PART TWO

This is in Five Chapters and has the objectives:

- To define the main building blocks of the main theories of economic growth and development and explain how economic theorizing about growth has evolved (Ch. 6)
- To explain the neoclassical theories of growth in their various manifestations and demonstrate the limitations of such approaches to explain real world development (Ch. 7)
- To present a generalised model (the “AK” model) that avoids the diminishing returns that characterise the classical and neo-classical approaches (Ch 8).
- To introduce various economic approaches that show consistency with the general structure of the AK model and use these to illustrate some of the greater policy richness that modern growth theory can embrace.(also Ch. 8)
- To explicitly introduce the economic analysis of technical and technological change and illustrate how this can enrich further the insights from the earlier models (Ch 9).
- To offer a quick overview of the key messages that we can distil from this large and complex literature and carry forward to later parts of the book

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CHAPTER 6

THE THEORY OF ECONOMIC GROWTH- BUILDING BLOCKS AND ASSUMPTIONS

"Newton's laws (the three laws of motion) explained so many things – the slosh and roll of ocean tides, the motions of the planets, why cannonballs trace a particular trajectory before thudding back to earth, why we aren't flung into space as the planet spins beneath us at hundreds of kilometres per hour, and why the earth is not quite round." Bill Bryson commenting on Sir Isaac Newtons' Principia Mathematica published in 1666

6.1 Introduction

Growth (of income) as we saw in the earlier chapters is a key central component of economic development. Thus a *theory of economic growth* serves as the hard analytical core of development economics. The subject needs – and has long sought - an agreed core of ideas to serve as the point of reference for assessing ideas and policies to promote faster growth - and all the desirable things such as poverty reduction that seem to go with that. Ideally we need to establish something analogous to the basic physical laws of motion that explain the movements of the planets and of atomic particles in an integrated manner.

But physics and economics are not really alike in this regard and the economists' unanimity about what drives growth is far less secure than the confidence that physicists have enjoyed for over three centuries about the basic laws of motion as expounded by Sir Isacc Newton. Indeed, until about 20 years ago, the literature of "economic growth" and the literature of "development economics" inhabited two rather different domains with only relatively little intersection. Most policy-makers in developing countries and in the international donor agencies did not regard formal growth theory, as the essential analytical core of their ideas. Many regarded and still regard the writings of mathematical growth theorists as far too aggregative and over-simplified to address the real practical problems with which they deal on a daily basis. Academic growth theorists for their part have seen the implicit theories underlying much development policy-making as lacking in rigour and so likely to lead to unpredictable and misleading results.

At the present time the process of unification of the theoretical rigour of the growth theorists with the practical economic concerns of the more practically-oriented development economist is at an interesting stage but is still incomplete. Although it has made great strides in the past 20 years, *the definitive theory* of economic growth still awaits discovery and certainly remains contentious. We do not yet have the economics equivalent of the precise theories articulated by Newton and Einstein.
In its absence, Part II of the book sets out a number of important and competing theories; assesses their strengths and weaknesses and considers their implications for practical policy in particular countries. By the end of Part II and especially in Chapters 8 and 9 we will have established a solid enough basis to see various important links between theory and practical policy. This present Chapter

- Defines the basic building blocks used in most growth models

- Explains the core assumptions that growth theorists have used and comments on the inherent problems associated with these
- Briefly reviews the evolution of the mainstream models of growth associated with the classical, neo-classical, Harrod-Domar traditions, and the role of the newer endogenous growth models
- Considers certain things that might have been expected but never actually happened in real world development.

Chapter 7 concentrates on the models that have characterised the majority of the literature through the mid-1980s. Chapter 8 exemplifies the newer, and more practically useful, endogenous growth models that have become far more prominent since the mid-1980s. Chapter 9 finally probes in more depth on the topic of technology and its role in growth. Chapter 10 identifies a few of the key issues to carry over into Parts III and IV of the book.

6.2 Building Blocks

The basic structure of relationships implied by all the main growth theories to be considered below is represented schematically in Figure 6.1 The arrows show the influences on GDP growth of the two generic influences namely:

i. the availability of resources and the accumulation over time (of land, labour, capital and technology) and

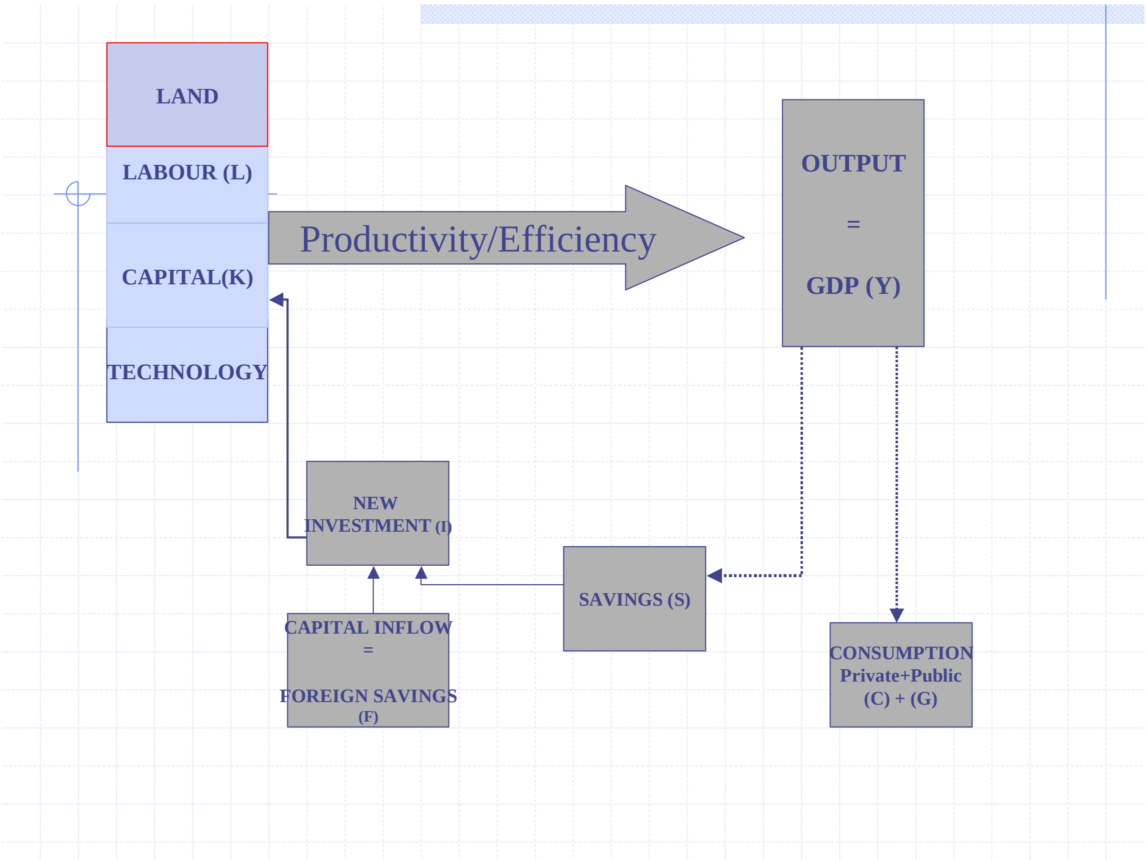
ii. the productivity/efficiency with which these resources of land, labour, capital and technology are used. The greater the efficiency, or productivity, of the four types of resources, the greater will be the output achieved from any given volume of resource accumulation.

The diagram is intentionally vague about where in the list of the four factors of production we should include the *human capital* of the labour force derived from its education training and health status as discussed in the previous chapter. Should it be seen as part of capital (in which case labour needs to be thought of merely as the head-count of workers) or as part of labour (in which case labour incorporates the education, skills and health condition of the work force and is not merely a head count of workers). As we go through the models we will see that earlier theories tended to do the former and later models to adopt a more realistic view of what “labour” actually comprises.

The diagram is similarly vague about what we mean by the factor of production referred to as *“technology”*. We will be elaborating much more on this difficult point in what follows. The greater precision to the meaning and role of technology is an important aspect of the more policy-relevant literature of the past two decades.

Economists in the past have differed over the emphasis attaching to each of the four types of factor that generate growth. Land, for example, played a considerably greater role in the classical growth models than it does in the neo-classical models. This was for very good reasons. In the days of Adam Smith and Thomas Malthus, land was indeed the dominant factor of production and also the main source of livelihoods for a majority of the population. The British economic historians Phyllis Dean, W.A. Cole and Jack Revell, have together provided data on the stocks of wealth in the UK from the C17th to the C20th. These data show that the proportion of total wealth accounted for by land fell from 64% at the end of the C17th to 55% by the time of Malthus at the end of the C18th. By the second part of the C20th land accounted for less than 3% of total UK wealth!

Figure 6.1: The Building Blocks of Growth Theory



6.3 Assumptions – Building Blocks and Models

So well so good. But converting this simple cause-effect diagram 6.1 into more rigorous mathematical formulations of growth requires some fairly tricky footwork. Specifically, most theories of growth require three connected but controversial assumptions namely:

- that “output” can be analysed as a single aggregate commodity.
- that the four types of resources listed in Figure 6.1 are also analytically distinguishable one from another. In other words it requires the assumption that there are unique *aggregates* to which we can attach the labels “land”, “labour”, “capital” and “technology”, and
- that the *accumulation* of any of the resources can indeed be distinguished from the *efficiency* with which those resources are turned into output.

Let us examine some of these assumptions in more detail

Aggregation of Output

A moments reflection on specific examples shows how problematic is this assumption. We know for sure that the food that we eat is different from the clothes that we wear and from the machines of various complexity that are needed for all forms of production of both physical commodities and many services. So there is clearly a gross over-simplification involved in the assumption that growth can be represented in terms of what is happening to a *single homogenous commodity*. This would only be truly credible if all demands for goods and services grew over time (in both demand and supply) at identical rates. We already know from our brief discussion about Engels curves and the ideas about structural change from Colin Clark that this is not historically the case. Particularly important to the assumption of aggregate output is the idea that the single commodity can serve as both a consumption and as a capital good. This too is a serious over-simplification of reality.

Four Unique and Aggregated Factors of Production

Consider first the example of *capital*. We know from direct experience that each type of capital has its own specific functions and that there are very many different types to consider. The machine tools and CAD-CAM machines of the modern manufacturing sector are easily distinguished from the tractors, ploughs and spades of agriculture, and these in turn are quite different from the ovens, cooking pans, school buildings and blackboards used in some service industries. We also know already from our discussion in Chapter 5 that an absolutely central feature of economic development over time, is a radical shift in the *mix* of the different economic activities (remember also the third building block from the bare-bones model of Ch.2). Different products and sectors are known to wax or wane in their relative importance. But so too is the mix of production activities *within* each sector.

As a result the *specific* machines that the economy as a whole employs, is also subject to upheaval as an inevitable feature of development – the modernisation of agriculture and the gradual substitution of mechanical equipment for hand tools is one obvious example from many.

In short the various things that we think of as “capital” are not really sufficiently alike for them to be meaningfully aggregated together. Nor are these types of capital likely to retain the same relativities of price and rates of return during the course of a country’s development to truly justify adding them together and treating them as a single aggregate. But much of the growth theory considered below, pragmatically needs to do just that thereby treating “capital” as a single homogenous aggregate associated with a *single* rate of return.

Critics such as Nobel Laureate, Sir John Hicks [1969] long ago argued that this gives the game away as far as analysing growth is concerned. How can you truly analyse the turmoil of a real growth process in a real country if the *differential rates of return* that are essential to drive real economies into new types of activity and new ways of doing old activities are assumed not to exist! By working with a single aggregate called “capital” economists are essentially throwing away the engine that drives growth in the real world.

A similar problem exists with *labour*. Labour in reality is a useful resource in production in part because of the *innate* abilities with which each of us individually enters the world . But as we saw in Chapter 5 the major part of the benefits of the labour input into production accrues from the different *acquired* abilities that people achieve through their education, training and their experience. It is blindingly obvious that aggregating all labour together and treating it as a homogenous mass is an exercise of limited value if we want to derive robust measures about how the accumulation of labour influences an economy's growth over time (as in Figure 6.1). The aggregation of the time input of an unskilled agricultural labourer with that of a skilled engineer or nuclear physicist makes little sense in economic terms. But that again is what mainstream growth theory pragmatically needs to do. The turmoil involved in real world economies associated with people – rich or poor – seeking better education, improved health and more responsible, better-paid jobs is essentially assumed away by the abstraction of an *aggregate* labour force. Hence another key part of the engine of growth in the real world is assumed away.

A comment from one of the pioneers of our subject namely Theodore Schultz (!981) can help to show the relevance of this point to low-income countries. He writes:

"People in low-income countries are not indifferent to opportunities that offer worthwhile incentives to undertake investment in their own human capital. The belief that they are listless, passive creatures of habit, unperceptive of new opportunities is not consistent with their behaviour. They are in fact, calculating human agents. Although they are poor, they tend to be efficient in allocating their meagre resources with a fine regard to marginal costs and benefits" (Investing in People, pp 16)

Accumulation versus Efficiency

What though of the third of the assumptions listed earlier in this sub-section? Can the concepts of "accumulation" and "efficiency" really be uniquely separated as our Diagram suggests? Our critical comments on the practice of aggregating both capital and labour into single aggregates also suggest reasons why "accumulation" and "efficiency" are not the tidy distinct concepts that may appear.

To explain this, imagine an economy in some start year "t_o" (South Korea perhaps in 1950) having very primitive and limited capital stocks and a very poorly educated, unhealthy and poorly nourished labour force. Then run this economy on for a period of, say, 50 years during which time the economy accumulates capital of increasing sophistication and also manages to improve both the health and the educational standards of its work-force. (This is largely what most real world economies have done since 1950 – see Ch.4). An accurate assessment of the contribution of labour to the growth of that economy in the 50 elapsed years would require the data on numbers employed to be adjusted for the gradual but significant increase in labour *quality* that our example assumes. In the absence of such an adjustment, the assessment would be likely to understate seriously the contribution of labour to growth. Standard methods of growth accounting (as described in Ch.7) would most likely assign the contribution coming from the improved health and education of the labour force into another and residual category such as "technology".

Similarly in that same economy, a simple adding up of the machinery accumulated in that 50 year period would lead to an understatement of the growth contribution of "capital". The benefits that were associated in reality with the greater sophistication of the *newer* machinery might easily be attributed, in growth accounting, to one of the non-capital categories of input or to the "efficiency" factor.

The reader may at this point begin to see why we have been a bit tardy in saying what exactly we mean by technology in Figure 6.1. They are asked to await Chapters 8 and 9 to receive real satisfaction on this point.

The main conclusion from this present discussion is that the apparently watertight aggregates – output, labour, land, capital and technology - as well as the growth theory concepts of accumulation and efficiency, are in reality rather indistinct and even interchangeable. A dedicated "human capital" view of the growth process for example would document the many and various ways in which "labour" had enhanced its quality over the 50 years and so made a contribution to development far greater than any simple head count of workers would suggest. The dynamic that drives real world growth in any country comes from the many millions of individuals responding to the incentives to improve the situation of themselves and their children. The useful results obtained from theories of growth considered in this and the next chapter are only possible if we allow a degree of abstraction from this type of reality.

