What Do Endogenous Growth Models Contribute?

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Abstract

Endogenous growth theory is one of the mainstream economics approaches to modelling economic growth. This paper provides a non-technical overview of some key strands of the endogenous growth theory (EGT) literature, providing references to key articles and texts.[1] The intended audience is policy analysts who want to understand the intuition behind EGT models. The paper should be accessible to someone without much economics training.

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O31—Technological Change; Research and Development—Innovation and Invention: Processes and Incentives
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Keywords
Endogenous Growth, Innovation

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Contents

1 Introduction

This paper provides a non-technical overview of some key strands of the endogenous growth theory (EGT) literature, providing references to key articles and texts.[2] The intended audience is policy analysts who want to understand the intuition behind EGT models. The paper should be accessible to someone without much economics training.

The starting point for the survey, as for EGT itself, is the neoclassical growth model. Whereas the primary focus of the neoclassical growth model is on the growth of productive inputs, EGT adds to this a more developed treatment of the process of innovation. As I will show, modelling the process of innovation is not as straightforward as it might seem, and in general requires some tricky technical methods to generate defensible models.

I will explain why the modelling is unavoidably complex, and focus on the common-sense intuition about innovation that the models endeavour to capture. Essentially, the models assume that *something* can grow without bound, but in a way that does not generate explosive growth, and which can be sustained in a market economy. Such assumptions are necessary to combat the "ever present threat of diminishing returns" (Aghion and Howitt (1998), p. 4).

2 Precursors to endogenous growth theory

Understanding economic growth has long been a central concern in economics. At the risk of vastly oversimplifying the rich insights about economic growth gained over more than two centuries of economic thought, I will focus on three generic ingredients—factor accumulation, diminishing returns, and new discoveries.

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Adam Smith's *Wealth of Nations* (Smith (1776)) is arguably concerned primarily with economic growth, or, in Smith's words, the "progress of opulence". Given that Smith was writing during the industrial revolution, it is perhaps not surprising that he emphasised the rising ratio of capital to labour as a key ingredient in economic growth. The growth of inputs such as capital was making a strong contribution to the growth of output, so Smith could understand a lot about eighteenth century growth by looking at the processes by which capital was accumulated, through deliberate savings ("parsimony"). More generally, increasing the quantity of inputs (factors of production) will (usually) lead to an increase in the quantity of outputs, so studying *factor accumulation* is a key strand in attempts to explain economic growth.

The second ingredient of economic thinking about growth that I wish to emphasise is that of diminishing returns, which relates to the link between factor accumulation and output growth. In particular, diminishing returns captures the idea that doubling the amount of capital will in general lead to less than a doubling of output. The idea was discussed in detail by Ricardo (1821), although it appears earlier in the work of Turgot.[3] Ricardo focused on the case of agricultural (corn) production, where land was in fixed supply, and adding more capital or labour forced activity onto less fertile land, leading to less than proportional increases in output as inputs grew. The more general version of the "law" of diminishing returns, which has been incorporated into many subsequent economic models, applies the same principle to any set of factors where one is in relatively fixed supply. This point will be picked up again in the discussion of the neoclassical growth model in the next section.

The third element from the growth theory literature that I want to focus on is what I will refer to as "discovery". This is a disproportionately large "catch-all" for changes in what is produced, how things are produced, or how they are used. For the purposes of this paper, I will keep the definition of "discovery" very general.

[3] See Cannan (1892).

It covers a wide range of phenomena, some of which have acquired more specific usages in the literature, and is intended to include the discovery of new markets, processes, products, and ideas; innovation; invention; technical change; technological shifts; research; development; etc. It may seem a little strange to clump such a wide range of concepts under a single heading, especially as the list includes a variety of forces that many people would identify as obvious potential drivers of growth. This treatment reflects the way that economic growth has been approached in the literature, at least in the mainstream (neoclassical) economics literature.

