones as they are supposed to do. Both lines of research – technology and human capital – have led to a welcome emphasis on social norms and institutions as enabling or limiting factors or even as actual sources of growth.

The extent of interest in such ideas is represented explicitly in the *Handbook* by the chapters by Acemoglu–Johnson–Robinson, Greif, Alesina, Parente–Prescott, and implicitly by others. This emphasis on the role of institutions at least opens up the possibility – about which I am now more optimistic than I once was – of connecting up growth theory with the problem of economic development, in which issues of institutional change are clearly central. My own prejudice – Ghosts are allowed, even encouraged, to have prejudices – is that there may have been a premature tendency to assimilate growth and development, abetted by the vogue for cross-country regressions. A country is a country, one might say, just another point in $(n + 1)$-dimensional space, although loud squeals from the data have sometimes forced a restriction of the sample to OECD countries. This is something that needs to be straightened out; and detailed analysis of institutions is probably a better method than cross-country regressions.

The breathtakingly broad sweep of the story-line proposed by Daron Acemoglu and colleagues is irresistibly fascinating. Much of it has the ring of truth. I must confess nevertheless to a certain skepticism about firm conclusions at this level of generality, especially when they bear on "ultimate" causality. "Good" political institutions can certainly make the path to growth-friendly economic institutions shorter and smoother. But there are cases of "bad" – autocratic – governments opting for enforceable property rights and other "good" economic institutions, possibly in the belief that economic success will ultimately strengthen the hand of the autocrats themselves. Singapore and early post-war South Korea are examples; one of them evolved toward political democracy and the other did not.

The interaction of political institutions and the available stock of human capital can be very complex. Very poor countries are usually characterized by very bad governments and very deficient human capital, and these probably reinforce one another. I would not find it hard to accept the notion that there is no universally reliable way to escape this trap. Some countries succeed and others fail, for reasons that may be totally obscure *ex ante* and only partially and tentatively explicable *ex post*.

Whatever generalizations we are prepared to accept, however, there has to be a next stage: after history has made it plain that secure property rights and markets are better for growth than mere hierarchical rent-extraction, what do you do for an encore? The devil is in the details. What sort of patent protection provides the best mixture of incentives for innovation and diffusion? How should the free-rider problem intrinsic to non-firm-specific training best be handled? Do alternative feasible norms for corporate governance have any significant implications for growth?

These and many other institutional choices are practically invisible on the Acemoglu scale, but they bulk pretty large if you are considering alternative policies for a growing capitalist economy or for a transition economy. A very similar point is made by Rodrik in his chapter of the *Handbook*, but in a slightly different context. It is reassuring that many of the same considerations that preoccupy Acemoglu et al. also figure at the nitty-gritty level: those institutional choices have real distributional consequences that can in turn help or hurt the vested interests that in turn may be able to block those very choices. Can the protagonists be bought off or overcome politically or satisfied by compromise? The familiar elasticities and marginal whatnots come back into play as soon as one tries to face up to those questions in systematic but practical ways.

The translation of any "institutional" question into the language of an aggregative model is always tricky. The concepts and quantities that appear in an economic model need not be capable of expressing what a knowledgeable observer would like to say about institutional differences. An example of this occurs in the pleasing and informative chapter by Philippe Aghion and Peter Howitt. It is an incidental matter that caught my eye because it relates to some independent work of my own. The standard Schumpeterian wisdom is that active competition is bad for innovation because it erodes entrepreneurial rents too soon. But the standard empirical–historical finding is that active competition is associated with productive innovation. Aghion and Howitt find a way to enlarge their model so that the competition-innovation nexus can in principle go either way. (It is a clever and useful device that the interested reader should study.) The trouble is that the competition that Aghion and Howitt can conveniently model is between an innovating monopolist and the competitive fringe still stuck with the older technology. But the typical way in which the absence of competition deadens economic performance is that regional or national monopolies are protected by legal or other barriers against competition from best-practice firms, or just better-practice firms, domestic or foreign. They can survive without innovating or adopting best practice and they do so. To incorporate that chain of causation in a standard growth model might be difficult. Is it worth doing? We will not know until somebody tries.

No one would claim that we now have a really good causal account of either technological and organizational progress or of the accumulation of human capital in all of its various forms. (Schooling is not the same thing as human capital.) As the *Handbook* shows, a lot of ingenuity has gone into that research and lot of ground has been covered; if there is a lot more ground still to be explored, that is hardly surprising. Nor is there any guarantee that everything one would want to know about these processes is knowable. Some regression residuals represent not omitted variables but mere sound and fury, signifying nothing.

It is possible that the obvious importance and interest of these matters, combined with a less worthy temptation, the sheer convenience of the Cobb–Douglas production function, may have diverted attention from an older-fashioned topic, namely the substitution of (physical and human) capital for raw labor. In the beginning, one of the surprising implications of the neoclassical growth model was not merely that the steady-state growth rate was independent of the saving-investment rate, but perhaps even more that the (moving) equilibrium *level* of output per person apparently responds very weakly to changes in the saving-investment quota. To be more precise, the elasticity of output per worker with respect to the saving-investment rate is the ratio of the capital share to the labor share (in steady-state equilibrium). Back then the conventional numbers were 1/4 and 3/4, giving an elasticity of 1/3. The message appeared to be that as big an increase in the rate of investment as policy could manage would yield only a disappointing increase in productivity. The conventional numbers have changed, partly as a matter of fact and partly because the capital concept has been enlarged. Apart from that, there may be some interesting points of principle to be investigated. (I have to admit that I dwell on this because Olivier de La Grandville and I have written a substantial paper on the subject.)

The point I want to make here starts from the fact that the relative shares of capital and labor once seemed to be trendless in modern industrial economies; and that may still be a fair description. (This generally accepted fact provided a respectable justification for the addiction of theorists to Cobb–Douglas.) Nowadays, however, there is some basis for thinking that the capital share may have risen. It is useful in this connection to keep in mind that the aggregative elasticity of substitution, taken as measuring the responsiveness of relative factor prices to relative factor intensity, is not a purely technological concept (as John Hicks realized when he invented it in 1932). One quantitatively important way in which the aggregate economy can substitute capital for labor is through a factor-price-and-commodity-price-induced shift in demand from labor-intensive to capital-intensive goods and services. That sort of easy substitution, just like easy technical substitution, is also a way of fending off diminishing returns.