6.4 The Evolution of Ideas

Let's lay out the route map in broad outline before embarking on the main technical materials of Part II. This can be done by noting that the mainstream economic theorizing about growth has evolved through just *five main stages* as summarised below. These stages had quite a few things in common. Most mainstream models have built stories of the growth process from the ***supply side***. That is to say the growth of output in the models has been driven by the ability of the economy to produce/supply more output over time. All economists in this tradition have recognised that the economic growth depends in turn on (a) the *accumulation* of resources and (b) the *efficiency* with which resources are used. They have differed however, about which resources are the most significant; how exactly greater efficiency might be achieved; and what are the main constraining forces likely to hold back resource accumulation and improved efficiency.

The *five* main stages of evolution of this tradition are broadly as follows:

1. the classical tradition attributable to Adam Smith and later Malthus (1798), Ricardo (1817), Mill (1848) and Marx (1848) recognised the important role of all three main factors of production – land, labour and capital. Smith in particular recognised that it was both the quality/productivity as well as the quantity of these three factors that led to growth. Hence any policies that promoted better quality – e.g. public support for education – were also important in the growth equation. But since land and labour faced natural limits on their supply, the real drivers of growth were seen to be the *quantity* of capital accumulation and the gradually improving *quality* of labour (e.g. better education and health), land and capital itself.

   The various protagonists as listed above came out with very different views about the long-term prospects for the economy. Malthus' particular angle was that growth would be limited by the relatively slow pace at which the quantity and quality of land (and so food production) could rise. (Remember how important was production based on land at the time when he wrote). Periods of above average growth would merely stimulate rising numbers of mouths to feed and so a moderation of income growth per capita. Marx saw the limits to growth quite differently and in terms of the inexorable downward pressures on rates of capitalist profit. These pressures came about through a relentless cycle of higher wage rates, more labour-displacing investment designed to sustain profitability, a smaller base to generate surplus labour and so an even more frenzied competition for that "surplus" among the capitalist classes. Ricardo saw problems with an increasing proportion of total income becoming concentrated on land and landowners as "rent". This was largely at the expense of the capitalists – the group that he saw as responsible for the innovations and investments that pushed economic development forward.

2. The early 20th Century literature attributable to early "neo-classical" economists such as Alfred Marshall, and also to Joseph Schumpeter and John Maynard Keynes essentially introduced a fourth factor of production into the growth calculus namely *technological and organisational innovation*. This fourth factor had the effect, *inter ali*a, of rescuing capitalism from the ever-downward trend of profits anticipated by Karl Marx and also showing (contrary to Ricardo) that profits could arise and be sustained long-term even in a very competitive capitalist economy. The enhanced theory could also be interpreted as saying something more specific about how the *quality* improvements in the labour input – stressed by some of the classical economists - might be achieved. Technological innovation was also, and largely remains, the only real game in town when it came to explaining the huge shift in global levels of prosperity from around 1800 after several millennia during which the average citizen of the world had a very static and modest standard of living (see data in Chapter 4 above).

3. These ideas began to get codified mathematically only in the late 1940s. Unfortunately this process of codification initially abstracted from some of the important insights of the earlier and less mathematical contributions. Specifically, the so-called Harrod-Domar model Domar [1946] and Harrod [1948] respectively, showed formally that the growth rate of *total* income was dependent on just three parameters. The first was the savings rate of an economy that determined its ability to accumulate capital. The second was a measure of efficiency namely the ratio of total capital to output (i.e. the capital:output ratio) that was assumed constant). The third was the rate at which existing capital depreciated – so necessitating part of current saving being diverted merely to replace the worn out machines. The H-D growth rate of total income interacted with the growth rate of population that was a fourth exogenously determined parameter (determined by biological rather than economic factors). The growth rates of income and population interacted together to determine the growth rate of *income per capita*.

   Although very over-simplified, the textbook representations of this model *have had an impact on the practical business of economic policy-making for developing countries since World-War 2 wholly out of proportions to its true merits*. Some examples and reasons for this are given in Chapter 8.

4. This is in spite of the fact that the *mathematical and logical* shortcomings of the H-D model were spotted quite quickly and especially in papers by Solow [1956] and Swan [1956]. Their *practical* shortcomings as descriptors of the realities of low-income countries were partly addressed by the labour-surplus models pioneered in the mid-1950s by W. Arthur Lewis in particular (Lewis, 1954). As regards the mathematical shortcomings, Solow et al noted that since the growth rates of total income and population in the H-D model were determined through two quite separate processes, the model in technical terms was over-identified – there were too many independent parameters to tie down which of the two growth rates would be the dominant one: that for population growth or that for total income? The Solow/Swan innovation in the so-called "neo-classical growth model" was to fix this problem by making the

capital:output ratio endogenous. So, for example, if the labour force (as determined by the population growth rate) was rising at a faster rate than capital (as determined by the savings rate), then capital would become *relatively* more scarce and less of it would be used in production relative to labour. As a result the long-term ratios of the capital input to the labour input would fall as would the capital to output ratio (this is fully explained in Chapter 7.

This neo-classical solution was very neat but notice two things. First, in common with the H-D model it had resolved the mathematical weaknesses only by sacrificing some at least of the rich details of growth processes analysed in depth by earlier economists such as Smith, Marx, and Schumpeter and later ones such as Lewis. In particular, many of the more obvious links with policy were largely ignored in the modelling – e.g. trade policies as in Adam Smith and the rural-urban mix as in Lewis.. Second, the mathematical trick needed to make the two growth rates equal created a new problem that took the model wholly off the rails in terms of compliance with the known historical facts. (ie. the stylised facts elaborated in Chapter 5). In particular, if total income and population were to grow in the long run at the same rates, then income per capita would be have to be *constant* in the long-run! We know quite well from the large historical evidence summarised in Chapter 4, that this is not the case: people and countries generally do achieve higher income over time. Solow knew it too and rescued the N-C model by a further device of adding a fifth growth-determining parameter. This was the rate of technical progress – also exogenously determined. Technical progress was modelled as a factor that raised the efficiency of the labour input by a regular (e.g. annual) amount. Hence its inclusion in the model ensured that the growth of income per capita would also occur at the rate of *exogenous* technical progress.

The Solow/Swan model ruled the roost with some authority for around 30 years – the mid-1950s to the mid-1980s. During this period it co-existed in the textbooks somewhat uneasily with models in a more classical tradition such as that of Lewis. But notwithstanding its considerable intellectual power and elegance, it never cut too much ice with hard-pressed practitioners. They tended to rely, if they relied on theory at all on the messier models developed by authors such as Paul Rosenstein-Rodan, Ragnar Nurkse and Albert Hirschman which offered strong stories about the need for active government intervention in development.

It is easy to see why practitioners drew little of use to them from the Solow model. The constant rate of technical progress was the critical influence on living standards (income per capita) in the model but the model itself offered no explanation of the economic influences on that rate of technical progress. This was often taken to mean *either* that there was one single global rate of TP with incomes per capita in all countries therefore likely to converge to the same level. This high tendency for income convergence left little role *for policy-makers in this case – just wait for this egalitarian world to appear!* Or, it meant that there were many different rates of TP across different countries. *Not much of a guide to policy here either since the theory offered no explanation of why those rates might differ!*

5. The escape from this dilemma has come with the more recent models of growth that show how the technical progress actually achieved by any country

or group of countries may be *endogenous* and so explicable in terms of a variety of economic influences. This new literature is widely assumed to have been kicked off by a much cited article by Paul Romer in the *Journal of Political Economy* in 1986: Romer [1986]. In fact elements of the same ideas showed up much earlier in, for example the work of Kenneth Arrow on "learning-by-doing" more than a quarter of a century earlier Arrow [1962]. Nonetheless as one authority put it – this new approach due to Romer and others "throws all windows wide open". (Gylafason [1999]). Certainly as we will see in Chapter 7, the insights from the new *endogenous* growth theory provides economists with an entrée more rigorously to link factors such as trade reform, education policy, taxation policy and a wide range of real-world policies to economic growth. So in principle at least this fifth stage in the evolution of the ideas of growth theory turns the wheel full circle and brings some of the issues of practical political economy considered by the classical economists back into the arena of debate. The difference is that this can now be done with more rigour than was applied by the C18th and C19th writers. We will see several specific examples in Chs 8 and 9. However, radical economists argue that the new approaches still fail to capture the political realities and divisions of the real world and also lack the historical and country-specific depth of older but less formal "theories". (see for example Jomo and Fine [2006]. In this very real sense the jury is till out and the unified model that would parallel the Newtonian rules about the planets is still awaited

6.5 The Paradox of Diminishing Returns

The Role of Diminishing Returns

It is significant that there are certain things that generally did ***not*** happen as countries developed even though economic theory seems to suggest that they would. As in the Conan-Doyle novel quite a number of dogs failed to bark in the night! Explaining this requires us to probe more closely into the economist's concept of Diminishing Returns.

The Law of Diminishing Returns (LDR) is one of the oldest and most important postulates in Economics. In short, this law states that, increasing one input into production while keeping all other inputs constant results in a *decreasing* marginal impact on output. This law has important implications for growth. Specifically, If growth requires the expansion of two or more factors in broadly constant proportions[1], but one factor is relatively fixed in supply (i.e. it cannot be accumulated), then growth itself will be limited. This point was first stressed by the classical economists who applied it mainly to land - Thomas Malthus (1798) and David Ricardo (1817). They argued that, because land expansion is subject to physical limits, any growth of the labour force implies a more intensive use of land, leading to a *decline* in labour productivity and wages. At some stage wages will fall below a given subsistence level, and then both population and output will stop growing. This theory is briefly and more formally described in Box 7.1 in Ch..7.

The combination of the LDR with the Malthusian/Ricardian ideas about the fixed supply of land predicts the eventual stagnation of output and wages at the subsistence level. But this has definitely *not* been one of the facts of real world

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[1] and especially if the neo-classical production function involves Constant Returns to Scale (CRS).

development even in most poor countries (see the data in Ch. 4). The reason why that particular dog did not bark in the night (as later growth models have shown) is that the diminishing returns to the fixed factor (land in this case) have invariably been neutralised by the rapid accumulation of ***other factors*** such as capital and technology that are not fixed in supply.

Notice this is what has happened in most real world experience. Increasing capital intensity in farming combined with technological innovations such as hybrid cereals, chemical fertilisation, and intensive horticulture have kept diminishing returns to land at bay. There are dramatic examples of this – United States corn production for example virtually tripled between 1932 and 1979 even though the acreage harvested by the Americans was significantly lower in 1979 than it had been 47 years earlier! (Schultz [1981 pg 7).

But we need not stop the analysis there. Even when there are *two* factors and *neither* is fixed in supply in the way that land is, *diminishing returns can still prevent either factor from being the critical determinant of long-term growth*. For example in the neo-classical model, the two factors of production doing most of the work are labour and capital (we will see this formally in Ch. 7). Of these two, capital is the factor most amenable to unconstrained accumulation over time. But the LDR ensures that as more and more capital is accumulated, the extra output produced by each successive (marginal) unit of capital will fall. So although the rapid accumulation of capital can enable output (and incomes) to grow faster than population growth (i.e. the ratio of capital to labour can increase), this can only be a temporary situation. Eventually the slowing down of output growth, caused by diminishing returns to capital, will bring output growth into equality with the growth of population and thereafter output per capita and income per capita will be stagnant.

It is a striking logic from this analysis that *rapid capital accumulation in itself cannot generate ongoing and sustainable increases in income per capita.* If the large gaps in living standards between rich and poor countries identified in Ch. 3 are to be closed, poor countries need to accumulate factors of production *additional* to capital to ensure that increases in living standards are sustainable. This conclusion has important implications for many aspects of the development debate and particularly the debate about aid-effectiveness. Aid lobbies are wrong to see increased volumes of foreign aid as the unique route to achieve growth in poor economies.

Notice the parallelism here between the problems of the classical and the neo-classical models. In the models of Malthus and Ricardo, the introduction of an additional non-fixed factor of production namely physical capital relieves the stagnation of output per capita that is predicted to occur because of the fixed supply of land. The stagnation of output per capita in the neo-classical model can be similarly relieved by the introduction of some other non-fixed factor such as technological progress or human capital.

The recognition that these *other factors* are needed for sustainable growth to support the growth of capital brings us to the heart of the challenge of truly understanding the nature of growth and development. A reference back to Figure 6.1 shows that we can look for these *other factors* either in the input labelled "technology" or in the "quality" component of the "labour" input. Successful real world development has normally been characterised by both of these *other factors* becoming more plentifully available: that has been a important feature of real world development.

Successful countries have been characterised by the gradual accretion over time of far greater knowledge and skills amongst their labour force. This among other things has included improved organisational skills that then makes possible and justifies the greater utilisation of the more advanced technologies that have become increasingly available. (an obvious point perhaps – no organisation or country can operate sophisticated machinery with labour that has only minimal education). The synergy between these various drivers of growth are capable in turn of offsetting the diminishing returns that seem to be associated with non-expanding resources such as land, as well as those associated with accumulating resources such as capital. But if these other factors of knowledge, skills, technology are **not** being accumulated for whatever reason, then no amount of capital can sustainably drive growth forward.

We now move on to look in more detail at particular models of growth.

CHAPTER 7. THE NEO-CLASSICAL GROWTH MODEL

*"I conclude that there are elements of automaticity built into the nature of the growth process; but there are also a succession of challenges which must be overcome as growth unfolds, whose solutions are not automotic, as the irregularities of growth – in the past and present – attest" ....*Walt Rostow*, The Stages of Economic Growth,* 1971,pg 178

7.1. The basic Solow Model

7.1.1. Introduction

Robert Solow developed his famous model in 1956 with the main purpose being a better understanding of the growth performance of the US economy. He was particularly interested in explaining the long-run tendency noted in our Chapter 5 for output and capital to both grow at the same rates – a statistical regularity first documented for the U.S. by Simon Kuznets. The main characteristic of the Solow model is the emphases on *capital* as the main engine of growth. In contrast to other inputs, such as land or labour, capital can be produced and accumulated. Installing new capital, firms can avoid the decline in labour productivity that would be otherwise caused by the expansion of the labour force, as implied by the Law of Diminishing Returns[2].

7.1.2. The main assumptions

Consider a closed economy with no government where all firms produce a single homogeneous good, *Y*, using an input that evolves at an exogenous rate (Labour, *N*) and an input that can be accumulated (Capital, *K*). Population and the labour force are the same. Inputs are hired from households, who are also the owners of the firms and the consumers of this economy. Households save a constant fraction of their income, *s*, to buy new capital. The capital stock depreciates at a constant rate, *δ.* We further assume perfect competition in factor markets and flexible prices, so that full employment holds at each moment in time.

The production function is assumed to take the following form[3]:

$$Y_t = A_t K_t^{\beta} N_t^{1-\beta} \qquad 0 < \beta < 1 \qquad (6.3.1)$$

This production function exhibits constant returns to scale (CRS) (in labour and capital) and decreasing marginal returns to each of those inputs (i.e. the LDR applies to each of them)[4]. The parameter *A* stands for the level of technology. Throughout this section it will be assumed that the level of technology is constant:

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[2] if some essential inputs, like land, cannot be accumulated, the possibility of expanding production by increasing the labour force is limited. This limitation is further explored in Box 7.3.1.