2.1 Neoclassical growth models

The accumulation of productive factors and the existence of diminishing returns have found modern expression in neoclassical production theory in the form of a production function. The production function summarises the amount of output that can be produced with various combinations of inputs. The most commonly used form of the production function models output as depending on just two inputs—capital and labour, according to a particularly convenient mathematical form (the Cobb-Douglas production function).[4] It is commonly assumed that the production function is "constant returns to scale". This means that a doubling of *all* inputs will lead to a doubling of output. However, decreasing returns to scale apply to an input if other inputs do not increase. For instance, if the amount of capital is increased without any increase in labour, each subsequent addition of capital will yield smaller and smaller increments to output.

[4] In the past there has been considerable debate within the economics literature about the validity of specifying an aggregate production function, or even whether the concept of "aggregate capital stock" has any sensible meaning. The mainstream consensus is that, while it is hard to justify theoretically, it is a sufficiently useful abstraction that can provide many useful insights.

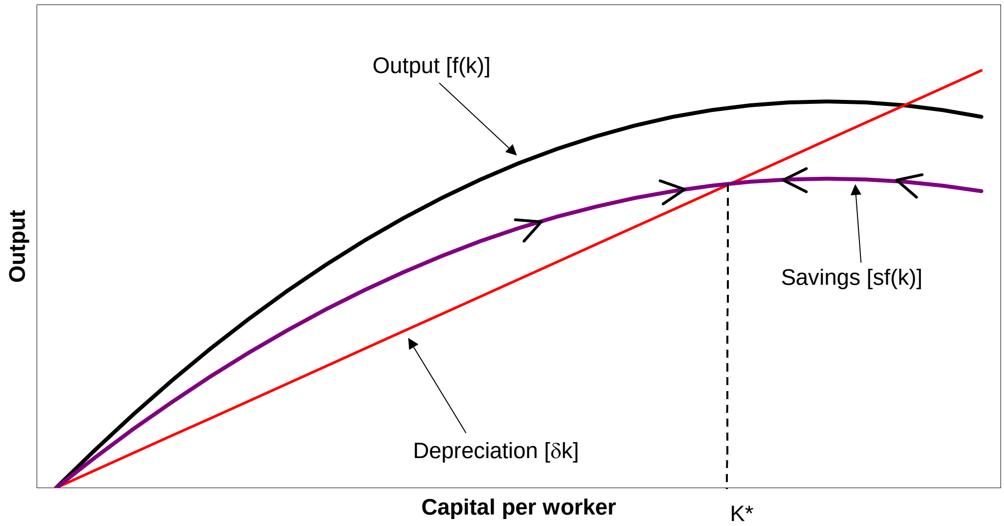
The neoclassical growth model uses such a production function to examine how output grows as inputs are accumulated. The key insights can be gained by assuming that the amount of labour input is fixed, and that capital can be accumulated by saving a fixed proportion of output each period and investing it in new capital.[5] The model is summarised in Figure 1. The upper line shows the amount of output that is produced with different levels of capital.[6] It curves as it does because of diminishing returns—the growth in output as capital increases gets less and less. Savings are shown as a fixed proportion of output. The straight line captures the amount of saving that is required just to keep up with capital depreciation. If capital per worker is less than the amount shown as K^*, savings exceed depreciation, and some saving is available to increase capital. Over time, capital will increase, as shown by the arrowheads on the savings curve. To the right of K^*, savings are insufficient to meet depreciation, and capital decreases. In the long run, capital per worker will end up fixed at K^*.

The clear implication from this model is that in the long run, growth stops. Moreover, growth gets slower as capital per worker approach K^* from below. Not only does the amount of investment decline, but the output generated by an additional dollar of investment also gets smaller. The neoclassical growth model so far is a model of no growth, at least in the long run.

[5] The Cass-Koopmans-Ramsey model endogenises the savings rate in an intertemporal utility maximisation model. See Aghion and Howitt (1998, section 1.2) or Blanchard and Fischer (1989).

[6] Capital is shown as capital per worker, but since we have assumed that labour input is fixed, the difference is immaterial. If we use a Cobb-Douglas production function, the illustrated relationships hold for the ratio of capital to labour, which is what the graph shows.