So it is at least thinkable that the aggregative elasticity of substitution might be or might become fairly large, especially at high capital–labor ratios. It was part of the original neoclassical growth model that a large enough elasticity of substitution allows sustained growth in output per worker and capital per worker even without technological progress (and faster still with it).

Now, to get back to where I started, since the elasticity of substitution is larger than one in such a process, the (competitive) share of capital would be rising along with the capital–labor ratio, indeed rising toward one. But then the elasticity of productivity with respect to the saving-investment rate would be getting very large. Remember: I am not prepared to tell this story, only to suggest that the mechanics of the aggregative elasticity of substitution might be as interesting an object of study for growth theorists as the last little twist on endogenous technical progress. There may be several ways to postpone or hold off the influence of diminishing returns to broadly-defined capital.

Discussion of these various facets of growth theory calls to mind a background decision that is rarely explicit: What sort of characteristic time interval are we talking about? Is growth theory 5-year, 20-year or 100-year economics? I know what I had in mind at the beginning: growth models were about intervals of time just long enough so that deviations above or below potential output would be small relative to the increment to output from beginning to end. An older terminology would have said that the model is about trend with business cycle removed; but that is awkward because the model itself is supposed to determine the trend, and I have doubts about the utility of the "cycle" idea. Anyhow that was then.

The range of time perspectives implicit in current research, as represented in the *Handbook*, is very broad. At one extreme, many macroeconomists propose to use a growth model to describe events quarter by quarter, presumably week by week if the data were available. At the other extreme, the focus on political economy and institutional change seems to call for marking the clock in intervals of a century more or less. I have already suggested that I think the first choice seems willfully to ignore or deny economic events that ought to be important in macroeconomics. The very long perspective tends to treat as mere perturbations or disturbances changes that ought to be at the center of growth theory itself. If I were using a growth model to interpret century-long time series, I would want to re-calibrate the parameters a couple of times in between if the data seemed to call for it.

I think I am driven back to the earlier convention. To be excessively concrete: an economy growing at an average rate of three percent a year will roughly double in 25 years. Episodes of recession or overheating amounting to five percent of total output would cover most short-run fluctuations, and would probably count as relatively small compared with overall growth. This suggests to me that the natural habitat of growth-theoretic explanations is time-spans of 25 to perhaps 40 or 50 years. Anything much shorter is likely to mix up supply-side and demand-side effects, and anything much longer runs the risk of overlooking some events that ought to be accounted for explicitly. That cannot be called an error; the very-long-run perspective has its own rewards. But then we needs some nomenclature to distinguish it from the 30-year perspective.

These scattered observations and remarks seem to coalesce – at least they do for me – in a general reflection. I have set it down before, obscurely, and it may bear repeating. Growth theory has focused mainly on the steady state. This is partly because accounting for Nicholas Kaldor's "stylized facts" was one of the early goals of growth modelling; and they were essentially a description of a steady state. In addition, it is much easier to work out general and robust properties of steady states than to do the same for transition paths. So the emphasis on steady states is both explicable and reasonable.

There is a side-effect, however, that strikes me as not so good. Somehow the convention has become established that a policy aimed at "growth" is by definition a policy that will increase the steady-state growth rate. A policy package that merely increases output by 10 percent at every point along an already established trajectory is somehow disappointing. You might take this as just another example of the principle that where there is life there is hype. But for growth theorists it has led to a premium on models that do offer a direct connection between easily manageable policies and the steady-state growth rate. The early crop of so-called “AK” models was the predictable response. I thought they were uninteresting theory, in the sense that they more or less assumed what they purported to prove, and also misleading guides to policy, in that they made something look easy that is in fact very difficult. The fashion for such models seems to have waned. William Easterly’s chapter in the *Handbook* demonstrates rather convincingly that these apparently easy levers on the growth rate are indeed illusory, as we should have known.

If you look closely, however, even more serious models of endogenous growth seem to depend, at a key point, on the blunt assumption that, for some important X, $\mathrm{d}X/\mathrm{d}t = A(\ldots)X$, where $A(\ldots)$ is a function of one or more easily manipulable level variables. Maybe that is a logical necessity: if you want an exponential solution, you better have a linear differential equation. One has to accept that piece of wisdom. The real point, however, is that any such linearity assumption, because it is so powerful, ought to require much more convincing justification than it gets in the standard models of endogenous technological change or accumulation of human capital.

I wonder if it would be a fair summary of the *status quo* to say that the broad neoclassical model of growth is widely accepted as a valid description of the mechanism of economic growth in advanced economies; most current research is aimed at unpacking, understanding and testing those aspects that the basic model takes as given. The Ghost could go along with that, subject to a couple of minor amendments already stated. The mechanism itself needs extension so that it can cover international flows of goods, capital and technology (and perhaps labor), so that it can better describe interactions between demand-driven fluctuations and the path of potential output, and so that it can allow explicitly for the existence of many goods and sectors with different technologies and different demand conditions. These needs were foreseeable and foreseen early in the story; they are merely unfinished old business.

PART I

THEORIES OF ECONOMIC GROWTH

Chapter 1

NEOCLASSICAL MODELS OF ENDOGENOUS GROWTH: THE EFFECTS OF FISCAL POLICY, INNOVATION AND FLUCTUATIONS

LARRY E. JONES

University of Minnesota and Federal Reserve Bank of Minneapolis

RODOLFO E. MANUELLI

University of Wisconsin

Contents

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Abstract

Despite its role as the centerpiece of modern growth theory, the Solow model is decidedly silent on some of its basic questions: Why is average growth in per capita income so much higher now than it was 200 years ago? Why is per capita income so much higher in the member countries of the OECD than in the less developed countries (LDC) of the world? In this chapter we review the recent literature on endogenous growth. We concentrate on convex models and we restrict attention to the case in which markets are competitive.