[3] The theories explored in this chapter are consistent with less restrictive technologies, but we stick with the Cobb-Douglas case as in Equation 6.3.1, for simplicity.

[4] CRS means in plain language that if one increases the use of all inputs in the same proportion, output will rise in that proportion. The CRS property can easily be checked in

$$A_t = A \qquad (6.3.2)$$

Households use their income either for consumption expenditures or for savings. Formally:

$$Y_t = C_t + S_t \qquad (6.3.3)$$

where, *C* and *S* denote aggregate consumption and aggregate savings, respectively. Given the constant saving rate, *s*, the flow equilibrium of this economy can be described by[5]:

$$S_t = sY_t = I_t \qquad (6.3.4)$$

where *I* denotes gross investment. With the passage of time, capital wears out or becomes obsolete. This process is called *depreciation* and implies that additional investment is needed every year to replace the depreciated equipment. The change in the capital stock (net investment) is thus equal to gross investment minus depreciation. The later is assumed to be proportional to the existing capital stock:

$$\dot{K}_t = I_t - \delta K_t \qquad (6.3.5)$$

Population is assumed to grow at a constant and exogenous rate *n*:

$$n = \dot{N}_t / N_t \qquad (6.3.6)$$

The above equations describe the basic Solow model.

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equation (6.3.1): if one multiplies the use of both inputs by a positive amount, say k, then output will rise in that same proportion: $\kappa Y = B(\kappa T)^{\beta} (\kappa N)^{1-\beta}$.

[5] Equation (6.3.4) implicitly postulates that the price of the capital good is the same as the price of output. Think, for example, that the only output in this economy were potatoes: potatoes can be either consumed or planted (invested) to grow more potatoes. Things would be slightly different if total investment included a plough. In that case, a given amount of saved output (potatoes) would translate into more or less capital accumulation (ploughs), depending on how many potatoes would be necessary to buy a plough. Analytically, the difference is that the saving rate in equation (6.3.4) should be divided by the relative price of capital. We will return to this important issue in Chapter 7.

7.1.3 Factor prices and factor income shares

From the twin assumptions of profit maximisation and perfect competition in factor markets, it follows that the prices of the two factors (wages in the case of labour and the "user cost", in the case of capital) will be equal to their respective marginal productivities:

$$w_t = (1-\beta)\frac{Y_t}{N_t} \qquad (6.3.8)$$

$$r_t + \delta = \beta\frac{Y_t}{K_t} \qquad (6.3.9)$$

In (6.3.8), *w* is the real wage rate, namely the cost of a unit of labour. In (6.3.9), *r* denotes the real interest rate on capital and δ is the rate of depreciation of the capital stock (notice that the "user cost" of capital, that is, the cost of renting one unit of capital for one unit of time, is the sum of these two terms).

Equations (6.3.8) and (6.3.9) also imply that the factor income shares, namely $(r+\delta)K/Y$ and wN/Y are constant and equal to β and $1-\beta$, respectively. That is, even though the quantities of capital and labour may vary, changes in the wage rate and in the user cost of capital will be such that the shares of national income paid out to each factor of production remain constant. This is a direct implication of using the Cobb- Douglas production function. Nonetheless this is a reasonable propsition since, as we saw in Chapter 5, constant factor shares is in accordance to the stylised historical facts, as listed there.

7.1.4. The Fundamental Dynamic Equation

To understand how the model works, note that the main determinants of output, *A*, *N* and *K* are given at each moment in time. This means that, in the absence of major shocks that alter the size of the population or of the capital stock (e.g, a destructive earthquake damaging physical assets or a plague killing humans), the output level will be pre-determined. This does not mean that output will be constant. Since population grows continuously, the output level will also evolve continuously.

Since we are trying to establish how output growth affects the well-being of the average person, the variable we are mainly interested in is per capita output. Dividing the production function (6.3.1) by the size of the workforce (*N*) gives a new expression which relates per capita output to the availability of capital to the average worker:

$$y_t = Ak_t^{\beta}, \qquad (6.3.10)$$

where *y*=*Y/N* (per capita output) and *k*=*K/N* (the capital-labour ratio). Equation (6.3.10) is called the production function in the *intensive form* and stresses the role of the capital-labour ratio as a main driver of per capita income. To understand how this driver evolves over time, take its time derivative:

$$\dot{k} = \left(\frac{\dot{K}N - \dot{N}K}{N^2}\right) = \frac{\dot{K}}{N} - \frac{\dot{N}}{N}k$$

After some substitutions using (6.3.4), (6.3.5), (6.3.6) and (6.3.10), we obtain the so-called Fundamental Dynamics Equation of the Solow model:

$$\dot{k}_t = sAk_t^{\beta} - (n+\delta)k_t \qquad (6.3.11)$$

This equation states that the capital-labour ratio (i.e. the amount of capital available to each worker) increases with per capita savings ($sy = sAk_t^{\beta}$) and decreases with the depreciation rate (δ) and the population growth rate (*n*). The term ($n+\delta$) may be interpreted as the rate of "depreciation" of the two elements of the capital-labour ratio taken together: on one hand, the depreciation rate reduces *k* by causing the capital stock *K* to wear out; on the other hand, population growth results in less capital being available to each worker (this negative effect of population growth on capital per worker is called *capital dilution*). According to equation (6.3.11), whenever per capita savings exceed its depreciation the change in the capital-labour ratio is positive, and conversely.

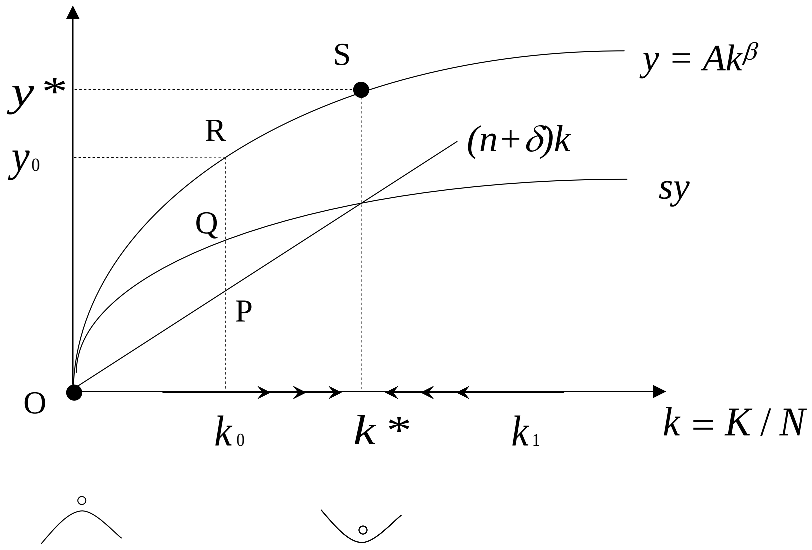
7.1.5. A graphical illustration

Figure 7.1.1 describes the dynamics and the equilibria of the model, as implied by equation (6.3.11). The uppermost curve is the production function in per capita terms (6.3.10). The figure also depicts the two terms in the right hand side of (6.3.11): per capita savings (*sy*), and the locus $(n+\delta)k$. This second locus is known as the *break-even investment line*: it denotes the exact amount of gross savings that would be necessary to offset the "depreciation" of the capital-labour ratio.

To see how the capital-labour ratio evolves over time, assume first that the economy is initially providing all its workers with an amount of capital such that the capital-labour ratio is equal to k_0. In that situation, per capita output is y_0, of which the amount *QR* is devoted to consumption and the amount k_0Q is devoted to savings. Since in this case per capita savings exceed the "break even investment" (given by k_0P), from equation (6.3.11) we know that the change in the capital-labour ratio will be positive. In words, since the production of the economy generates savings (and hence new investment) larger than the amount needed to keep the amount of capital per worker constant, the capital-labour ratio will rise.

Thus, in the moment after, the capital-labour ratio will be slightly to the right of k_0. Again, since the corresponding level of savings per capita is above the break even investment line, the capital-labour ratio will keep raising. However, we can see visually that, as *k* progressively approaches the point $k=k^*$, the distance between the two locus decreases (this is because of the LDR), implying that each progressive change in *k* results in a smaller increase in income, savings and investment.
At point $k=k^*$ the amount of savings per capita is just enough (but no more) to equip the new entrants into the labour force and to replace depreciating capital. Hence, the capital-labour ratio at that point is constant – the move to higher levels of *k* ceases. This is the *steady state* (equilibrium) of the model.

Figure 7.1.1: Dynamics and equilibria in the Solow Model



7.1.6. The steady state

Formally, the equilibria of the model are obtained by solving (6.3.11) for $\dot{k} = 0$. This equation has only two solutions, the origin (*k=0*) and:

$$k^* = \left(\frac{sA}{n+\delta}\right)^{\frac{1}{1-\beta}} . \qquad (6.3.12)$$

Since the economy will approach the steady state (6.3.12) from any departing point in its neighbourhood, this equilibrium is said to be *stable*[6]. Substituting (6.3.12) in (6.3.10), one obtains the corresponding steady state level of per capita income:

$$y^* = A^{\frac{1}{1-\beta}}\left(\frac{s}{n+\delta}\right)^{\frac{\beta}{1-\beta}} \qquad (6.3.13)$$

Equations (6.3.12) and (6.3.13) imply that the steady state levels of both capital per worker and per capita income are constant in the long run. They also imply that the steady state level of per capita income (capital per worker) depends positively on the saving rate, negatively on the depreciation rate and negatively also on the population growth rate. Intuitively, the more resources are devoted to capital accumulation and the lower is the depreciation of the capital-labour ratio, the higher will be the

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[6] We invite the reader to explain why the capital-labour ratio converges to the very same point departing from k1. Formally, the equilibrium described by k* is locally stable because the condition $\partial\dot{k}/\partial k < 0$ holds in its neighbourhood. The reader may verify that the same condition does not hold in the neighbourhood of the other steady state, k=0. The last one is an unstable equilibrium.

sustainable level of capital per worker. It is also apparent that the steady state can be shifted if there is some exogenous increase in the level of technology (i.e. a higher value for "*A*"). Any such increase raises the productivity of capital, inducing more investment and hence a higher level of capital per worker and output per worker in the steady state.

7.1.7. Solow's quest

According to equations (6.3.12) and (6.3.13), the capital-labour ratio and output per capita are both constant in the steady state. Since the labour force is growing at rate *n*, this means that in the steady state both capital and output are growing at rate *n*. Thus, the model displays the stylized fact from Simon Kuznets (and our Chapter 5) that Robert Solow wanted to explain: the long run tendency for capital and output to grow at the same rate. Note that, technically, this outcome is a direct consequence of the CRS property: if labour and capital are set to grow at rate *n*, output will also grow at rate *n*![7]

The steady state level of the average productivity of capital may be obtained dividing (6.3.12) by (6.3.13):

$$\left(\frac{Y}{K}\right)^{*}=\frac{n+\delta}{s} \qquad (6.3.15)$$

This ratio is constant, because all three parameters on the right hand side are themselves constants. In figure 7.1.1, this ratio is measured by the slope of the ray OS.

An important implication of a steady average productivity of capital is that the interest rate will also be steady (remember equation 6.3.9). This accords to another of the stylised facts mentioned in Chapter 5.

Box 7.1. What if there was no capital accumulation? The Malthus-Ricardo model of growth

The theory of economic growth as developed by the classical economists Thomas Malthus (1798) and David Ricardo (1817) was based on two key assumptions. The first is the Law of Diminishing Returns (LDR). At the time the theory was developed, the most important factor of production other than labour was land. Since – contrary to capital - land cannot be accumulated, this assumption implies a negative relationship between employment and labour productivity and wages. The second assumption is of a positive effect of the standard of living on the growth rate of the population: according to Malthus, income gains were mainly translated into raising fertility rates and from there into additional population.

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[7] The outcome that the steady state growth rate of output is equal to the growth rate of population is somehow paradoxical, because the model focus is precisely the relationship between capital accumulation and growth. That is, although capital is introduced into the model as the key driver of economic growth, in the steady state it is the exogenous rate of population growth rather than capital accumulation that drives output growth.

With these two ingredients, the classical theory of growth follows in a simple way: in the absence of technological progress, the LDR implies that a growing labour force will lead to a more intensive use of land and thereby to a decline in labour productivity and wages. As wages fall, however, population expansion decelerates. At the moment wages fall below a given "subsistence" level, both population and output will stop growing. Hence, given the land availability and the level of technology, the size of the population is self-equilibrating. Any technological progress will be offset, in the long run, by an increase in the size of the population, without any positive impact on wages.

Despite the simplicity of the Malthusian model, its predictions are consistent with the evolution of technology, population and output per capita for most of human history (see the data in Chapter 4). The Malthusian model might also be thought to provide a reasonable representation of the situation of many of the world's poorest countries. The model fails, however, to describe economic growth in industrial economies. On the one hand, its predictions concerning the relationship between population growth and per capita income no longer holds in modern societies. On the other hand, the model conflicts seriously with the stylised fact that, in the contemporary world, per capita incomes exhibit a tendency to growth, not to remain constant at a very low (subsistence) level. The Solow model, as just explained, shows that somewhat greater realism can be achieved once it is recognised that some inputs – and notably capital - can be accumulated to provide support to a rising labour force.

7.1.8. Savings, population and per capita income in the real world

An important result revealed by equation (6.3.13) is that, in countries where the saving rate is higher or where the population expands at a slower rate, the long run level of per capita output will be higher. Figures 7.1.2 and 7.1.3 check how these predictions go along with the empirical evidence. The figures plot the level of GDP per capita in 2000 against (i) gross investment as a share of GDP and (ii) population growth rates, respectively, based on a sample of 169 countries and average data over the 50 year period from 1950 to 2000.

Figure 7.1.2 suggests that the countries with the higher savings/investment rates do indeed tend to enjoy a higher income per capita. However, there is also a broad scatter of experience with some relatively poor countries achieving high rates of investment and savings (as noted also in Chapter 5). Figure 7.1.2 suggests that countries with higher population growth rates tend to be poorer than the average but again with a substantial cross-country variation of experience. This evidence is in broad accordance with the predictions of the Solow model[8].