Figure 1: The neoclassical growth model



Factor accumulation as modelled here cannot generate long-run growth. This is clearly a problem if we want to model the long-term growth of real economies. What is needed is some way of countering the "growth-destroying forces of diminishing returns"[7] over time. The simplest way to achieve this within the model is to assume that the output curve shifts up over time, which is equivalent to assuming that capital becomes more productive each period. The steady state level of capital per worker (*K*)* consequently increases over time, and if productivity grows strongly enough, can generate sustained growth. The growth in productivity is often referred to as "technical progress", and in growth accounting studies is termed "total factor productivity".

2.1.1 Growth accounting

One common application of the concept of an aggregate neoclassical production function is in "growth accounting". Growth accounting endeavours to identify how much of observed output growth is due to changes in inputs and how much is due to other factors. We start with an estimated production function and knowledge of the quantity of inputs at two points in time. From this we can predict how much growth there would be as a result of the change in inputs.

[7] Aghion and Howitt (1998, p. 39).

In practice, this generally predicts less growth than actually occurs, and the residual is labelled as “total factor productivity (TFP) growth”, or sometimes as the “Solow residual”. TFP thus captures the impact of all of the phenomena referred to above as “discovery”, as well as any errors in the specification of the production function. It is a summary of everything that the model does *not* capture, and has been referred to as a “measure of ignorance”.[8]

The fact that the neoclassical growth model and growth accounting do a poor job of explaining the forces that cause growth does not negate the insights that can be gained. Young (1995), for instance, examined the growth performance of East Asian economies, and concluded that much of the impressive growth performance can be attributed to factor accumulation (savings, education, labour force participation), with TFP growth playing a minor role.

3 EGT—modelling discovery

EGT is a collective term applied to a fairly diverse set of theories that model the process of discovery. It is for this reason that Aghion and Howitt (1998) repeatedly refer to the field as “endogenous *innovation* growth theory”. As with the analysis of factor accumulation, the analysis of discovery has a long history within economics. Smith, for instance, thought of it as a consequence of the division of labour, itself a consequence of the size of markets:

> “This great increase of the quantity of work which, in consequence of the division of labour, the same number of people are capable of performing, is owing to three different circumstances; first to the increase of dexterity in every particular workman; secondly, to the saving of the time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many”.
>
> Smith (1776), Book1, Chapter 1, Section 1.1.5.

Rae (1834) appears to be the first to have argued for “invention” as the primary source of economic growth.[9]

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[8] The phrase is attributed to Abramowitz, as cited in Aghion and Howitt (1998, p. 66).
[9] Brewer (1996?).

The renewed emphasis on these issues, evidenced by the development of EGT, reflects in part dissatisfaction with the lack of attention paid to the process of discovery within the neoclassical growth framework. Assuming growth in productivity, as is done in the neoclassical growth model, is sufficient to generate sustained growth in output but it is not very informative about what is driving growth or whether policy can influence it.

In reality, the conclusions of EGT models are also dependent on assumed growth relationships. Cameron (2003) points out that "to generate permanent growth...A model must contain a fundamental linearity in a differential equation". What this means is that something within the model must be assumed to grow without limit. For neoclassical growth, the assumption is that productivity grows exogenously (i.e. by assumption, and not as an outcome of the model).

What makes endogenous growth theories *endogenous* is that growth is a consequence of scale and accumulation. As I have shown, in the neoclassical model accumulation leads to diminishing returns. EGT (generally) incorporates that relationship, but adds another relationship. Instead of assuming that growth is determined exogenously, EGT theorists posit a mechanism that generates a positive relationship between scale and productivity. The impact of the posited mechanism is to offset, and in most cases outweigh, the impact of diminishing returns.

The most direct way to incorporate this sort of positive feedback mechanism in the neoclassical growth model is to assume that productivity depends on capital per worker. With an appropriate characterisation of this mechanism, the modelled growth in productivity can exactly offset the effects of decreasing returns, making the output curve in Figure 1 a straight line. Both capital and output can grow forever, and the rate of growth is determined by savings and investment. Such models are often referred to as "y=*Ak*" models or just "*Ak* models" because of the implied linear relationship between capital per worker and output.