After a brief review of the basic mechanisms that produces growth, we concentrate on three topics: the impact of fiscal policies on growth, the role of innovation and the relationship between uncertainty and growth.

Keywords

endogenous growth, convex models, competitive markets, taxation, innovation, uncertainty

JEL classification: H2, H3, O4

1. Introduction

Despite its role as the centerpiece of modern growth theory, the Solow model is decidedly silent on some of its basic questions: Why is average growth in per capita income so much higher now than it was 200 years ago? Why is per capita income so much higher in the member countries of the OECD than in the less developed countries (LDC) of the world? The standard implementation of the Solow model provides no answers for these questions except, perhaps, for differences across time and across countries in the production possibility set. This is typically summarized by differences in Total Factor Productivity (TFP). The fundamental reasons for why TFP might be different in different countries, or in different time periods is left open for speculation. If these differences are supposed to be due to differences in innovations, it is not made clear why access to these innovations should be different, nor is it noted that these innovations themselves are economic decisions – they have costs and benefits, and are made by optimizing, private agents.

This basic weakness in the Solow model (and its followers) was the driving force behind the development of the class of endogenous growth models. This literature has been wide and varied, with the models developed ranging from perfectly competitive, convex models to ones featuring a range of types of market failures (e.g., increasing returns, external effects, imperfectly competitive behavior by firms, etc.). A common feature that has been emphasized throughout is knowledge, or human capital, and its production and dissemination. In some cases, this has been directly treated in the modeling, in others it has been more tangential, an important consideration for quantitative development, but less so for qualitative work. That this focus is essential follows from the fact that the Solow model already accurately reflects the quantitative limits of using models with only physical capital. (That is, capital's share is determined by the data to put us in the Solow range, technologically.) Although they differ in their details, in the end, what this class of models points to as differences in development are differences in social institutions across time and countries. Thus, countries that have weaker systems of property rights, or higher wasteful taxation and spending policies, will tend to grow more slowly. Moreover, these differences in performance can be permanent if these institutions are unchanging. As a corollary, those countries who developed these growth enhancing institutions more recently (and some still have not), have levels of income that are lower than those in which they were adopted earlier, even if current growth rates show only small differences.

In this paper we limit ourselves to studying neoclassical models. By this we mean models with convex production sets, well behaved preferences and a market structure that is consistent with competitive behavior. Therefore, we do not review the large literature that addresses the role of externalities and non-competitive markets. As it turns out, most of the basic ideas behind this literature can be expressed in simple, convex models of aggregate variables without uncertainty. These are the models that are the first focus of this chapter. They have proved both highly flexible and easy to use. With them, we can give substance to statements like those above that property rights and other governmental institutions are key to long run growth rates in a society. Most of this branch of the literature is well known by now, and much of it appears on standard graduate macro reading lists. Accordingly, our discussion will be fairly brief.[1] One important, and as of yet unresolved issue, is the size of the growth effects of cross-country differences in fiscal policy. Thus, our review of the standard convex model is complemented with a discussion of the more recent findings about the quantitative effects of taxes (and government spending) on growth. Even though the theoretical effects of social institutions are well understood, this is less true of the recent work on perfectly competitive models of innovation, and so, comparatively more space is used to discuss that ongoing development. As a second focus, one issue that comes immediately to light in studying this class of models is the possibility that uncertainty per se might have an impact on long run performance. This points to the possibility that instability in property rights and institutions might change the incentives for investment. That is, how are the time paths of savings, consumption and investment affected by uncertainty in this class of models? How does this compare with how uncertainty affects decisions in the Solow model [i.e., Brock and Mirman (1972) vs. Cass (1965) and Koopmans (1965)]?

Much less is known about the answers to these questions at the present time and that knowledge that does exist is much less widespread. For this reason, we present a fairly detailed discussion of the properties of stochastic, convex models of endogenous growth. To this end, we study models in which technologies and policies are subject to random shocks. We characterize the effects of differential amounts of uncertainty on average growth. We show that increased uncertainty can increase or decrease average growth depending on both the parameters of the model and the source of the uncertainty. A separate, but related topic, is the business cycle frequency properties of these models. This is left to future work.

In Section 2, we lay out the basics of the class of neoclassical (i.e., convex) models of endogenous growth. We show how differences in social institutions across time and across countries can give rise to different performance, even over the very long run. We also lay out some of the interpretations of the model, including human capital investment and innovation and knowledge diffusion sectors, that lend richness to its interpretation. Section 3 discusses properties of the models when uncertainty is added, and shows how this can affect the long run growth rate of an economy.

2. Endogenous growth: Infinite lifetimes

Historically, the engine of growth as depicted in Solow's seminal work on the topic (1956) was the assumption of exogenous technical change. Thus, initially, growth models aimed at being consistent with growth facts, but gave up on the possibility of

[1] Other authors have also presented comprehensive surveys of this literature [see Barro and Sala-i-Martin (1995), Jones and Manuelli (1997), and Aghion and Howitt (1998) for examples]. Our aim is to complement those presentations, rather than repeat them, and hence, our focus is somewhat distinct.

explaining them. Moreover, this approach has weaknesses in two distinct areas. First, it is difficult using the exogenous growth model to explain the observed long run differences in performance exhibited by different countries. Second, the productivity changes that are assumed exogenous in the Solow model are, in fact, the result of conscious decisions on the part of economic agents. If this is the case, it is then important to explore both the mechanism through which productivity changes as well as the factors that can give rise to the observed long run differences if we are to understand these phenomena. In this section we briefly review the basic optimal growth model as initially analyzed by Cass (1965) and Koopmans (1965). We then discuss the nature of the technologies consistent with endogenous growth and the role of fiscal policy in influencing the growth rate. We conclude with an analysis of the role of innovation in the context of convex models of equilibrium growth.