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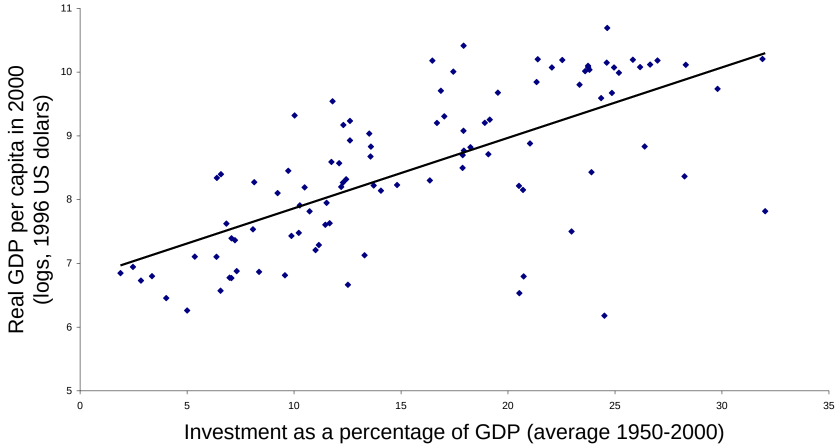
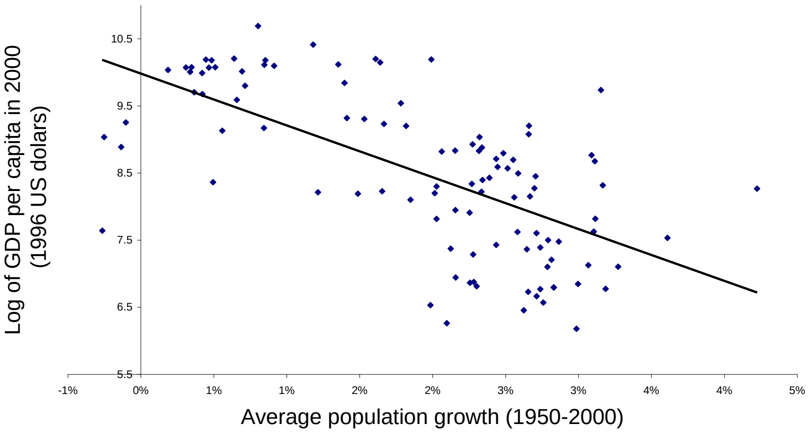
[8] Note, however, that these figures tell us nothing about the direction of causality. For example, it could be that the low rate of savings in the poorest countries was explained by the fact that people there are living at the margin of subsistence, so that they can't afford to save.

Figure 7.1.2: Per capita GDP and gross Investment 1950-2000



Source: Penn World Tables 6.1, Summers and Heston (1991).

Figure 7.1.3: Per capita GDP and population growth rates, 1950-2000



Source: Penn World Tables 6.1, Summers and Heston (1991)

7.1.9. Transition Dynamics

An important feature of the Solow model is that if the economy is not in the steady state, it will converge to the steady state. But the economy cannot jump instantaneously from one steady state to the other. Since capital accumulation at each moment in time is bounded by the availability of savings in that period, there will need to be an adjustment period during which the economy *approaches* the new steady state. Moreover, any growth of per capita income will be merely transitional, reflecting the adjustment of the model from one steady state to the other.

This point is important because in the real world any individual economy that we study in a particular year may be in that adjustment process rather than at its steady state: e.g. perhaps because the savings rate has risen recently but has not yet been reflected fully in higher per capita income. In the light of the Solow model, that economy will be experiencing a transitory growth.

We will learn more about the transition dynamics of the Solow model in the following sections.

7.1.10. What Happens if the Savings Rate Rises?

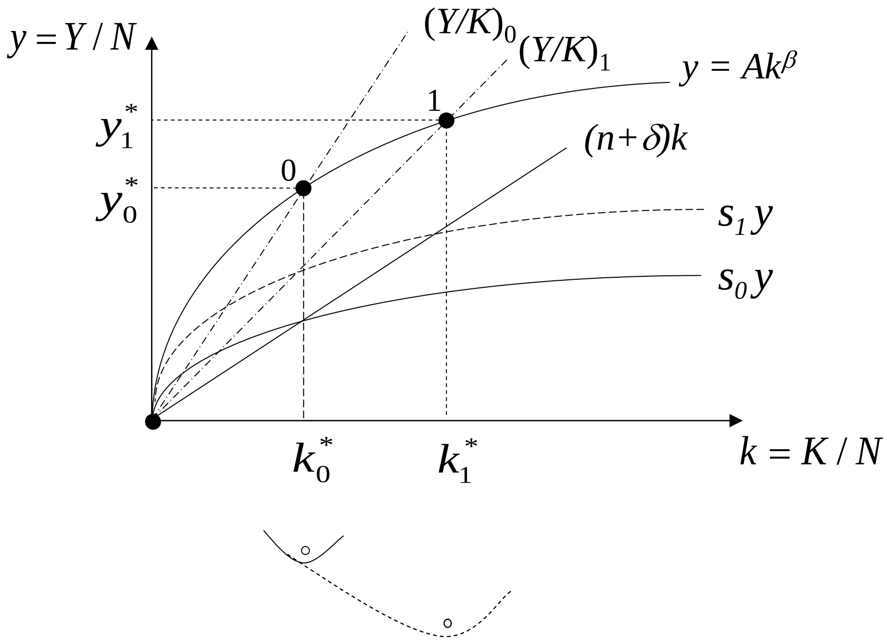
Figure 7.1.4 shows how the model adjusts to a rise in the saving rate. When the saving rate rises from s_0 to s_1, the curve measuring per capita savings shifts upwards, moving *the* steady state from k_0^* to k_1^*. Thus, the economy engages in an expansion process until the new equilibrium is met. In the long run, the rise in the saving rate produces a *level effect*: that is, in the new steady state, the economy enjoys a higher *level* of output per worker. During the transition from one steady state to the other, per capita output will rise. But, because of diminishing returns, that rise in output is no more than a *temporary* phenomenon.

The implication of what we just learned is that, in low-income countries with low savings (say 10% as in Tanzania), a growth surge could eventually be achieved by raising the saving rate (or getting permanently more aid from abroad, as an equivalent source of new capital). But, once the economy achieves a new steady state, the rate of output growth is again just equal to the rate of growth of the labour force and so per capita income is again constant. In order for a country to achieve an ongoing continuous rise in output per worker, saving rates would need to increase continuously. And clearly, there are limits in exploring this avenue: the maximum level of the savings rate observed in countries in the real world is around 30-35%. Rates much higher than this obviously eat into available consumption and so the current standard of living.

It is worth mentioning that the average productivity of capital (Y/K) in the new steady state is lower than in the old steady state. This can be checked by reference to equation (7.1.15), where the saving rate enters in the denominator, and also in figure 7.1.4, by the observation that the slope of the ray that departs from the origin and crosses the production function in point *1* is lower than the one corresponding to the ray that crosses the production function in point *0*. This also means that *the interest rate has declined*: intuitively, one consequence of there being relatively more capital per worker available in the economy is that capital is now relatively cheaper.

A different question relates to what happens to per capita consumption when the saving rate rises. At the impact, the rise in the saving rate produces a fall in per capita consumption, because more savings are drawn from a fixed amount of income. As time goes by, however, per capita income starts rising, leading to a proportional recovery of per capita consumption. Whether the second effect offsets the former or not depends on the specific values of the old and new saving rates. Section 7.2 examines this problem in greater detail.

Figure 7.1.4: A higher saving rate raises the steady state level of per capita income but only boosts growth rates temporarily



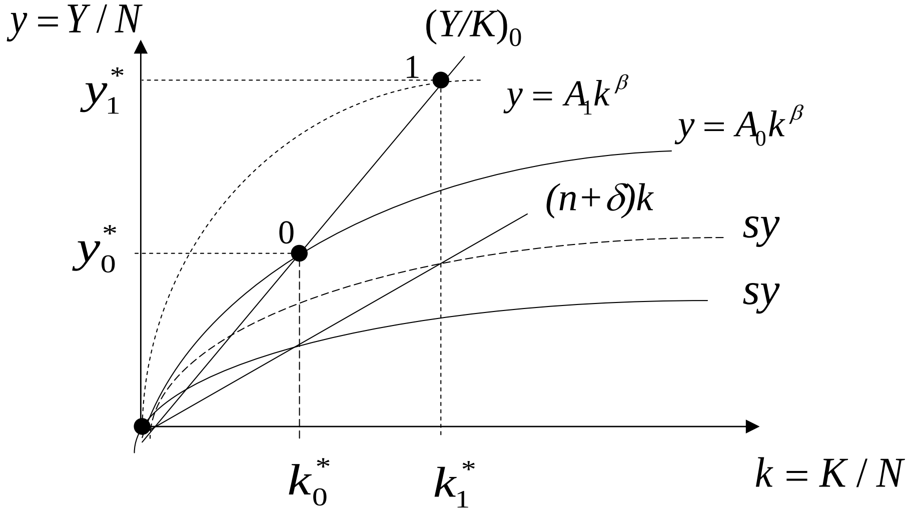
7.1.11. What Happens if Population Growth or the Depreciation rate Decline?

Parallel comments about levels and growth rates hold for changes in the rate of growth of population. By consulting equation (6.3.13) we see that a lower population growth rate will have similar effects on per capita income to those of a rise in the savings rate. In terms of the Figure 7.1.1, the difference is that the change is motivated by a downwards shift of the break-even investment line. In response, output and capital per head will increase but the growth rate of per capita output will be positive only in the transition from one steady state to the other. Once the new steady state is reached, output per capita will become constant again, with an average productivity of capital (and interest rate) lower than in the initial steady state. Similar conclusions apply for the rate of depreciation. If this were to decline, any given savings rate would be consistent with a higher ratio of capital per worker in the steady-state, so that equilibrium would move rightwards. This new equilibrium would also be associated with a higher steady state level of income per capita.

7.1.12 What happens if the level of technology improves?

Figure 7.1.5 shows how the model adjusts to a rise in the parameter describing the state of technology, *A*. When this parameter rises from A_0 to A_1, both the production function and the curve measuring per capita savings shift upwards, moving the steady state from k_0^* to k_1^*.

Figure 7.1.5; An improvement in technology raises the steady state level of per capita income but does not change the output capital ratio



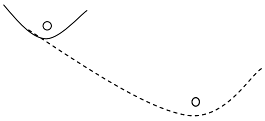
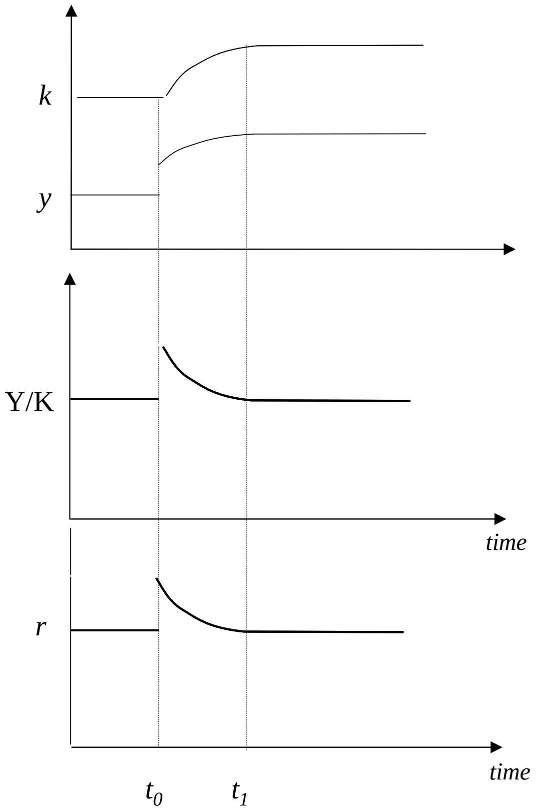


Figure 7.1.6 describes the paths of per capita output and the interest rate over time following a once-and-for-all improvement in technology. By contrast to the case of the rise in the saving rate, in this case there is an initial jump in per capita output: an increase in productivity means that a higher production level is achieved out of a given amount of inputs used. This also means that, at the time of the shock (t_0), the average productivity of capital (and the interest rate) both rise to higher levels.

Along the adjustment to the new steady state, the average productivity of capital declines again (this is because of diminishing returns) and so will the interest rate. However, in the new steady state (after t_1), the average productivity of capital is the same as in the initial steady state – you may check this by noting that the steady state level of Y/K, given by equation (6.3.15), does not depend on the technological parameter, A.

Figure 7.1.6: The time paths of per capita output, the capital–labour ratio, the output capital-ratio and the interest rate, following an improvement in technology



Box 7.2 Consumption per capita and The Golden Rule

We have seen that the steady state level of per capita *income* depends positively on the saving rate (Eq. 6.3.13). But what does this mean for the main concern of development economists namely the *consumption* level (living standards) of a typical person? The answer is not obvious. The reason is that when the saving rate rises, the steady state level of per capita income rises, but a lower *proportion* of income is devoted to consumption. The final impact on per capita consumption depends on the balance between these two opposing effects.

Formally, the problem may be solved finding out first the value of *k* that maximizes per capita consumption in the steady state. Formally, this is to maximize $c = y_t - sy_t$, subject to $\dot{k} = 0$, which is equivalent to[9]:

$$\max_{k} \quad c = Ak_t^{\beta} - (n + \delta)k \, .$$

The first order condition of this problem leads to:

$$\frac{\partial y}{\partial k} = n + \delta$$

---

[9] Note the in the steady state $sy^* = (n+\delta)k^*$. The symbol "*", which refers to the steady state, is suppressed to simplify the algebra.

This condition is known as the "Golden Rule of Capital Accumulation" (Phelps, 1961). It states that per capita consumption is maximised when the slope of the production function (i.e. the marginal productivity of capital) is equal to the slope of the break-even investment line (i.e. to the rate of growth of the labour force plus depreciation).

Geometrically, this problem is illustrated in Figure 7.1.7. The Golden Rule is met at point k^G. Whenever the steady state level of capital per worker is below this level (that is, when $k^* < k^G$), the rise in output that results from a possible increase in k^* more than offsets the rise in the amount of savings that is necessary to sustain such equilibrium, so that more resources are available for consumption. Conversely, whenever the steady-state capital-labour ratio is higher ($k^* > k^G$), the rise in output that would result from any further raise in k^* is less than the increment in break even investment, so that less resources become available for consumption.
Algebraically, the optimal level of k^* is given by :

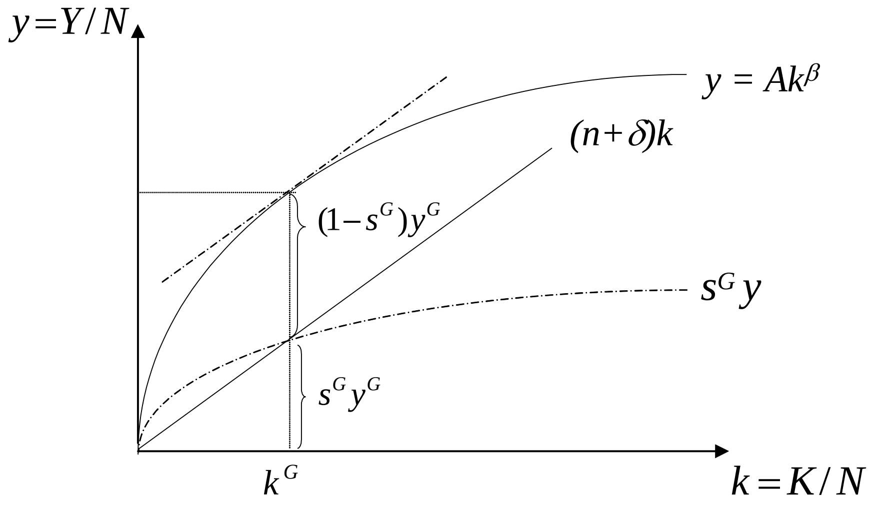
$$k^G = \left(\frac{\beta A}{n+\delta} \right)^{\frac{1}{1-\beta}}$$

The value of *s* that turns k^G into a steady state is called the “golden rule” saving rate. Comparing the expression for k^G with the general expression (6.3.12), we conclude that the golden rule saving rate is $s^G = \beta$ (the share of capital in total income).