A range of stories has been proposed to justify such an assumption. Arrow (1962), for instance, proposed that a firm can make more productive use of capital when the *aggregate* stock of capital is higher because people learn collectively through experience. He termed this effect "learning by doing". Other writers have incorporated additional inputs into production functions—inputs that can, like capital, be accumulated (e.g. aggregate human capital, "technical knowledge"). By assuming that output can double when these inputs are doubled (i.e. even if labour is fixed), their models are also able to generate sustained growth, and thus are a type of *Ak* model.

There are many different ways of incorporating the necessary positive types of feedback in EGT models, each with its own more or less plausible story to support it. When looking at particular EGT models, it may not be immediately obvious which assumption is the crucial one, especially to the untrained eye. It is not that theorists are trying to deceive—tracing the implications of different (assumed) sources of growth in differently structured models is the way that they gain insights into the mechanics of growth. It also enables them to check the consistency of various stories about growth, both internally and with observed patterns.

Two common ways that EGT incorporates the assumption of growth are in the form of spillovers, and by the assumption of increasing returns. Spillovers occur when the accumulation of an input has an unintended (and unrewarded) positive effect on productivity. I have already given an example of this, in the "learning by doing" approach of Arrow (1962). As capital is accumulated, productivity rises to offset diminishing returns. One feature of models that assume spillovers is that there is underprovision of the input that is the source of the spillover. In the Arrow model, the capital stock is too low—if people took into account the positive effect that investment has on productivity, they would do more of it. Similarly, if we assume that productivity increases as human capital is accumulated, an implication of the resulting model would be that subsidies to human capital could increase growth.

One of the most significant advances made by EGT is to find a way to model increasing returns. In fact, the appeal of EGT is arguably as much a result of its having generated useful modelling methods for general equilibrium theorists as it is a result of the insights it provides into growth. The main problems with modelling increasing returns are first that it can easily lead to explosive growth, which is plainly unrealistic, and second that it is in general inconsistent with a competitive equilibrium. For instance, in the Arrow (1962) model, if capital were paid according to what it contributed to output, the price of capital would be bid up until it absorbed the full value of output—there would be nothing left to reward labour inputs. In the case of spillovers, the positive feedback is assumed to be unintentional, and thus does not need to be rewarded. To model increasing returns without assuming this sort of spillover, some theorists incorporate "monopolistic competition" in the model, using a particularly convenient functional form introduced by Dixit and Stiglitz (1977). An example of this approach is discussed briefly below, in the outline of the key elements of the Romer (1990) model. Being able to write down models that incorporate both increasing returns and a competitive equilibrium is an important step in delivering on the EGT "vision of perpetual change and innovation through competition" (Aghion and Howitt (1998, p. 2)).

Both spillovers and increasing returns provide appealing "common-sense" stories to underpin growth models, especially when applied to the accumulation of knowledge. Marshall went as far as to assert a *law* of increasing returns, capturing scale effects in the development of new production methods:

> ...while the part which nature plays in production shows a tendency to diminishing return, the part which man plays shows a tendency to increasing return. The law of increasing return may be worded thus:—An increase of labour and capital leads generally to improved organization, which increases the efficiency of the work of labour and capital.
>
> Marshall (1920), Book 4, Chapter XIII, Paragraph IV.XIII.11.

It is understandable that so many EGT models emphasise knowledge, research or ideas as sources of growth. There is one property of ideas that makes arguments of spillovers or increasing returns seem particularly plausible and palatable. My knowing an idea does not in any way stop you knowing it. Economists refer to this property by saying that ideas are “non-rivalrous”. It seems natural to accept that my accumulation of ideas can “spill over” and increase your productivity. Many EGT models also assume that ideas are “partially excludable”, meaning that I am able to capture some of the benefits from my ideas (e.g. through intellectual property rights, patents, etc). Without this assumption, there would be little incentive for me to invest time and energy in seeking out new ideas.