2.1. Growth and the Solow model

In the simplest time invariant version of the Solow model, it can be shown that the per capita stock of capital converges to a unique value independent of initial conditions. It is then necessary to assume some exogenous source of productivity growth in order to account for long run growth. In Solow (1956), it is assumed that labor productivity grows continually and exogenously. In response, the capital stock (assumed homogeneous over time) is continually increased allowing for a continual expansion in the level of output and consumption. The literature on endogenous growth has concentrated on replacing this assumed exogenous productivity growth by an endogenous process. If this change in productivity of labor is thought to arise from the invention of techniques consciously developed, the literature on endogenous growth can then be thought of as explicitly modeling the decisions to create this technological improvement [see Shell (1967) and (1973)]. For this to go beyond a reinterpretation of the Solow treatment, it must be that the technology for discovering and developing these new technologies does not have itself a source of exogenous technological change. Because of this, these models all feature technologies that are time stationary.

The consumer problem in the simple growth model is given by

$$\max_{\{c_t\}} \sum_{t=0}^{\infty} \beta^t u(c_t)$$

subject to

$$\sum_{t=0}^{\infty} p_t(c_t + x_t) \leqslant W_0 + \sum_{t=0}^{\infty} p_t r_t k_t, \tag{1a}$$

$$k_{t+1} = (1 - \delta_k)k_t + x_t, \tag{1b}$$

where c_t is the level of consumption, x_t is investment, k_t is the capital stock, p_t is the price of consumption (relative to time 0), and r_t is the rental price of capital, all in period t, and W_0 is the present value of wealth net of capital income. The first order condition for (an interior) solution to this problem is just

$$u'(c_t) = \beta u'(c_{t+1})[1 - \delta_k + r_{t+1}]. \tag{2}$$

If, as is standard in the literature, the instantaneous utility function, $u(c_t)$, is assumed strictly concave, growth – defined as a situation in which $c_{t+1} > c_t$ – requires

$$\beta[1 - \delta_k + r_{t+1}] > 1. \tag{3}$$

Condition (3) is fairly general, and must hold *independently of the details of the production side* of the economy. Thus, if the economy is going to display long run growth, the rate of return on savings must be sufficiently high.

What determines the economy's rate of return? In the standard Solow growth model – and in many convex models – firms can be viewed as solving a static problem. More precisely, each firm maximizes profits given by

$$\Pi_t = \max_{k,n} \; c + x - r_t k - w_t n,$$

subject to

$$c + x \leqslant F(k, n),$$

where F is a concave production function that displays constant returns to scale.

Since in equilibrium the household offers inelastically one unit of labor, the rental rate of capital must satisfy

$$r_t = f(k_t), \tag{4}$$

where $f(k) = F(k, 1)$, and k is capital per worker.

It is now straightforward to analyze growth in the Solow model. The equilibrium version of (2) is just

$$u'(c_t) = \beta u'(c_{t+1})\big[1 - \delta_k + f(k_{t+1})\big]. \tag{5}$$

If the *productivity of capital* is sufficiently low as the stock of capital per worker increases, then there is no long run growth. To see this, note that if $\lim_{k\to\infty} f'(k) = \underline{r}$, with $1 - \delta_k + \underline{r} < 1$, there exists a finite k^* such that $1 - \delta_k + f(k^*) = 1$. It is standard to show that the unique competitive equilibrium for this economy (as well as the symmetric optimal allocation) is such that the sequence of capital stocks $\{k_t\}$ converges to k^*. Given this, consumption is also bounded. (Actually, it converges to $f(k^*) - \delta_k k^*$.)

Can exogenous technological change 'solve' the problem. The answer depends on the nature of the questions that the model is designed to answer. If one is content to generate equilibrium growth, then the answer is a clear yes. If, on the other hand, the objective is to understand how policies and institutions affect growth, then the answer is negative.

To see this assume that technological progress is labor augmenting. Specifically, assume that, at time t, the amount of effective labor is $z_t = z(1+\gamma)^t$. In order to guarantee existence of a balanced growth path we assume that the utility function is isoelastic [see Jones and Manuelli (1990) for details], and given by $u(c) = c^{1-\theta}/(1-\theta)$. Let a ˆ over a variable denote its value relative to effective labor. Thus, $\hat{c}_t \equiv c_t/(z(1+\gamma)^t)$. In this case, the balanced growth version of (2) is

$$(1+\gamma)u'(\hat{c}_t) = \hat{\beta}u'(\hat{c}_{t+1})\big[1 - \delta_k + f'\big(\hat{k}_{t+1}\big)\big],$$

where $\hat{\beta} = \beta(1+\gamma)^{1-\theta}$.[2]

Standard arguments show that the equilibrium of this economy converges to a steady state $(\hat{c}, \hat{k})$. Thus, this implies that, asymptotically, consumption is given by $c_t = (1+\gamma)^t z\hat{c}$. Thus, even though there is equilibrium growth, the growth rate is completely determined by the exogenous increase in labor augmenting productivity.

2.2. A one sector model of equilibrium growth

As we argued before, the critical assumption that results in the economy not growing is that the marginal product of capital is low. The modern growth literature has emphasized the analysis of economies in which the marginal product of capital remains (sufficiently) bounded away from zero. This induces positive long-run growth in equilibrium. As we will show, how fast output grows in these models depends on a variety of factors (e.g., parameters of preferences). Because of this, these models have the property that the rate of growth is determined by the agents in the model.

Throughout, there will be one common theme. This mirrors the point emphasized above, that for growth to occur, the interest rate (either implicit in a planning problem or explicit in an equilibrium condition) must be kept from being driven too low. This follows immediately from the discussion above.

In terms of key features of the environment that are necessary to obtain endogenous growth there is one that stands out: it is necessary that the marginal product of *some* augmentable input be bounded strictly away from zero in the production of some augmentable input which can be used to produce consumption.

Since we are dealing with convex economies, the arguments in Debreu (1954) apply to the environments that we study. Thus, in the absence of distortionary government policies, equilibrium and optimal allocations coincide. Thus, for ease of exposition, we will limit ourselves to analyzing planner's problems.