It should be noted that the golden rule does not necessarily correspond to an optimality criteria. To find the welfare optimum in this economy, one would need to know the consumers preferences between current consumption and future consumption. Without knowing this, the only thing we can say is that a saving rate higher than the golden rule saving rate would be inefficient: this is because in that case the extra sacrifice of consumption today would not translate into higher consumption tomorrow. The possibility of having a saving rate larger than the golden rule saving rate has been referred to as "dynamic inefficiency".

In the real world, it has been observed that the share of capital in income varies between 0.3 and 0.4 (remember the Stylised Fact 5). In the formulation of the Solow model as presented earlier, this is also the contribution of capital to output, β. Hence, according to the discussion above, a case of “dynamic inefficiency” would only occur if the saving rate were higher then 0.3 or 0.4. In most low income countries, the saving rate is much lower than that.

Figure 7.1.7: Illustration of the Golden Rule



7.1.13. Growth accounting

Before leaving this discussion of the basic Solow model, let us introduce another seminal contribution of Robert Solow, that appeared only one year after his famous model was published. This is the “growth accounting” technique. It starts from a standard neo-classical production function, such as (6.3.1). By taking logs of that relationship and then the time differentials, an expression for overall growth decomposed into its component elements is obtained as follows:

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + \beta\frac{\dot{K}}{K} + (1-\beta)\frac{\dot{N}}{N}$$

This equation states that the growth rate of output equals the growth rate of “A”. plus a weighted average of the growth rates of physical capital and labour, where the weights are the corresponding elasticities in the production function. The growth rate of A is commonly referred to as Total Factor Productivity (or TFP) and we follow that convention here. If factor markets are competitive, as assumed by the model, then these elasticities can be measured directly by the factor income shares calculated from national income accounts (remember 6.3.8 and 6.3.9). In plain language if the labour share of income is twice that of the capital share (say 67% versus 33%) and both factors get accumulated over time at the rate of 3% per annum, then the accumulation of labour will contribute twice as much to overall growth (namely a 2% contribution) as does capital (a 1% contribution).

The major snag with this approach as noted by Solow is that the rate of technological progress is not observable. For this reason the TFP term is usually estimated as the residual i.e. as the difference between the actual growth of output per capita and the growth implied by factor accumulation. Hence the label “Solow residual” that is often applied to TFP.

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \beta\frac{\dot{K}}{K} - (1-\beta)\frac{\dot{N}}{N} \qquad (6.3.1a)$$

In the intensity form of the equations of the model (i.e. those equations where we analyse ratios rather than the absolute numbers), the Solow residual is obtained as:

$$\frac{\dot{A}}{A} = \frac{\dot{y}}{y} - \beta \frac{\dot{k}}{k} \qquad (6.3.10a)$$

To look at a specific case, the US economy in the first half of the C20th grew its GDP at about 3% per annum on average[10]. Its capital stock also grew at about 3% per annum in that same period whereas its labour input (number of working hours) grew at only about 1% per annum. With a capital share in total GDP of one third and a labour share of two thirds, a growth equation such as Equation (6.3.1a) suggests that labour and capital together accounted for about 1.7 percent per annum of the total growth of 3 percent. The residual balance of 1.3 percent per annum is accounted for by TFP:

$$\frac{\dot{A}}{A} = 3\% - \left(\frac{1}{3}\right)3\% - \left(\frac{2}{3}\right)1\% = 1{,}3\%$$

In per capita terms (i.e, using 6.3.10a), the conclusion is even more starling: 2/3 of the change in per capita output is accounted for TFP:

$$\frac{\dot{A}}{A} = 2\% - \left(\frac{1}{3}\right)2\% = 1{,}3\%$$

Of course, computed in such way, we do not expect the TFP estimate to capture only “technological progress” in a narrow sense. It will also capture changes in the “efficiency” with which major US sectors such as industry and agriculture use the *existing* technologies. As also noted in Chapter 6 there is considerable ambiguity in practice about where “quality” improvements appear in these growth models. At the same time any influences on measured output that are not included as explicitly measured inputs in the model, including aggregation errors and unmeasured input quality, such as skill increments in the labour force will be captured by this Solow residual. We will return to this discussion later in the book. For the moment, the reader is asked just to hold on to the main conclusion of the accounting exercise.This tells us that since the calculated TFP is so large (it is certainly not zero) we cannot realistically assume that the state of technology is constant.

7.1.14. The Story so Far

The model, as presented thus far, provides a sensible story about why historical ratios of capital to output and real interest rates appear to be relatively stable in the long run. It also offers the credible suggestion that countries where savings rates are high and population growth rates are low can expect higher levels of per capita income than countries with low saving rates and rapid population expansion.

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[10] The figures are from the World Bank, World Development Report, 1991 pg 42. Solow (1957) used a different data source, but achieved a similar conclusion.

In its current form, however, the model fails to explain the first and most basic of the stylised facts referred in Chapter 5, namely that most countries see per capita income rising over time. By contrast to this, in the current model, any growth in per capita income has merely a transitory nature, reflecting the adjustment of the model from one steady state to the other. Furthermore, if the growth of per capita income in the real world was really accounted for by successive rises in the saving rate, interest rates around the World should exhibit a long-term declining trend as development takes place. This does not accord to the stylised facts mentioned in Chapter 5. The conclusion is that rising savings rates cannot explain long term growth as we observe it.

The key to overcoming this limitation of the basic model was already suggested earlier: the model has to be adapted so as to allow the level of technology to expand over time. As we saw in section 7.1.12, an increase in the level of technology leads to a rise in per capita output, leaving the capital-output ratio unchanged. This avenue – that was opened in the original Solow article with a brief indication on how technological progress could be incorporated into the model - will be explored in the next section.

7.2 Exogenous Growth

7.2.1. Introduction

As shown in Section 7.1, the basic Solow model is incapable of explaining the first and most basics of the stylised facts, namely that most countries see rising living standards over time. In the 1960s, the Solow model was rescued from this incompatibility by allowing technology to expand over time[11].
This section presents this extension of the Solow model and shows how this small change renders the model capable of describing most stylized facts of economic growth.

7.2.2 Perfect technological diffusion

Technology is different from most other goods, in that it is composed by *ideas*, rather than by *objects*. One implication of technology's non-physical nature is that its use is *nonrival*: it can be used by more than one person at the same time without loosing its effectiveness. This is in sharp contrast to physical capital as we have so far been defining it. After all if a firm owns a machine or even a hand-held hoe, no other firm can use that equipment at the same time. In other words, equipment is "rival" in its use. This is not true for ideas and knowledge even if they do come packaged up in bits of capital equipment: the fact that a given company uses some software to manage its operations does not preclude other firms from using the same software. If that were indeed the case Bill Gates and Sergiy Brin would never have made their $ billions from the Microsoft and Google software which their respective companies developed.

Technology may vary, however, in its degree of *excludability*. Excludability is the degree to which an owner of something can prevent others from using it without permission. Because of its nature, knowledge is often non-excludable: it is difficult to prevent an agent from using a good idea, once he or she becomes aware of it. There are, of course, mechanisms, such as trade secrets, patents and copyrights, that prevent some inventions from becoming freely available. These issues will be analysed in Chapter 9. At this stage, however, it is convenient to stick with the assumption of *perfect technological diffusion*: that is, we assume that, once new technology is created, it becomes equally available to all agents (say, through books that describe the technology or through the internet). Remember that this is a key assumption in the model that relies as does our model so far on perfect competition.
To the extent that technology is freely available to all agents, it becomes a *pure* public good: no user will be willing to pay for it and no profit maximising firm will engage in a deliberate effort to produce it. In terms of our model, this implication is rather convenient: we don't need to address returns to technology creation or to model the research activity. We instead stick with the one sector and the framework of perfect competition used in section 7.1.

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[11] The failure of the Solow model in terms of the first stylised fact about development could possibly be explained by very long transition periods (several years) between steady states. In this case a country that had seen a decline in, for example the growth rate of population would indeed experience rising per capita income for several years before the achievement of the new steady state put a halt to that growth. This line of analysis is discussed, for example, in Gylfason, (1999). But we by-pass this approach here in favour of the more mainstream approaches that have more commonly been used to rescue the basic Solow model from its predicament.

The other face of the coin is that technological progress will enter in the model exogenously. Since there are no profit opportunities in technology creation, we are condemned to assume that all technological progress takes place for non-economic reasons (in the form of unintended discoveries that come out through the passage of time, by importing technology from abroad or by chance). The term "manna from heaven" has sometime been used to describe this way of accumulating technology.

7.2.3. Labour augmenting technological progress

In the model of Section 7.1, the state of technology, captured by parameter *A* in the production function (6.3.1), was assumed constant (see equation 6.3.2). In this section, it is assumed instead that technology improves over time at the constant rate, *g*:

$$A_t = Ae^{gt} \qquad (6.4.2)$$

Technological progress introduced in such way is said to be *Hicks Neutral*. The constant term A corresponds mathematically to the state of technology at moment zero, but it may also be interpreted as capturing the efficiency level with which the economy combines its resources and the available technology. We will return to efficiency in Chapter 8.

Substituting (6.4.2) in the production function (6.3.1), one may rewrite the later in the following convenient form:

$$Y_t = AK_t^{\beta} L_t^{1-\beta} \qquad (6.4.1)$$

where $L_t = N_t e^{\gamma t}$ and $\gamma = g/(1-\beta)$. The term *L* now measures labour in "efficiency" units (i.e, the number of workers adjusted for their efficiency level). In other words, as time goes by, the typical worker becomes more efficient because new skills/abilities are costlessly bestowed upon him/her at the rate γ. It is this new "improved" set of workers (*L*) that now figure as inputs into the production function.
For notational convenience, throughout the following sections we will denote the "effective labour input per worker" by:

$$\lambda_t = L_t / N_t \qquad (6.4.3)$$

Under the assumptions above, the "effective labour input per worker" will grow at an exogenous rate, γ. This rate is called the *Harrod neutral* or *Labour Augmenting* rate of technological progress (analytically, it produces the same effect as an increase in raw labour, *N*). Note that, for a given rate of Hicks neutral technological progress (*g*), the corresponding rate of Harrod neutral technological progress (γ) is larger.

7.2.4 The Fundamental Dynamic Equation Revisited

Consider an economy described in the same way as in Section 7.1.2, with the exception that the state of technology now evolves over time according to (6.4.2).
As before, we are interested in describing the path of per capita income, *y=Y/N*. To solve the model in the same manner as in Section 7.1, however, it is convenient to focus on output "per unit of efficiency", which will be denoted as $\tilde{y} = Y/L$. The path of *y* will then be obtained as:

$$y_t = \tilde{y}_t \lambda_t = \tilde{y}_t e^{\gamma t} \qquad (6.4.4)$$

Dividing all terms in (6.4.1) by *L*, one obtains the production function in the *intensive* form:

$$\tilde{y}_t = A\tilde{k}_t^{\beta} , \qquad (6.4.10)$$

where and $\tilde{k} = K/L$ denotes physical capital per “efficiency unit” of labour”. After some manipulation one obtains the modified version of the Fundamental Dynamic Equation as follows[12]:

$$\dot{\tilde{k}}_t = sA\tilde{k}_t^{\beta} - (n + \delta + \gamma)\tilde{k}_t \qquad (6.4.11)$$

The two terms in the right hand side of (6.4.11) are depicted in Figure 7.2.1, together with equation (6.4.10). The first term measures gross investment per unit of efficiency labour. The second term gives the “break-even investment”, that is, the one that would be necessary to compensate for the "depreciation" of $\tilde{k}$ (note that now the later depends, not only on the depreciation of physical capital, but also on the growth rate of the effective labour force, $n+\gamma$).

Apart from the way the endogenous variable is defined, the interpretation of equation (6.4.11) is the same as that of the corresponding equation in the basic Solow model, (6.3.11). In brief, $\tilde{k}$ rises whenever gross investment per unit of efficiency is larger than the break-even investment - as in $\tilde{k}_1$ of Figure 7.2.1 - and conversely. The model of Section 7.1 can now be seen as a particular case of the model developed in this section, with $\gamma=0$.

7.2.5. The steady state

As before, the steady state equilibria are obtained setting $\dot{\tilde{k}} = 0$ in (6.4.11). Using $k_t = \tilde{k}_t e^{\gamma t}$, $y_t = \tilde{y}_t e^{\gamma t}$, we find new equations for the steady state paths of capital per worker and per capita income:

$$k^* = \left(\frac{sA}{n + \delta + \gamma} \right)^{\frac{1}{1-\beta}} e^{\gamma t} \qquad (6.4.12)$$

$$y_t^* = A^{\frac{1}{1-\beta}} \left(\frac{s}{n + \delta + \gamma} \right)^{\frac{\beta}{1-\beta}} e^{\gamma t} \qquad (6.4.13)$$

Comparing this solution to the corresponding solution in the basic Solow model, (6.3.12) and (6.3.13), we see that per capita output and the capital labour ratio, instead of being constant, now grow at rate γ in the steady state. Hence, the device of adding a constant rate of exogenous technical change brings the model into compliance with stylised fact number 1: income per capita can now grow on a sustained basis in the steady state – as it seems to do for most countries in the real world (see Chs 3 and 5). Furthermore, since the wage rate is proportional to per capita output (equation 6.3.8), wages also evolve at the same constant rate, γ, which is in accordance to the stylised fact number 3.

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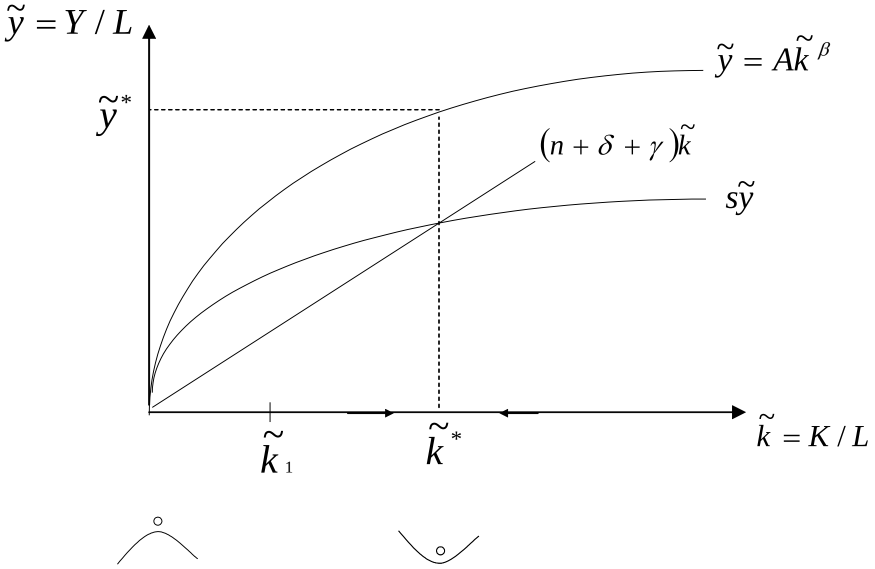
[12] The method is the same as used in Section 6.3: take time derivatives in $\tilde{k}$ and use (6.3.4), (6.3.5) and (6.3.6). Note that $\dot{L}/L = \dot{\lambda}/\lambda + \dot{N}/N = \gamma + n$.