4 Some endogenous growth examples

The themes that I have identified in EGT models (assumed scale mechanism, spillovers, increasing returns) are perhaps best illustrated with reference to some examples of specific influential models. In this section I will provide a very brief outline and discussion of four particular approaches, each emphasising a particular type or feature of innovation. The approaches are horizontal innovation (expanding the range of products); vertical innovation (improving existing products); heterogeneous innovation (research v learning by doing); and “lumpy” innovation (general purpose technologies).

4.1 Horizontal innovation—Romer (1990)

Romer’s 1990 article contains what is probably the most influential early model of endogenous growth. It is a model of “horizontal” innovation, which means that innovation takes the form of developing new varieties of goods. The intuitive summary that follows does not do full justice to what is a carefully constructed and clever model, but I hope it will serve to illustrate the key assumptions and mechanisms.

The model has three sectors. The first is the *research sector*, which employs labour and produces research outputs (referred to as designs, blueprints, or licenses). The licenses to use the designs are sold to the *intermediate goods sector*, which produces inputs for the production of a final good. The *final goods sector* combines labour inputs and the intermediate goods to produce a final output.

Spillovers are assumed in the research sector, on the basis that the knowledge embodied in designs is non-rival. Once a design is developed, all other researchers can see it, and can more readily develop additional designs. The growth in research outputs is thus positively related to the stock of designs, which grows over time. The strength of this effect is even greater when there are more researchers. As well as being non-rival, the knowledge embodied in the designs is also partially excludable. Designs can be licensed (patented) so that the research sector can sell to the intermediate goods sector the right to exclusive use of each design.

When the intermediate goods sector buys a license, it has a monopoly in the use of each design. This gives it some market power, and enables it to earn a monopoly rent. These rents are, however, all captured by the research sector in the price that is paid for licenses. There is a source of increasing returns within the intermediate goods sector that adds to the effect, increasing returns due to research spillovers. As the number of licenses (and hence intermediate goods) increases, more firms (varieties of intermediate good) enter with the same marginal product as the other firms. Growth is thus insulated from decreasing returns. Such an increasing returns relationship may arise as a result of greater specialisation, which, as Adam Smith has noted, is limited by the extent of the market.

The final goods sector combines the intermediate inputs with the labour input that is not being used in the research sector to create a final good for consumption.

For the model as a whole, the growth rate depends on the size of the research sector, both in terms of how much labour is used there, and how large the stock of accumulated designs is. The applicability of these insights is, however, dependent on the set of assumptions and functional forms that is incorporated in the model. To turn the implications of the Romer (1990) model (that increased research effort raises growth) into a policy prescription is only valid if the assumptions of the model are valid. Recall that these assumptions include research spillovers that are sufficiently strong to overcome diminishing returns in the research sector, excludability that generates monopoly power for intermediate goods producers, and a characterisation of research outputs with licenses for intermediate goods that enter into final goods production.

4.2 Vertical innovation (Aghion and Howitt)

A second strand of EGT models a different pattern of innovation—one in which innovation takes the form of improvements in existing products. Innovation thus creates new products or technologies, as well as destroying the value of old products or technologies by making them redundant. These models are referred to as “vertical innovation” or “quality ladder” models. The approach is much closer in spirit to the process of “creative destruction”, which is how Schumpeter famously characterised technical progress:

> The fundamental impulse that keeps the capitalist engine in motion comes from the new consumers’ goods, the new methods of production or transportation, the new markets, the new forms of industrial organisation that capitalist enterprise creates. [The process] incessantly revolutionizes from within, incessantly destroying the old one, incessantly creating a new one. The process of Creative Destruction is the essential fact about capitalism.
>
> Schumpeter (1947), pp. 82–3.

Aghion and Howitt (1992) introduced the seminal model in this vein, which they also summarise in Aghion and Howitt (1998, Chapter 2). Unlike the model in Romer (1990), the Aghion and Howitt (1998) version of this model abstracts completely from capital accumulation. There is, however, still a spillover in the research sector, this time modelled as a positive relationship between research employment and the rate at which new innovations are made.