The planner's problem in the basic one sector growth model is given by

$$\max_{\{c_t\}} \sum_{t=0}^{\infty} \beta^t u(c_t),$$

[2] Existence of a solution requires that $\beta(1+\gamma)^{1-\theta} < 1$, which we assume.

subject to

$$c_t + x_t \leqslant F(k_t, n_t),$$
$$k_{t+1} \leqslant (1 - \delta_k)k_t + x_t,$$

where c_t is per capita consumption, k_t is the per capita stock of capital, x_t is the (non-negative) flow of investment, and n_t is employment at time t. Since we assume that leisure does not yields utility, the optimal (and equilibrium) level of n_t equals the endowment, which we normalize to 1. The Euler equation for this problem is just (5) given that, as before, we set $f(k) = F(k, 1)$. It follows that if $\lim_{k\to\infty} \beta[1 - \delta_k + f(k)] > 1$, then $\limsup_t c_t = \infty$. Thus, there is equilibrium growth. This result does not depend on the assumption of just one capital stock. More precisely, in the case of multiple capital stocks, the feasibility constraint is just

$$c_t + \sum_{i=1}^{I} x_{it} \leqslant f(k_{1t}, \ldots, k_{It}),$$
$$k_{it+1} \leqslant (1 - \delta_{ik})k_{it} + x_{it}.$$

In this case, the natural analogue of the assumption that the marginal product of capital is bounded is just that there is a homogeneous of degree one function – a linear function – that is a lower bound for the actual production function. However, it turns out that all that is required is that there exist a ray that has bounded marginal products. Formally, this corresponds to

CONDITION 1. *Assume that* $f(k_1, \ldots, k_I) \geqslant h(k_1, \ldots, k_I)$, *where* h *is concave, homogeneous of degree one and* C^1 *for all* $(k_1, \ldots, k_I) \in \mathbb{R}_+^I$. *Moreover, assume that there exists a vector* $\hat{k} = (\hat{k}_1, \ldots, \hat{k}_I)$, $\hat{k} \neq 0$, *such that if* $\hat{k}_i > 0$,

$$\beta\big[1 - \delta_k + h_i\big(\hat{k}\big)\big] > 1, \quad i = 1, \ldots, I.$$

The basic result is the following [see Jones and Manuelli (1990)].

PROPOSITION 2. *Assume that Condition 1 is satisfied. Then, any optimal solution* $\{c_t^*\}$ *is such that* $\limsup_t c_t^* = \infty$.

As Jones and Manuelli (1990) show, the planner's solution can be supported as a competitive equilibrium. An extension to multiple goods is presented by Kaganovich (1998) and it is based on similar insights. It is clear that Condition 1 does not rule out decreasing returns to scale. This, in turn implies that this class of models is consistent with a version of the notion of conditional convergence: relatively poor countries are predicted to grow faster than richer countries, with the consequent closing of the income gap. Put it differently, theory suggests that, with a finite amount of data, it is difficult to distinguish an endogenous growth model from a Cass–Koopmans exogenous growth model. The main difference lies in the tail behavior of the relevant variables (output or consumption), and not in the balanced (or unbalanced) nature of the equilibrium path.

2.3. *Fiscal policy and growth*

In this section we describe the effects of taxes and government spending on the long run growth rate. Consider the problem faced by a representative agent

$$\max \sum_{t=0}^{\infty} \beta^t u(c_t, 1 - n_t)$$

subject to

$$\begin{aligned}&(1+\tau^c)c_t + (1+\tau^x)p_t x_{kt} + (1+\tau^h)q_t \\ &\quad \leqslant w_t(1-\tau^n)(n_{ct}h_t + n_{kt}h_t) + (1-\tau^k)r_t k_t + T_t + \Pi_t,\end{aligned}$$

where τ^j represent tax rates, c_t is consumption, x_{kt} is investment in physical capital, q_t are market goods used in the production of human capital, $n_{it}h_t$ is effective labor – the product of human capital and hours – allocated to sector i, k_t is the stock of capital, T_t is a government transfer, and Π_t are net profits.

Accumulation of human capital at the household level satisfies

$$h_{t+1} \leqslant (1-\delta_h)h_t + F^h(q_t, n_{ht}h_t),$$

where F^h is homogeneous of degree one, concave and increasing in each argument.

The economy has two sectors: producers of capital and consumption goods. Output of the capital goods industries satisfies

$$x_t \leqslant F^k(k_{kt}, n_{kt}h_t),$$

where F^k is homogeneous of degree one and concave.

Feasibility in the consumption goods industry is given by

$$c_t \leqslant F^c(k_{ct}, n_{ct}h_t),$$

where F^c is increasing and concave. It is not necessary to assume that this production function displays constant returns to scale.

It is illustrative to consider several special cases. Throughout, we assume that the utility function is of the form that is consistent with the existence of a balanced growth path. Specifically, we assume that $u(c, \ell) = (cv(\ell))^{1-\theta}/(1-\theta)$. Moreover, since our emphasis is on the role of taxes and tax-like wedges between marginal rates of substitution and transformation, we assume that lump sum transfers, T_t, are adjusted to satisfy the government budget constraint.

Case I: One sector model with capital taxation. We assume that the consumer supplies one unit of labor inelastically. In this case $F^c = F^k = Ak + \hat{F}(k)$, where $\hat{F}(k)$ is strictly concave and $\lim_{k\to\infty} \hat{F}'(k) = 0$. For now we ignore human capital and set $F^h \equiv 0$. It follows that the balanced growth rate satisfies

$$\gamma^\theta = \beta\left[1 - \delta_k + \frac{1-\tau^k}{1+\tau^x}A\right].$$

Thus, in this setting, increases in the effective tax on capital, $(1-\tau^k)/(1+\tau^x)$ unambiguously decrease the equilibrium tax rate. Thus, unlike exogenous growth models, government policies affect the growth rate. Moreover, this simple example illustrates that the size of the impact of changes in tax rates on the long run growth rate depends on the intertemporal elasticity of substitution $1/\theta$. More precisely the elasticity of the growth rate with respect to τ^k is given by

$$\frac{\partial\gamma}{\partial\tau^k}\frac{\tau^k}{\gamma} = -\frac{1}{\theta}\frac{\frac{\tau^k}{1+\tau^x}A}{1-\delta_k+\frac{1-\tau^k}{1+\tau^x}A}.$$

It follows that, other things constant, high values of the intertemporal elasticity of substitution result in large changes in predicted growth rates in response to changes in tax rates. Thus, even an example as simple as this one illustrates that the quantitative predictions of this class of models will heavily depend on the values of the relevant preference (and technology) parameters.