Figure 7.2.1 provides a diagrammatic statement of the new solution

Figure 7.2.1: The Solow model with technical progress



Dividing (6.4.13) by (6.4.12) we obtain the expression for the average productivity of capital:

$$\left(\frac{Y}{K}\right)^* = \frac{n+\delta+\gamma}{s} \qquad (6.4.15)$$

Since all parameters on the right hand side are constant, this means that the average productivity of capital will still be constant in the steady state. This accords to the stylised fact number 5 in Chapter 5. From equation (6.3.9), it follows that the interest rate is also constant in the steady state. This is stylised fact 4.

7.2.6. What Happens if the Savings Rate Rises?

The implications of a once-and-for-all increment in the saving rate may once again be assessed with the help of Figure 7.1.4 of the earlier section (though keeping in mind that the variables in the axes are now defined in slightly a different way). As before, a rise in the saving rate shifts the steady state to the right and lowers the average productivity of capital, *Y/K*. The adjustment is not instantaneous because capital accumulation is bounded at each moment in time by the availability of savings. Thus, the economy engages in an adjustment process until the new steady state is met.
Figure 7.2.2 describes the time paths of the main variables of the model, following a rise in the saving rate. The top panel depicts the evolution of output per unit of efficiency ($\tilde{y} = Y/L$) and capital per unit of efficiency ($\tilde{k} = K/L$). The Middle panel depicts the paths of output per capita (*y=Y/N)* and per capita consumption (*c=C/N*) – these are displayed in logs, so as to stick with linearity. The bottom panel depicts the paths of the interest rate (*r*) and of the growth rate of per capita output (γ_t).
Let t_0 be the moment at which the saving rate raises to the new level. Assume that in the moment before, the economy was in a steady state, with a constant level of output per unit of efficiency and with per capita income growing at the exogenous rate γ (remember equation 6.4.13). Since capital and the labour force are both pre-determined, at the time of the shock *(t_0,)* the income level remains unchanged. Per

capita consumption, however, jumps to a lower level, because a higher proportion of per capita income is now devoted to savings.

The adjustment process takes place between t_0 and t_1. Since savings become temporarily larger than the break even investment, both *K/L* and *Y/L* will rise. This means that the growth rate of output per capita (defined as γ_t) temporarily jumps above its steady state level, which is given by the exogenous rate of technological progress, γ. However, because of diminishing returns, as output per unit of efficiency approaches the new steady state, the growth rate of output per capita falls back, converging to γ. The new steady state occurs when $\gamma_t = \gamma$.

Note that, because of diminishing returns, the rise in *Y* achieved by the rise in the saving rate is proportionally lower than the rise in *K*. This means that the average productivity of capital (*Y/K*) has declined during the adjustment process (reference again to Figure 7.1.4). Thus, the interest rate also declines from one steady state to the other.

It is important to observe that in the new steady state (after t_1), the consumption path may be above or below the original consumption path. Referring to our discussion in Box 7.1.2 above, this will depend on how the new and the old saving rates compare with the Golden Rule saving rate[13]. Figure 7.2.2 below depicts the special case, in which the rise in the saving rate leads to a *higher* level of per capita consumption in the steady state.

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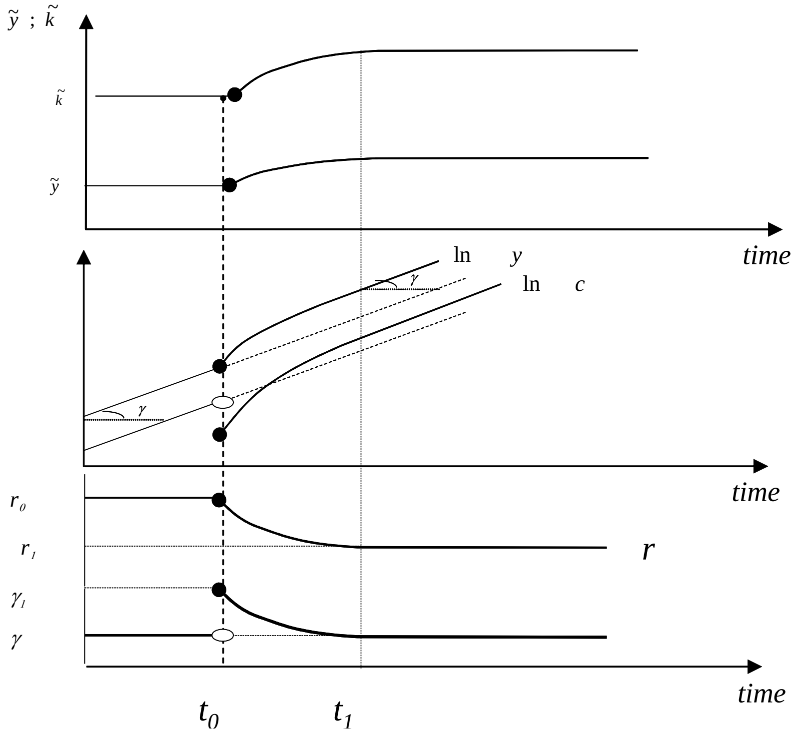
[13] We invite the reader to verify, along the lines of Box 7.2, that the Golden Rule saving rate in this version of the model is, as before, equal to the capital income share, β.

Figure 7.2.2: Implications of a rise in the saving rate



7.2.7. Interpreting growth patterns using the Solow model

Figure 7.2.3 depicts the evolution of per capita incomes in the United States, France, Japan and Germany over the 130 year period from 1871 to 2001. Let's see if can we use the Solow model to interpret these growth patterns?
We observe that:

1. In all cases, per capita GDP exhibits an upward trend.

This is consistent with the predictions of the Solow model with technological progress.

2. The growth rates of per capita output appear to be pretty stable in the long run and also quite similar across these four industrial countries.

This suggests that the draconian assumptions of technology evolving at a constant rate and with all agents drawing from a common technological pool may not be so at odds with reality at least in this particular sample of countries.

3. The long term paths of per capita incomes are parallel but not coincident.

The Solow model does not imply that steady states should be the same in each country: according to equation (6.4.13), the long run path of per capita income may be higher or lower, depending on the saving rate (*s*) and the population growth rate (*n*).

4. During this long period from 1871, some major disruptions pushed the economies away from their respective long term paths. These included a major crash in the stock markets and the Great Depression in the 1930s

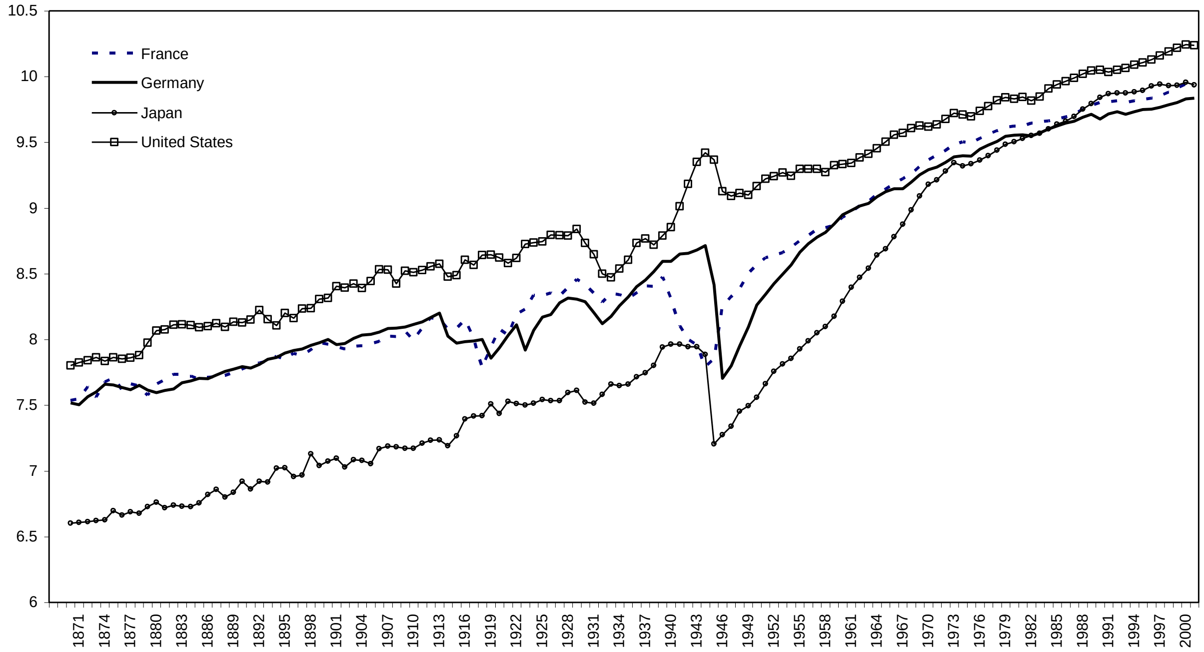
and two World Wars that destroyed economic assets, like factories, roads and bridges.

According to the Solow model, the steady state levels of per capita output are independent of a country's initial capital endowments. So if some shock destroys some part of the capital stock, per capita GDP will fall initially, but then it will recover until once again attaining the steady state. In Figure 7.2.3, we see that this prediction fits the data quite well. For example after the three main shocks (the Great Depression from 1929 in the U.S.A, the First World War (1914-1918) in France and Germany and the Second World War (1939-1945) also in France and Germany), these three economies all saw GDP decline but this was followed some decades later by growth rates similar to those that had characterised the pre-shock situations.

5. In the case of Japan, a "level effect" is likely to have occurred after the Second World War.

The growth path of Japan suggests that this is indeed to a distinct case. Specifically, after WWII this country seems to have moved from one steady state to another, closer to that of United States. According to the Solow model, such move could be explained by a change in a fundamental parameter, such as the saving rate, the population growth rate or the efficiency parameter, A.

Figure 7.2.3: Per Capita GDP in Japan, France, Germany and US, 1871-2001



Source: Maddison (1995).

At this point readers may also like to refer back to the country and regional growth examples also depicted graphically in Chapter 4. The question to ask is can the differing growth profiles seen since 1950 (e.g. for Africa, Asia etc) be explained in terms of the Solow propositions? If not what are some of the particular features –

akin to the two World Wars and the Great Depression – that may explain the divergences?

7.2.8 Convergence

As was noted in earlier chapters, a question that has received considerable attention in the economics literature is whether there is a general tendency for poor countries to grow faster than rich countries. The hypothesis that poor economies tend to grow faster than rich economies is known as *absolute convergence*. The formal equation used to define and test for this is Equation 4.1 in Chapter 4. Empirically, this hypothesis has been investigated using cross-sectional data correlating the countries' growth rates of per capita GDP over a given period of time with the corresponding *initial* levels of GDP.

Figure 7.2.4 illustrates how this test performed in one well known paper by Gregory Mankiw et al that used a large world-wide sample of countries. The figure relates the growth rate of GDP per working age person from 1965 to 1985 (vertical axis) with the corresponding 1965 level, for a sample of 98 non-oil countries. If there was a general tendency for poor countries to grow faster than rich countries, the slope of the regression line should be negative and not slightly positive as happens in the figure. The conclusion is that “absolute convergence” does not apply to this broad cross section of countries for this tume period[14].

This evidence is however consistent with the Solow model. This is because the Solow model does not predict *absolute* convergence. What the model says is that *per capita income in each economy converges to a steady state and that the speed of convergence relates inversely to the initial level of capital per worker* (this property has been named as “conditional convergence” and will be specifically addressed in Section 7.3). Since economies are different in terms of their fundamental parameters, this weaker proposition says only that they are expected to reach *different* steady states. In this case it is impossible to use the theory to predict whether the poorer economy will grow faster or slower than the richer economy. So it is perhaps no real surprise that the hypothesis of “absolute convergence” performs so poorly in the world-wide sample just considered and in similar samples as shown for example in Chapter 4.

Of course, countries that are similar in terms of fundamental parameters, such as the saving rate and the population growth rate, should be expected to approach the same steady state. This is why in Figure 7.2.5 the same Mankiw paper was able to identify a negative relationship between growth rates and initial income levels in OECD countries. Because these richer economies are similar in terms of the fundamental parameters, they might be expected to approach steady states that are close to each other[15].

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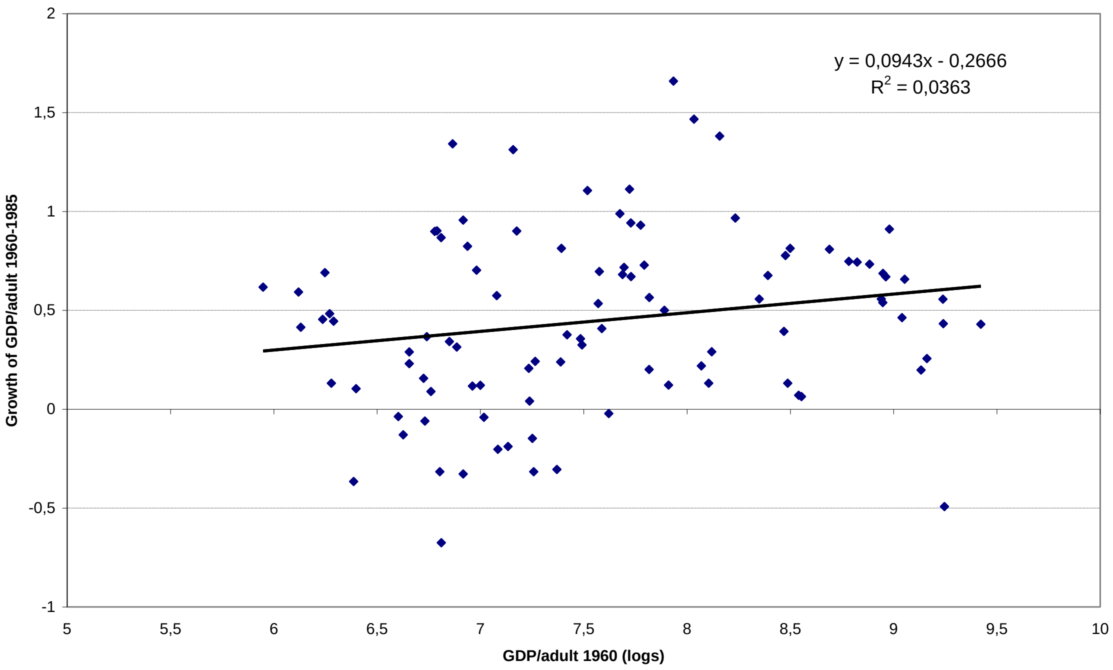
[14] But note too the evidence from Chapter 2 that looked at the convergence tendencies of countries in terms also of their population sizes. This showed that some of the faster growing poor countries have very large populations (China is the main example). Hence convergence is more evident for poor *people* than for poor *countries*: a more hopeful prospect.