There are also monopoly rents generated in the intermediate goods sector, although this time they are only partially captured by the research sector.

The merits of expanding the research sector are less clear in this model than in the Romer model. Here it is possible to have too much research. Innovations are more productive than the designs that they replace, but there is a negative impact that must be taken into account—the innovation destroys the value of an existing design by superseding it. This is referred to as a "business-stealing" effect. Furthermore, product market competition is unambiguously bad because it reduces the monopoly rents which provide the rewards for research.

Jones and Williams (1999) examine a model that incorporates elements of both horizontal and vertical innovation. They argue based on empirical evidence that in practice the net real-world effect of the various forces is to yield an underprovision of research in the real world.

4.3 Heterogeneous (two-stage) innovation

Some EGT models relax the assumption that research is homogeneous by acknowledging the distinction between fundamental research and more applied development activities. They start with the fact that:

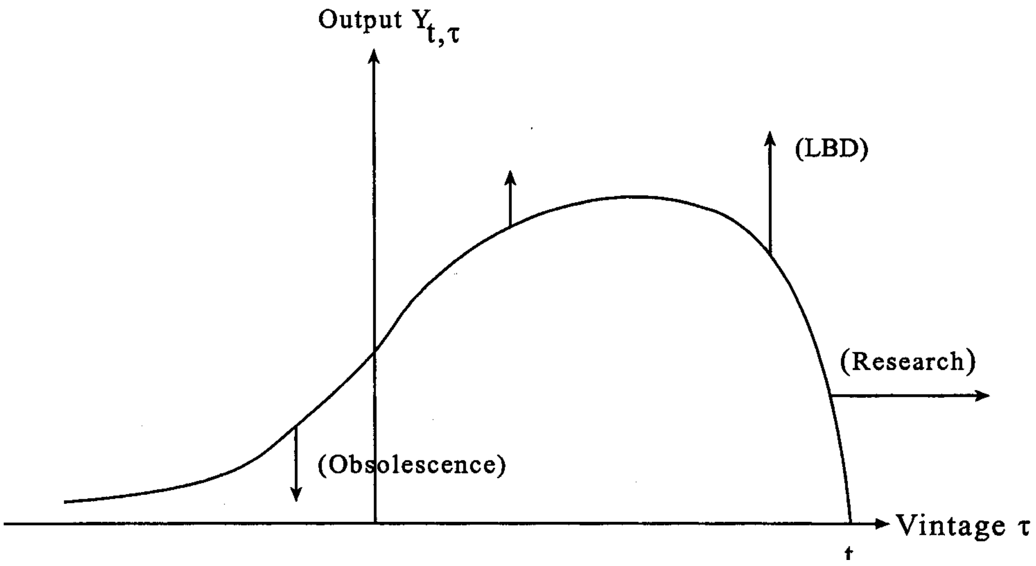
> [f]undamental and secondary research are complementary activities; in order to exploit fully the fundamental knowledge generated by R&D, a firm must put that knowledge into practice and resolve the unexpected problems and opportunities that only experience can reveal.
>
> Aghion and Howitt (1998), p. 173.

In these models, growth is enhanced by the right mix of fundamental and secondary research, and the age of intermediate goods becomes important. Fundamental research produces new intermediate goods that have the *potential* to be more productive than the previously developed intermediate goods. The value of the research output is zero, however, until there is a secondary innovation that applies the new knowledge.

Secondary innovations are achieved as a result of learning by doing. The general knowledge that is built up by the combined effect of fundamental and secondary innovations increases the value of subsequent research of both types.

Figure 2 summarises the process graphically. The rightmost edge of the curve (the “cutting edge”) represents the most recent vintage of research output, which contributes nothing to output. To the left of this are previous periods’ research outputs, which now make a positive contribution to output as a result of learning by doing (LBD). For old enough research outputs, the contribution to output is smaller (because recent innovations are better), and eventually obsolescence outweighs the improvements available from learning by doing.