Case II: Physical and human capital: Identical technologies. In this section we assume that $F^c = F^k$, and $F^h = q$. This implies that all three goods – investment, consumption and human capital – are produced using the same technology and, in particular, the same physical to human capital ratio. As in the previous section, τ^k and τ^x do not play independent roles. Thus, to simplify notation, we will set $\tau^x = 0$. However, the reader should keep in mind that increases in the tax rate on capital income are equivalent to increases in the tax rate on purchases of capital goods.

In this case, the balanced growth conditions are

$$\gamma^\theta = \beta\bigl[1-\delta_k+\bigl(1-\tau^k\bigr)F_k(\kappa,n)\bigr], \tag{6a}$$

$$\frac{c}{h}\frac{v'(1-n)}{v(1-n)} = \frac{1-\tau^n}{1+\tau^c}F_n(\kappa,n), \tag{6b}$$

$$\bigl(1-\tau^k\bigr)F_k(\kappa,n)-\delta_k = \frac{1-\tau^n}{1+\tau^h}F_n(\kappa,n)n-\delta_h, \tag{6c}$$

$$\frac{c}{h}+(\gamma+\delta_k-1) = F(\kappa,n). \tag{6d}$$

There are several interesting points. First, increases in the tax rate on consumption goods (i.e. sales or value added taxes) are equivalent to increases in the tax rate on labor income. Second, the relevant tax rate to evaluate the return on human capital is $(1-\tau^n)/(1+\tau^h)$. Thus, it is possible that increases in τ^n – as observed in the U.S. between the pre World War II and the post WWII periods – if matched by decreases in τ^h (corresponding, for example, to expansion in the quantity and quality of free public education) have no effect on the physical capital–human capital ratio, κ. Third, it is possible to show that increases in τ^k, τ^n, τ^h or τ^c result in lower growth rates. Last, without making additional assumptions about preferences and technology, it is not possible to sign the impact of changes in tax rates on other endogenous variables.

Case III: Physical and human capital: Different factor intensities. In this case, we assume that only human capital is used in the production of human capital. Thus, $F^h = A_h n_h h$. This is the technology proposed by Uzawa (1964) and popularized in this class of models by Lucas (1988). For simplicity, we only consider capital and labor taxes. The relevant steady state conditions are (6a), (6b), and (6d). However, (6c) becomes

$$\gamma^\theta = \beta[1 - \delta_h + A_h n_h]. \tag{7}$$

In this version of the model, changes in labor income taxes, reduce growth through their impact on hours worked (relative to leisure). However, if total work time is inelastically supplied, i.e. $v(\ell) \equiv 1$, the growth rate is pinned down by

$$\gamma^\theta = \beta[1 - \delta_h + A_h].$$

Thus, in this setting [which corresponds to Lucas (1988) model without the externality, and to Lucas (1990)], taxes have no effect on growth. Increases in the tax rate on capital income simply change physical capital–human capital ratio and they leave the after tax rate of return unchanged. The reason for this extreme form of neutrality is that even though taxes on labor income reduce the returns from education, they also reduce the cost of using time to accumulate human capital (the value of time decreases with increases in taxes), and the two changes are identical. Thus, the cost-benefit ratio of investing in education is independent of the tax code.

2.3.1. *Quantitative analysis of the effects of taxes*

Since the development of endogenous growth theory there have been several studies of the implications of substituting lump-sum taxes for a variety of distortionary taxes. Jones, Manuelli and Rossi (1993) analyze the optimal choice of distortionary taxes in several models of endogenous growth. In the case that physical and human capital are produced using the same technology and labor supply is inelastic, they find that for parameterizations that make the predictions of the model consistent with observations from the U.S., the potential growth effects of drastically reducing (eliminating in most cases) all forms of distortionary taxation is quite high. For their preferred parameterization the increase in growth rates is about 3%. They study a version of the model in which $F^c = F^k \neq F^h$, and the functions F^k and F^h are both of the Cobb–Douglas variety, but differ in the average productivity of capital. Jones, Manuelli and Rossi estimate the capital share parameter to be equal 0.36 in the consumption sector, and to be somewhere in the 0.40–0.50 range in the human capital production sector.[3] They also allow labor supply to be elastic. Their findings suggest that switching to an optimal tax code result in increases in yearly growth rates of somewhere between 1.5% and 2.0% per year. These are substantial effects.

[3] Jones, Manuelli and Rossi (1993) calibrate this share. Since they study the sensitivity of their results to changes in other parameters (e.g., the intertemporal elasticity of substitution), the market goods share is not constant across experiments.

The third experiment that they consider involves the endogenous determination (by the planner) of the level of government consumption. In this case, they revert back to the one sector version of the model, and they explore not only the consequences of changing the intertemporal elasticity of substitution, but they allow for varying elasticity of substitution between capital and human capital. For their preferred characterization, they also find growth effects of about 2% per year. Moreover, as in the other experiments, the predictions are quite sensitive to the details of the model – in particular, to the choice of the intertemporal elasticity of substitution, and the degree of substitutability between capital and human capital.