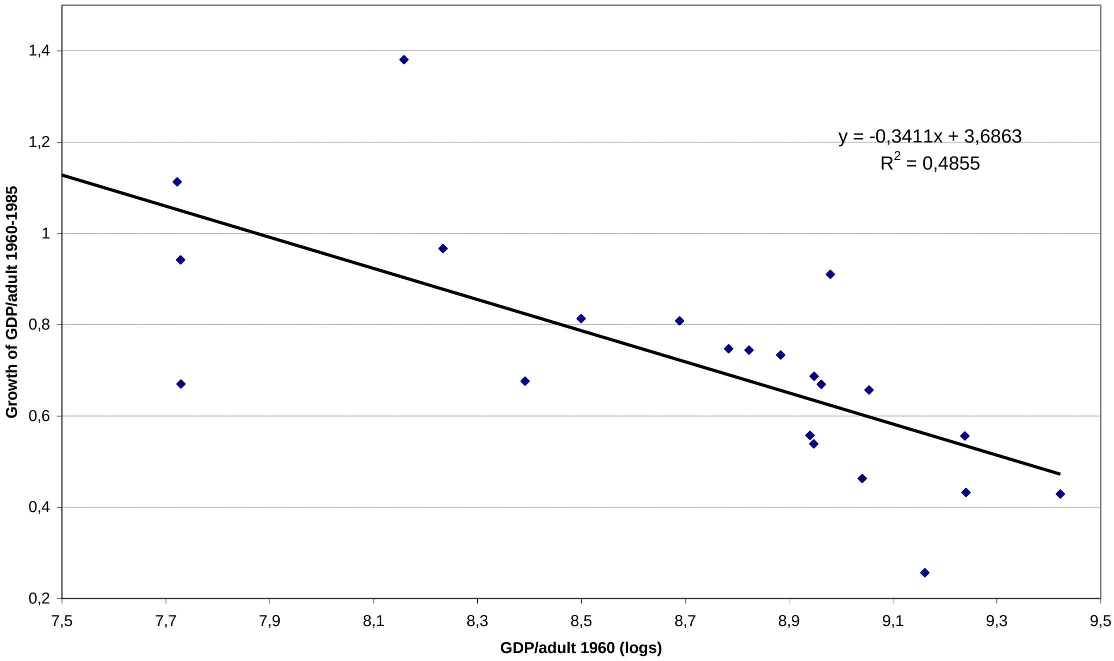
[15] This is not to say, however, they will converge to the same steady state: simply, in these economies, departures from the steady state account for a much larger share of cross-country variation of per capita incomes than differences in the steady states. In general, the evidence of absolute convergence, even in these particular samples, has been found to be fragile in respect to small modifications to the list of countries included (DeLong, 1988).

Figure 7.2.4: Evidence of Non-Convergence in 98 Countries



Source: Mankiw et al, 1992.

Figure 7.2.5: Evidence of Absolute Convergence among 22 OECD Countries



Source: Mankiw et al, 1992.

7.2.9. Growth accounting revisited

Section 7.1.13 above described a technique for assessing how much of a country's GDP growth is accounted for by factor accumulation and how much by (residual) TFP growth. A problem with the decompositions shown earlier in equations (6.3.1a) and (6.3.10a) is that they overestimate the role of factor accumulation. To see this, consider again the figures for the US economy during the first half of the twentieth century that we have already used in section 7.1.14: GDP growing at 3%; capital stock growing at 3% and labour input growing at 1%.

The fact that both capital and output grew on average at about 3% in US is consistent with the view that this economy evolved along a balanced growth path, with a constant saving rate.

But if the US economy was indeed evolving along a balanced growth path, why should a growth accounting exercise like (6.3.1a) produce a contribution of capital to GDP growth equal to 1%? Isn't that at odds with a constant saving rate?
Remember that the Solow model predicts a growth rate of the capital stock in the steady state equal to $\dot{K}/K = \gamma + n$. The key issue is that this growth of the capital stock is not autonomous (i.e. it is not implied by a change in the saving rate), but rather it is the endogenous response to the expansion of the effective labour force: if there was no population growth or technological progress (γ=n=0), then the capital stock would not exhibit any growth at all in the steady state.

Growth accounting based on equation (6.3.1a) measures the contribution of capital to growth, but does not distinguish whether the growth in capital was due to a rise in the saving rate (transition dynamics) or was induced by a growing labour force. When the economy is in the steady state, growth accounting using (6.3.1a) will attribute $\beta(\gamma + n)$ to the growth of capital, $(1-\beta)n$ to the growth of population and $g = \gamma(1-\beta)$ to technological progress. This is the accounting exercise we explained in Section 7.1.14. above.

To interpret growth patterns properly, however, the crucial question is whether the observed growth in per capita GDP reflects technological change or the transition dynamics from one steady state to the other. For this reason, some authors prefer to implement growth accounting exercises based on the re-parameterisation as shown in equation (6.4.10)[16]:

$$\frac{\dot{y}}{y} = \frac{1}{1-\beta}\frac{\dot{A}}{A} + \frac{\beta}{1-\beta}\left(\frac{\dot{K}}{K} - \frac{\dot{Y}}{Y}\right) \qquad (6.4.10a)$$

In (6.4.10a) the contribution of capital to the growth rate of per capita GDP is now evaluated by the extent to which its growth rate exceeds that of output growth. This method actually *expurgates* that part of the growth of the capital stock that is induced by the exogenous parameters (γ and n). Growth accounting based on equation (6.4.10a) will capture a contribution of capital only to the extent that the country is involved in a process of transition dynamics.

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[16] You may obtain this expression either by manipulating (6.4.10) or by substituting (6.4.15) in (6.4.13) and taking logs.

Using this new approach and the same figures above for the US economy, one obtains:

$$2\% = 2\% + \frac{1}{2}\left(3\% - 3\%\right) = \gamma$$

Note that the last term on the left is equal to zero. That is, in the U.S.A in the first half of the last century, capital accumulation by itself did not account for any of the growth of per capita GDP at all. The only exogenous source of per capita income growth in this period was TFP growth. Note, however, that the TFP estimate in (6.4.10a) is not the same as in (6.3.10a). In fact, what (6.4.10a) actually measures is the Harrod neutral rate of technological progress (our γ) in contrast to the Hick neutral rate of technological progress (g) estimated by (6.3.10a).

7.2.10. Conclusion: What have we now achieved?

In Section 7.1 we saw that, because of diminishing returns, the basic Solow model is not capable of describing the real-world tendency of per capita income to grow over time. In this present section, we have shown that sustainable growth of per capita income may be achieved by assuming an exogenous rate of technological progress. Technological progress introduced in such a way has the effect of neutralising the diminishing returns to capital that would otherwise constrain per capita income growth. The mechanism is simple: technological change economises progressively on the one input in the production function whose supply cannot easily be changed: namely labour. This avoids diminishing returns. The *effective* number of workers grows with the number of machines (capital) and hence diminishing returns never sets in.

With such an assumption, the model is successful in describing a wider range of stylised facts. In particular, the long-term positive growth of per capita income and wages observed in most countries historically and the relative constancy over time of interest rates and of factor income shares. It also correctly predicts that per capita incomes seem to depend positively on the saving rate and negatively on the population growth rate. The Solow model at this stage of its evolution can be fairly said to provide the correct answers to the set of questions it is designed to address. As such, it has become the basis of many advanced models in macroeconomics, such as real business cycles models.

7.3 The neo-classical model with Human Capital

7.3.1. Introduction

However, up to this point we have given the Solow model a pretty easy time in assessing its performance against the facts of real world development. As shown above, the Solow model is capable of explaining some broad facts about real world economic growth. During the last 30 years, however, various researchers who have subjected it to more demanding empirical investigation, have progressively uncovered some important inconsistencies with real world experience.
A direction explored in this further investigation relies on the fact that the model specification implies not only the expected *signs* of certain parameters but also their approximate *magnitudes*. Because the model implies that factors of production will be paid their marginal products, it also implies broad orders of magnitude for the coefficients linking per capita income to the savings rate and to the population growth rate. Results generally suggest that these magnitudes do not conform too well to the empirical evidence.

The key parameter in this further scrutiny is the elasticity of output with respect to capital, β, which, according to the model, can be measured by the capital income share in GDP. The empirical observation that the later varies across countries from 25 to 40% makes the model incapable of explaining the large differences in per capita incomes that we observe in the real world (see Ch. 3 for the numbers). The reconciliation would require, for example, differences in savings rates as between countries much larger than those actually observed in reality.

This current section addresses these inconsistencies and the avenues that have been explored to overcome them.

7.3.2. Differences in savings differences are too small

In the Solow model, the steady-state relationship between per capita output and the fundamental parameters is given by equation (6.4.13), which is repeated here:

$$y^* = A^{\frac{1}{1-\beta}} \left(\frac{s}{n+\delta+\gamma} \right)^{\frac{\beta}{1-\beta}} e^{\gamma t} \qquad [6.4.13]$$

The problem with this equation is that, for a capital share in income (β) lying between 0.25 and 0.4 (which conforms the evidence for many countries), the elasticity of income with respect to the savings rate, given by the exponent term $\beta/(1-\beta)$, is too low. For example, when $\beta=0.4$, the elasticity term will be equal to 0.67. This being the case, a 10% rise in the saving rate would imply a rise of only 6.7% in the steady state level of per capita income. But if the effect of such a sharp rise in the saving rate is so relatively low, then cross-country differences in the saving rate will hardly be able to explain the large differences observed in per capita incomes.

To further explore this argument, consider two countries, say a Rich Country (R), and a Less Developed Country (L). From (6.4.13), and sticking to the assumption that technology is the same in the two countries, the ratio of per capita incomes between the two countries in the *steady state* should be equal to:

$$\frac{y_R}{y_L} = \left(\frac{s_R}{s_L}\right)^{\frac{\beta}{1-\beta}} \left(\frac{n_L + \delta + \gamma}{n_R + \delta + \gamma}\right)^{\frac{\beta}{1-\beta}}$$

Assume that $\beta=0.4$, $\delta=3\%$ and $\gamma=2\%$ (the last corresponding to the trend growth rate of per capita GDP in the U.S.). Assume further the following (realistic) values for the remaining parameters: $s_R = 0.25$, $s_L = 0.10$, $n_R=0.5\%$ and $n_L=2\%$. In this case, per capita income in R will be 2.16 times that of L. Comparing to the real world differences in per capita incomes, this is indeed too low. Look, for example, at the observed per capita income differences between the U.S. and India (15:1), South Korea and Tanzania (27:1) or U.S and Tanzania (53:1), as implied by the Angus Maddison PPP calculations for the year 2000. Even using drastic assumptions concerning the differences in the saving rate and the population growth rate, there is no way of reproducing income gaps of such magnitude.

As an extreme case, assume that the poor country had instead s_L=1.5% and $n_L=5\%$. In this case, the ratio of per capita incomes would rise to 9.7, only. Clearly, these figures are extreme even in the developing world (no country has sustained a population growth rate as high as 5% and few save as little as 1.5% of income and in any case these numbers have moved in the opposite way in recent years). But they are still not enough to explain the 27:1 income gaps as between countries such as South Korea and Tanzania.

7.3.3 Lucas's Illustration

The Nobel Prize Laureate Robert Lucas put this problem in a different manner: if cross-country differences in per capita income were indeed explained by cross-country differences in the level of capital per worker, then the marginal productivity of capital in poor countries (those scarce in capital) should be higher than in rich countries (this is the LDR). Calibrating the Solow model, Lucas (1990), noted that, in order for the model to explain a difference of 15 times in per capita incomes, as it applies between the USA and India, the interest rate in India would need to be 58 times that of the USA[17]. If capital were generating a return of around 8% in the USA, then the corresponding average return in India would be 464%. Even admitting that poorer countries have very high risk premiums, this is wholly unrealistic. Lucas (1990) pointed out that, in face of such return differentials, capital should be flowing in substantial amounts from rich countries to poor countries. Moreover, one would expect almost no investment to occur in rich countries until capital-labour ratios - and hence interest rates - were more or less equalised. This, in turn, would imply a fast convergence of per capita GDP in levels. But clearly this does not conform to today's realities: capital does not flow in huge amounts to poor countries, interest differentials are nowhere near as large as 58 times and there is no *systematic* tendency for poor countries to grow faster than rich countries.

7.3.4. So how can we explain these inconsistencies?

So again the Solow model, even with the clever enhancement of allowing for exogenous technological progress, is not really consistent with some facts of the real world. The technical reason relates to two main points namely:

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[17] Readers are invited to use the Cobb-Douglas production function to replicate these numbers.

(i) the huge onus in this model put on the developmental role of physical capital is inconsistent with the empirical observation that capital income shares in GDP stand at around 25-40%;

(ii) the assumption that all countries can realistically be described by the same production function and a common rate of technological progress.

In the literature, two different avenues have been proposed to resolve these additional failures of the model:

1. Assume that the contribution of *reproducible* factors to output is larger than β. This avenue consists in augmenting the production function with reproducible factors other than physical capital and is explored in section 7.3.5 and also in Chapter 8.
2. Abandon the idea that technology is equally available across countries. This requires, however, a previous and also a more precise understanding of the factors that determine what we call "technology" in the production function. These aspects will be further discussed in Chapters 8 and 9.

7.3.5. The Solow model with Human Capital

We just saw that, if the earnings of physical capital represents only a relatively small contribution to total output (around 25-40%), then capital accumulation by itself cannot account for cross country differences of per capita income. As referred to above (option 1), one way of getting rid of this inconsistency is by adding other *reproducible* factors to the production function. This is precisely what Mankiw, Romer and Weil (1992) did, in a version of the Solow model augmented with human capital. Human capital (the society stock of labour skills) shares with physical capital the characteristic that it can be accumulated (or reproducible).

Formally, consider the following elaborated version of the production function:

$$Y = A_t K_t^{\beta} H_t^{\alpha} N_t^{1-\alpha-\beta} \qquad \text{with } \alpha+\beta<1 \qquad (6.5.1)$$

where the new variable "H" measures Human Capital which captures some of the educational and health attributes of labour that we discussed in Chapter 5. "A" still evolves according to (6.4.2) and all other variables are defined as before.

Note that, including human capital in the production function the weight of *all types of capital* in total output increases to $\alpha+\beta$. This implies that diminishing returns on broad capital are much less severe than in the original Solow model. Still, the shares of income that go to workers is $\alpha+(1-\alpha-\beta)=1-\beta$. Just as in the Solow model.

In the following discussion, it is assumed that human capital accumulation is driven by deliberate private decisions, such as schooling, on-the-job training and investment in health. Of course, this does not exhaust all forms of human capital accumulation, but, again, we need some simplifying assumptions. To keep matters simple, let us assume that human capital is accumulated in the same manner as physical capital. In particular, it is assumed that one unit of the consumption good can be transformed at no cost into *either* one unit of human capital *or* one unit of physical capital. We also assume that the stocks of physical and human capital depreciate at the same rate, δ. The depreciation of human capital may be interpreted as the erosion of knowledge (e.g. the obsolescence of particular skills as new technologies emerge) net of the benefits of accumulated experience.