Figure 2: Two-stage innovation



Source: Aghion and Howitt (1998), Figure 6.1, p. 177.

Adding a second type of research to EGT models introduces new issues and dynamics, and allows us to analyse a wider range of questions about patterns of growth. For instance, two-stage innovation models outline the nature of educational policy choices about the relative emphasis to be put on fundamental as opposed to applied research. Young (1992) draws a link between the rate of sectoral change and the negative impact that rapid sectoral change can have on the contribution of LBD to output growth.

4.4 Lumpy innovation (general purpose technologies)

The final strand of EGT that I will discuss relates to the fact that in most countries, growth is uneven, and appears to occur in spurts, albeit sometimes over extended periods. Aghion and Howitt (1998, Chapter 8) provide a good discussion of EGT insights into growth and cycles.

The positive scale effects that are built into EGT models would have the effect of magnifying the growth impact of temporary fluctuations. A temporary increase in output, by raising scale, would increase productivity, generating a more sustained increase in output growth. This line of reasoning has been pursued in the related field of “real business cycle” theory.

Fluctuations in growth are an implication of the vertical innovation models outlined above. The prospect of high research effort next period raises the likelihood that current research will be rendered obsolete, and reduces current research efforts.

A more significant and direct treatment of uneven growth comes from the modelling of the impact of “general purpose technologies” (GPTs). GPTs are innovations that have the potential to improve technologies in many sectors. Commonly cited examples of GPTs are computers, the steam engine, and electric dynamos. Because of the potential applicability to a wide range of firms, the appearance of GPTs raises the return to applied research (learning by doing) across the economy, at the same time as it renders many current methods obsolete. There can be a decline in growth while the system adapts to a new range of technologies. Cyclical downturns under this sort of model reflect a transition to a new, more productive, set of technologies.

5 Discussion

The range of issues to which EGT has been applied go well beyond what I have covered in the brief outline above. Aghion and Howitt (1998) discuss applications to sustainable development, market structure, inequality, eduation, and trade. The introduction to their book is brimming with excitement and confidence about the potential for EGT to shed light on many important growth-related questions in economics.

The stories that EGT theorists tell are often intuitively appealing, and there is much anecdotal and empirical support for the existence of forces such as knowledge spillovers, returns to specialisation, and monopoly rents from new ideas. Whether or not these operate in exactly the way that they are portrayed in growth models, or with enough force to completely outweigh diminishing returns, is less well established. It may be an obvious point, but it should be borne in mind that writing down a model to illustrate the operation or implications of a particular mechanism says nothing about whether the mechanism operates in the real world, or operates in the way that is modelled. Models are only as good as their assumptions, and there is a risk that a model's conclusions are little more than a rephrasing of some underlying assumptions. Models should be examined critically, especially when the underlying story is an appealing one.

> The idea of endogenous growth so captures the imagination that growth theorists often just insert favourable assumptions in an unearned way; and then when they put in their thumb and pull out the very plum they have inserted, there is a tendency to think that something has been proved.
>
> Solow (1994), p. 53.

The true test of the theories comes when implications of the model are compared with observed patterns. Cautious reviews of the empirical findings in the literature can be found in Temple (1999) and Gemmell (1999), both of which also summarise the problems of drawing causal inferences from the existing studies. Chapter 12 of Aghion and Howitt (1998) discusses and rebuts some of the main macroeconomic evidence against EGT as an explanation of sustained growth.

Jones (1995) presents a generalised version of the Romer (1990) model, relaxing the strong assumption about the strength of spillovers in the research sector. By comparing key predictions of his model with observed patterns, he concludes that it is unlikely that research spillovers are strong enough to generate sustained growth in output. They do, however, lead to a higher level of output, even though diminishing returns eventually extinguish the long-run growth impact of spillovers. Growth rates will, of course, need to be higher to reach the new steady-state income level. This transition, although temporary, may be prolonged. (In the theoretical model, growth rates get closer and closer to zero, but take forever to reach zero!) Jones (1998)[10] provides a more detailed discussion of growth "with or without scale effects".