Stokey and Rebelo (1995) undertake a thorough review of several models that estimate the growth impact of tax reform. They argue that in the U.S. tax rates in the post WWII period are significantly higher than in the pre WWII era. This conclusion is based on the increase in the revenue from income taxes as a fraction of GDP in the early 1940s. To reconcile the models with this evidence, they conclude that the human capital share in the production of human capital must be large, and that this sector must be lightly taxed. This description is close to the Case III above and, as argued before, it results in no growth effects.[4] Thus, in agreement with Lucas (1990) – and using a very similar specification of the human capital production technology – they conclude that changes in tax rates cannot have large growth effects.

This conclusion depends on several assumptions. First, that the U.S. evidence shows an increase in the general level of taxes after WWII. Second, that even if there is a tax increase, the additional revenue is used to finance lump-sum transfers. Third, that the balanced growth path is a good description of the pre and post WWII economy.

Measuring changes in the relevant marginal tax rates is a difficult task. Barro and Sahasakul (1986) using tax records compute average marginal tax rates for the U.S. economy. Their estimates, consistent with the Stokey and Rebelo assumption, show an increase in the 1940s. Even though the evidence about changes in the tax rate consistently points to an increase, the implications of this result for the model are not obvious. Consider, first, the uses of tax revenue. If, for example, additional income tax revenues (at the local level) are used to finance local publicly provided goods (e.g., education), then Tiebout-like arguments suggest that the 'tax effect' of a tax increase is zero. In the U.S. a substantial increase in government spending corresponds to increases in expenditures on education and, hence, the possibility of individuals sorting themselves to buy the 'right' bundle of publicly provided private goods cannot be ignored. A second quantitatively important public spending program in the post WWII era is Social Security. To the extent that benefits are dependent on contributions, the statutory tax rate on labor income used to finance social security overstates the true tax rate.[5] In this case,

[4] The results are continuous in the parameters. Thus, for market goods share close to zero, as Stokey and Rebelo prefer, the growth effects are small.

[5] In a pay-as-you-go system, even if the share of total payments that an individual receives is sensitive to his contributions, the same effect obtains.

tax payments purchase the right to an annuity whose value is dependent on the payment. Finally, in a model with multiple tax rates an increase in a single tax does not imply, necessarily, a decrease in the growth rate. For the U.S. the evidence on the time path of capital income taxes is mixed. In a recent study, Mulligan (2003) argues that the tax rate on capital income has steadily fallen in the last 50 years. Similarly, McGrattan and Prescott (2003, 2004) find that a decrease in the tax rate on corporate income – one form of capital income – is instrumental in explaining the increase in the value of corporate capital relative to GDP. Overall, we find that the quantitative evidence on the time path of the relevant tax rates to be difficult to ascertain. More work is needed, with an emphasis on matching model and data.

The next section considers the effects of endogenous government spending and transitional effects.

2.3.2. Productive government spending

A simple balanced growth result. In this section we study a simple one sector model that provides a role for productive government spending. Our discussion follows the ideas in Barro (1990). Assume that firm i's technology is given by

$$y_{it} \leqslant A k_{it}^{\alpha} h_{it}^{\eta} G_t^{1-\alpha-\eta},$$

where k_{it} and h_{it} are the amounts of physical and human capital used by the firm, and G_t is a measure of productive public goods that firms take as given. The government budget constraint is balanced in every period, and it satisfies

$$G_t = \tau^k r_t K_t + \tau^h w_t H_t,$$

where τ^k and τ^h are the tax rates on capital and income, and r_t and w_t are rental prices. For simplicity we assume that the instantaneous utility function is given by

$$u(c) = \frac{c^{1-\theta} - 1}{1-\theta}.$$

We also assume that the technologies to produce market goods and human capital are identical. In this case, it is immediate to show that the equilibrium is fully described by

$$\begin{aligned} \delta_h - \delta_k &= A^{1/(\alpha+\eta)} \big(\alpha\tau^k + \eta\tau^h\big)^{(1-\alpha-\eta)/(\alpha+\eta)} \\ &\quad \times \big[\eta\big(1-\tau^h\big)\kappa^{\alpha/(\alpha+\eta)} - \alpha\big(1-\tau^k\big)\kappa^{-\eta/(\alpha+\eta)}\big], \\ \gamma^{\theta} &= \beta\big[1 - \delta_k + \alpha\big(1-\tau^k\big)A^{1/(\alpha+\eta)}\big(\alpha\tau^k + \eta\tau^h\big)^{(1-\alpha-\eta)/(\alpha+\eta)}\kappa^{-\eta/(\alpha+\eta)}\big], \end{aligned}$$

where κ is the physical capital–human capital ratio.

Some tedious algebra shows that the growth rate is not a monotonic function of the tax rates. In general, there is no growth when taxes are either too low (not enough public goods are provided) or too high (the private returns to capital accumulation are too low). For intermediate values of the tax rates, growth is positive (if A is sufficiently high). Thus, in general, increases in tax rates need not result in lower growth if they are accompanied by changes in government spending. Thus, a variant of the model with endogenous government spending (or endogenous taxation and optimally chosen government spending) has potential to reconcile positive growth effects associated with the removal of distortions with the U.S. evidence.

What does the U.S. evidence show? In the U.S. there is a substantial increase in the ratio of government spending to GDP in the post WWII period on the order of 15%. Even ignoring defense related expenditures, the size of the federal government relative to output is close to 5% in the pre WWII period, and it increases steadily in the post war to reach about 20% of income. Of course, not all forms of government spending are productive, but if the trend in the productive component follows the trend in overall spending, ignoring changes in government spending result in biased estimates of the effects of distortions.

The Barro model is silent about the reasons why the desired ratio of (productive) government spending to GDP would increase. For this, it is necessary to have a model of the collective decision making mechanisms which is clearly beyond the scope of this chapter.

Progressive taxes and transition effects. Our discussion of the assumptions that suffice for sustained growth clearly shows that homogeneity of degree one is not necessary. In both theoretical and applied work it is common to appeal to linearity in order to ignore transitional dynamics [see Bond, Ping and Yip (1996) and Ladron de Guevara, Ortigueira and Santos (1997) for analysis of the dynamics of endogenous growth models]. However, when taking the model to the data, the assumption that the economy is on the balanced growth path may not be appropriate.