Identifying and analysing the mechanisms by which technological change occurs is a key contribution of the EGT literature, and arguments over whether growth effects are permanent or last only decades may be of less relevance. Temple (1999, p. 152) sums up the issues as follows:

> Either growth is endogenous, or it is exogenous and level effects are large. Given the presence of large level effects, distinguishing between exogenous and endogenous growth models is not as pressing as it might seem. The important point is that policy can have a major impact on a country's level of welfare. As pointed out earlier, the debate on whether policy affects the long run growth rate or just the steady state level of income is almost impossible to resolve, and not much of practical importance will turn on it.

Aghion and Howitt (1998) discuss the implications of particular EGT models for a range of policy issues, including the design of institutions and policies—regulation, subsidies, intellectual property rights. I am not familiar enough with all of the relevant literatures to judge which policy implications are particular to the specific assumptions and models that are used, and which are general insights. It seems that many apparently strong results are subsequently weakened or even reversed as a result of relatively small changes in assumptions or model specification.

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[10] A version of this paper was published as Jones (1999).

I am sure that the ongoing debate can shed light on policy choices in many areas. Distilling the insights in any particular policy area would, however, require a careful examination of the relevant literature, which is beyond the scope of the current paper.

When applying the insights of EGT to policy issues in New Zealand, we should not ignore the fact that New Zealand is a small, open economy. Most of the discussion so far has abstracted from national boundaries, and has said nothing about implications for international differences.

Chapter 11 of Aghion and Howitt (1998) discusses the implications of combining EGT with trade theory for international flows of final goods, intermediate inputs and ideas. The analysis raises questions about the presumption in favour of free trade. Arguments can be made for industry and trade policies to encourage specialisation in sectors where there are spillovers.

Free flows of intermediate goods, or of research designs, also raise the possibilities of imitation, and of differences across countries in the relative importance of fundamental as opposed to secondary (learning by doing) innovation. Some models, such as those presented by Grossman and Helpman (1991, Chapters 11 and 12) assume that developed countries ("the north") have an advantage in fundamental research and that for less developed countries ("the south"), growth is achieved by developing secondary innovations and imitating innovations from the North.

It seems plausible in a general model of learning by doing that the scope for secondary innovation within any particular country depends on the *global* amount of fundamental research. This opens the possibility of small, open economies such as New Zealand relying on international fundamental, and possibly even secondary, research efforts, at least in some sectors. With smaller scale, scale and spillover effects may be harder to achieve, and we would need to weigh up the costs of devoting resources to less productive research against the costs of being slightly behind the "cutting edge".

Overall, the impact of EGT has been great—in increasing attention on the determinants and dynamics of discovery; in introducing new modelling approaches; and in providing a richer understanding of growth issues than is available from the earlier neoclassical literature. It has forced researchers to think rigorously about what is required to generate sustained growth, and to formalise a wide range of appealing potential explanations of growth and innovation. I am sure that EGT researchers would acknowledge that their job is not finished. Aghion and Howitt (1998, pp. 65–67) catalogue several of the major shortcomings and limitations of EGT. These include the ability to fully account for: long term structural shifts; heterogeneous knowledge; learning and experimentation; institutions and transactions costs; and the political economy of innovation. Most of the subsequent discussions in their book present what they variously refer to as "first efforts" or "preliminary attempts" to fill these gaps. Only history will tell whether or at what point the growth of EGT will succumb to diminishing returns.

5.1 Key points

I will close with a list of the key insights about the contribution of EGT that I have tried to convey in the paper.

- Factor accumulation and innovation both matter for growth.
- Diminishing returns can extinguish growth.
- Models are only as good as their assumptions.
- All growth models assume that *something* can grow without bound.
- Ideas and knowledge are obvious candidates for sources of spillovers and scale effects (due to non-rivalry and partial excludability).
- EGT is important because of modelling methods as well as because of specific growth insights.
- Modelling a mechanism doesn't make it true.
    - It may or may not occur.
    - It may or may not be as strong as in the model.
- Level effects may be good enough.

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