In this section we describe the results of Li and Sarte (2001). The basic insight from their model that is relevant for our discussion is that in the presence of heterogeneity in individual preferences and nonlinearities in the tax code, shocks to the tax regime (they consider an increase in the degree of progressivity of the tax code) that ultimately result in a decrease in the growth rate can have basically no effects for several decades.

The basic model that they consider is one in which goods are produced according to the following technology

$$Y_t \leqslant AK_t^{\alpha} L_t^{1-\alpha} G_t^{1-\alpha},$$

where K_t is capital at time t, L_t is the flow of labor, and G_t is a measure of productive public goods. All individuals have isoelastic preferences given by $u(c) = (c^{1-\theta} - 1)/(1 - \theta)$, but they differ in their discount factors, β_i. Li and Sarte assume that each type has mass $1/N$, where N is population. The tax code is nonlinear. Given aggregate income Y, and individual income y_i, the *tax rate* is given by a function $\tau(z)$, where z is the ratio of individual to average income. In this application, Lin and Sarte assume that

$$\tau\left(\frac{y_i}{Y}\right) = \zeta \left(\frac{y_i}{Y}\right)^{\phi}.$$

Note that the case of proportional taxes – the case discussed so far – corresponds to $\phi = 0$. In this setting, higher values of ϕ are interpreted as corresponding to more progressive tax codes. Individual income is defined as the sum of capital and labor income. Government spending is financed with revenue from income taxes. Li and Sarte show that the equilibrium is the solution to the following system of equations:

$$\gamma^{\theta} = \beta_i \left\{ 1 - \delta + \left[1 - (1+\phi)\zeta \left(\frac{y_i}{Y} \right)^{\phi} \right] \alpha A^{1/\alpha} \left(\frac{G}{Y} \right)^{(1-\alpha)/\alpha} \right\}, \quad i = 1, 2, \ldots, I,$$

$$\frac{G}{Y} = \sum_{i=1}^{I} \zeta \left(\frac{y_i}{Y} \right)^{1+\phi} \frac{1}{N},$$

$$1 = \sum_{i=1}^{I} \frac{y_i}{Y} \frac{1}{N}.$$

In this model, changes in the progressivity of the tax code affect the rate of return – this is the standard effect – as well as the distribution of income. It is this last effect that generates the slow adjustment. It is possible to show that an increase in ϕ decreases long run growth, γ.

Li and Sarte explore the dynamic effects of a one time increase in ϕ that result in a decrease in the growth rate of 1.5%. On impact, output growth increases because since the distribution of income does not adjust immediately, government revenues increase and this, in turn, increases output. As the low discount factor individuals adjust their relative income (an increase in progressivity affects them more than proportionally), government revenue and spending decrease. For parameter values that are designed to mimic the U.S. economy, Li and Sarte find that the half-life of the adjustment is over 40 years. Thus, any test for breaks in the growth rate as suggested by models in which convergence is immediate would conclude (incorrectly) that the tax increase has no effects on growth.

It is difficult to evaluate how appropriate the Li and Sarte model is to study the impact of tax reform in the U.S. economy. However, it casts doubt on the approach by Stokey and Rebelo which ignores transitional dynamics. Models that rely on changes in tax rates that, in turn, affect the distribution of income, are consistent with the view that the effects of those changes are not monotone, and that the full impact may not be felt for decades.

2.4. Innovation in the neoclassical model

One of the things that seems unsatisfactory to many economists in the presentation up to this point is the starkness with which the technological side of the model is described. As we argued above, the key in improving over the Solow model is to explicitly consider decisions made by private agents about investments they make that cause technology to improve. This both endogeneizes the growth process envisaged by Solow and breaks away from another key assumption of the exogenous growth literature, that technological change happens without any resource cost. But, much of the detail that one thinks about as being an important part of the innovation process seems to be missing from the simple convex models of growth described above. The idea that innovation is carried out by specialized researchers who pass on their newfound knowledge to production line workers is just one example of this. Indeed, one question is whether or not that kind of structure is consistent with convex models of growth at all.

Because of this, in this section we describe a variant of the models presented in the last section that is more directed at identifying innovation as a special activity. The purpose of this exercise is not to fully exhaust the possibilities, but rather to show the reader that more is possible with the class of convex models than one might first think. In particular, since the model we will analyze is convex, standard price taking behavior is consistent with equilibrium behavior. In this sense, the example we will present is similar to the ideas developed by Boldrin and Levine (2002).

There are many models of innovation that do not have convex technology sets [e.g., see the surveys in Barro and Sala-i-Martin (1995) and Aghion and Howitt (1998)]. In this setting, standard price taking behavior is either not consistent with equilibrium in those settings or they must include external effects. Because of this, all policy experiments in those models mix two conceptually distinct aspects of policy, the desire to correct for monopoly power and/or external effects and the distortionary effects of 'wedges' (e.g., taxes). This, in turn, implies that the answers to questions about the effects of alternative policies on both the incentives to innovate and overall welfare depends on the details of the specifications of external effects (e.g., do other researchers learn new innovations for free after one month, or one decade) and/or market power (e.g., is there only one researcher at the frontier and so a monopoly analysis is in order, or are there two, or many). Thus, one thing that a convex model of innovation has to add is answers to some of these questions which are less dependent on those details.

2.4.1. Notation

We will follow the notation above as closely as is possible. We assume that there are two types of labor supply available, researchers and workers. Each individual of each type has his own level of knowledge. We will assume that there is a continuum of identical households each with some researcher time and some worker time to supply to the market. These are given by L_1 researcher hours per household, and L_2 worker hours per household, where $L = L_1 + L_2$ is total labor supply within the household. We will assume that L_1 and L_2 are fixed, with no ability to move hours between them. (In this sense, it might be easier to think of the household as being made up of L_1 researchers and L_2 workers.)

Each household has the level of knowledge H_t that they can use with researcher hours during period t. Thus, if households are symmetric, H_t symbolizes the absolute frontier of what 'society' knows at date t. Similarly, the level of knowledge for the average