Formally, the resource constraint of the economy can be written as[18]:

$$Y_t = C_t + I_t + I_t^H \qquad (6.5.3)$$

Where I^H refers to investment in Human capital and all other variables are defined as before. As before, assume that people devote a constant fraction of their incomes to capital accumulation. Let s_H be the fraction of income invested in human capital and s is the fraction of income invested in physical capital. The dynamics of K and H are given, respectively, by:

$$sY_t = I_t = \dot{K}_t + \delta K$$
$$s_H Y_t = I_t^H = \dot{H}_t + \delta H$$

To solve the model in the simplest manner, we need a clue. Our clue is that Physical Capital and Human Capital will be growing at the same rate in the steady state. Note that this is a natural outcome in a model with decreasing marginal returns. Imposing $\dot{K}/K = \dot{H}/H$ in the two equations above, one obtains the critical condition:

$$\frac{H}{K} = \frac{s_H}{s} \qquad (6.5.4)$$

Solving for H and substituting in the new production function (6.5.1), one obtains a function equivalent to (6.4.1), that holds only in the steady state:

$$Y = BK_t^{\theta}(\lambda_t N_t)^{1-\theta} \qquad (6.5.5)$$

where we used $\theta = \alpha + \beta$ and $B = A\left(\frac{s_H}{s}\right)^{\alpha}$. Given the similarities between (6.5.5) and (6.4.1), the student may guess that the steady state of this model will be also similar to that of the Solow model. This guess happens to be spot on. Adapting equation (6.4.13) for the parameters in (6.5.5), one obtains[19]:

$$y_t^* = B^{\frac{1}{1-\theta}}\left(\frac{s}{n+\delta+\gamma}\right)^{\frac{\theta}{1-\theta}} e^{\gamma t}$$

---

[18] An alternative way of modelling human capital accumulation is to assume that a fraction of the labour force is allocated to a second sector, devoted to the production of Human Capital (such as schools, universities and hospitals). This approach is followed in Lucas (1988) and it constitutes a fundamental departure from the neo-classical growth model. A model of that type is explored in the context of technological change, in Chapter 8.

[19] In a famous footnote to their paper (footnote 12), MRW noted that the properties of the model change dramatically in the case in which $\theta=1$. In that case, equation (6.5.5) simplifies to $Y = BK$: that is, the production function becomes linear in K. Because marginal returns to capital become constant, this slight modification of the model changes dramatically its dynamic properties. This case will examined in Chapter 8.

Substituting back $\theta = \alpha + \beta$ and $B = A\left(\frac{s_H}{s}\right)^{\alpha}$, one obtains the steady state level of per capita income in the MRW model:

$$y_t^* = \left[\frac{A s_H^{\alpha} s^{\beta}}{(n+\delta+\gamma)^{\alpha+\beta}}\right]^{\frac{1}{1-\alpha-\beta}} e^{\gamma t} \qquad (6.5.13)$$

where $\gamma = g/(1-\alpha-\beta)$. Note that (6.4.13) is a particular case of (6.5.13), with α*=0*. Equation (6.5.13) states that the steady state level of income per capita now depends positively on the saving rate and negatively on the rate of population growth (as before). It also states that per capita income rises in the long run at a constant rate γ (as before). As in the basic Solow model, the long run rate of growth of income per capita is not affected by the saving rates or by the population growth rate, but the level of per capita income is so affected. The novelty here is that the level of per capita income also depends on the share of income spent in Human Capital Accumulation, s_H.

An important property of this model is that the two saving rates impact on per capita income alone and also together, reinforcing each other: for any given rate of human capital accumulation, a higher saving rate leads to a higher level of per capita income in the steady state, which in turn leads to a higher level of human capital. This means that any given (e.g. small) differences in the saving rates may explain *larger* differences in per capita income. This allows the revised model to connect much better with reality.

7.3.6. Empirical evidence on the neo-classical model

Both (i) the Solow model presented in Section 7.2 and (ii) the augmented model introduced in this section were tested empirically by Mankiw, Romer and Weil (1992). The test was based on equation (6.5.13), in the log-linear form:

$$\ln y_i^* = a + \frac{\beta}{1-\alpha-\beta}\left[\ln s_i - \ln(n_i+\delta+\gamma)\right] + \frac{\alpha}{1-\alpha-\beta}\left[\ln s_{Hi} - \ln(n_i+\delta+\gamma)\right] + \varepsilon_i$$

with $a = \gamma t + \ln A/(1-\alpha-\beta)$ (6.5.13a)

The Solow model is the particular case, with α*=0*. The authors investigated whether the data supports the two models, using cross section data for the year of 1985. The implied assumption is that countries in 1985 were in their steady states or, more generally, that the deviations from the steady state were random. The random disturbance ε_i in (6.5.13a) captures these deviations, as well as country specific effects determining differences in the level of A, such as differences in resource endowments or in climate.

In estimation, the following proxies were used: the growth rate of the working-age population for *n;* the ratio of real investment to GDP for s; the fraction of the eligible population enrolled in secondary education for s_H; the real GDP per working age person for y; the authors also postulated $\delta + \gamma = 0.05$ for all countries.

The estimates of the Solow model (i.e, imposing $\alpha=0$) using a sample of 98 non-oil production countries were as follows (standard errors in brackets):

$$\ln y = \underset{(0.12)}{6.87} + \underset{(0..12)}{1.48}\left[\ln s - \ln(n+0.05)\right]$$

$R^2 = 0.59$ SEE = 0.69
Implied β = 0.60 (0.04)

According to these results, the model accounts for 59% of the cross-country variation of per capita incomes across the 98 countries. The estimated elasticity of output per capita with respect to savings was estimated to be equal to 1.48. The estimated coefficient has the predicted sign and is significant.
Nonetheless, with an estimated elasticity of 1.48, the implied value for β is 0.60 (note that: $1.48 = \beta/(1-\beta)$). This is just another incarnation of the problem we saw before: in order for the observed differences in per capita income to be explained by differences in capital endowments, one would need a capital income share much larger than that observed in reality.

The results using the Mankiw, Romer and Weil (1992) augmented model (equation 6.5.13a) were as follows:

$$\ln y = \underset{(0.14)}{7.86} + \underset{(0.12)}{0{,}73}\left[\ln s_K - \ln(n+0.05)\right] + \underset{(0.07)}{0{,}67}\left[\ln s_H - \ln(n+0.05)\right]$$

$R^2 = 0.78$ SEE = 0.51
Implied β = 0.31 (0.04)
Implied α= 0.28 (0.03)

This model explains almost 78% of the cross-country variation in per capita incomes. All coefficients have the expected sign and are highly significant. Moreover, the estimate for β now accords much more closely with the observed facts: β = 0.31.
Taken together, these results are much more favourable to the extended version of the Solow model than to the basic version.

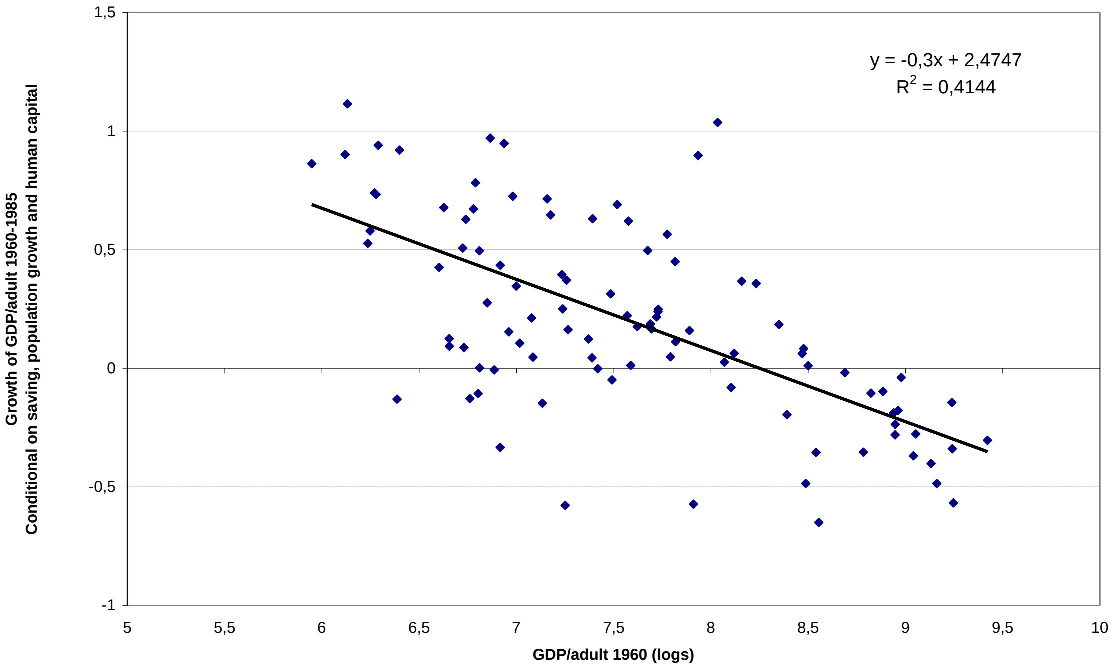
7.3.7. Conditional convergence

As shown in Section 7.2.8, there is no general tendency for poor countries to grow faster than rich countries and so to see their incomes converging. We argued that this finding is consistent with the neo-classical growth model. But the neo-classical growth model also predicts that the speed of convergence to the steady state relates inversely to the distance from the steady state. Thus, according to the model, economies lying initially bellow their balanced growth path should exhibit faster growth than those economies having per capita income initially above their balanced growth paths. In other words, the model predicts that a lower starting value of real per capita income tends to generate a higher per capita growth rate, once we control for the determinants of the steady state. This property of the neo-classical model is called *conditional convergence* (Mankiw, Romer and Weil, 1992, Barro and Sala-i-Martin, 1992).

Empirically, the conditional convergence hypothesis may be tested by observing the relationship between per capita growth and the initial level of per capita income, after the variables determining the steady state are controlled for. If a significantly negative partial relation between growth and initial level of per capita income is found, this is taken as evidence of conditional convergence.

Figure 7.3.1 illustrates this test, as implemented by Mankiw et al (1992). The data are the same as those used in Figure 7.2.4 above. However, the vertical axes now measures the growth rate of per capita income after expurgating the effects of investment in physical capital, human capital and population growth. As the figure shows, there is now a broadly negative relationship between growth and initial incomes, after controlling for the different steady states. In general, the empirical evidence has been favourable to the conditional convergence hypothesis, stated in this way.

Figure 7.3.1: Evidence of Conditional Convergence (98 countries)



Source: Mankiw et al, 1992.

7.3.8. Cross-country growth accounting with Human Capital

Section 7.1.13 in the previous Section described how Robert Solow (1957) concluded that technology was a key element in the explanation of long term growth in the US economy. In 7.2.9 of this present Section, the growth accounting methodology was revised, so as to distinguish the proportion of factor accumulation that is induced by technological change from the proportion that results from shifts in the saving rate.

Figures 7.3.2 to 7.3.4 below display the results of a similar exercise implemented by Klenow and Rodriguez-Clare (1997), extending the production function to include human capital, in line with the MRW model. The authors assumed $\alpha=0.28$ and $\beta=0.30$. The sample covers 98 countries over the period 1960-85. The figures plot the growth rates of Y/N with the growth rates of, respectively, K/Y, H/Y and A.
Although a positive correlation is obtained in the three graphs, suggesting that both TFP and factor accumulation are important for growth, the correlations differ substantially. In particular, the correlation is weak for both capital and human capital but very much stronger for the TFP factor. In other words, the factor that best explains the differences in per capita income growth across countries is TFP.

This evidence not only confirms the importance of (residual) TFP in explaining long term growth – as we explained originally in Section 7.1.13 above – but also that differences in TFP growth play an important role in discriminating between the growth performances of different countries. This means that the earlier simple assumption that technology is equally available across countries is wholly inappropriate to describe development differences in the real world..

Figure 7.3.2: Growth rates of output per worker versus physical capital per unit of output, 98 countries, 1960-1985

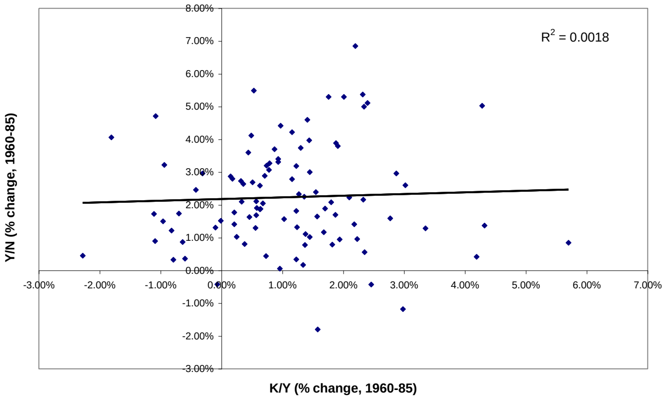


Figure 7.3.3 - Growth rates of output per worker versus human capital per unit of output, 98 countries, 1960-1985

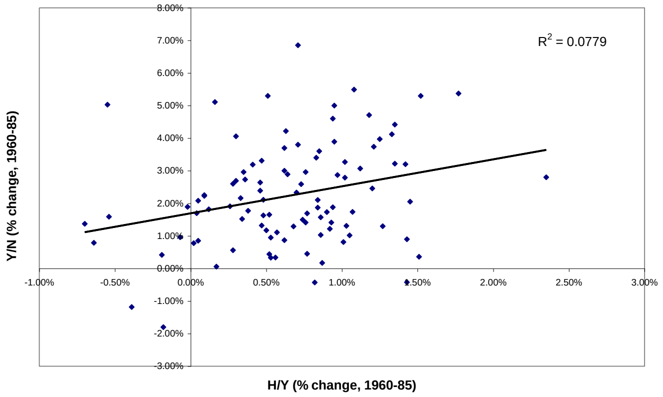
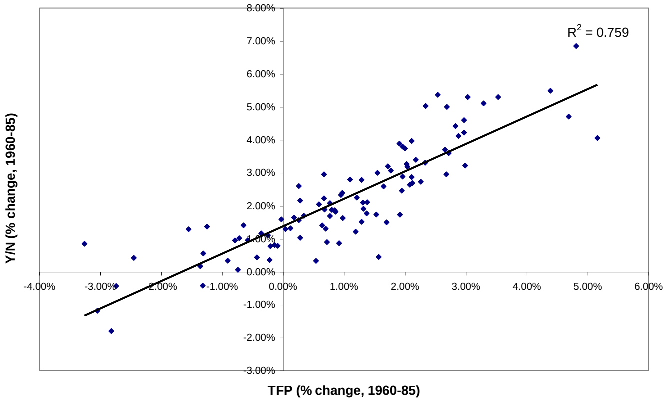


Figure 7.3.4 - Growth rates of output per worker versus total factor productivity, 98 countries, 1960-1985



Source: Klenow and Rodríguez-Clare (1997).

7.3.9. Discussion: some new directions for our quest.

According to the Solow model, cross country differences of per capita income should be explicable in terms of differences in the saving rate and the population growth rate. Although such predictions accord broadly to the empirical evidence in terms of *signs*, they do not in terms of *magnitudes*. The observed cross-country variation in saving rates and per capita incomes refutes the prominent role of physical capital suggested by the Solow model: and by the generation of development practitioners influenced by this proposition. This is especially true given the improved savings performance seen in many still-poor countries that we saw in Chapter 5: this has often not translated into higher growth In particular, we have shown that the weight given to physical capital in the neo-classical production function is too low for such an explanation to hold.

One solution to this problem is to increase the weight of reproducible inputs in the production function. This is the extension proposed by Mankiw, Romer and Weil, and analysed in this section. Augmenting the model so as to include human capital allows the model better to explain cross country income differences. However, while it does a quite good job in *describing* economic growth, the model is not capable of *explaining* economic growth: this is because technological progress is still assumed to evolve exogenously and to be equally available to all agents.

Indeed, the evidence of cross country differences based on growth accounting techniques suggests that “technology” (still a residual at this stage of our story) plays an extremely important role in explaining why some countries produce more output per worker than others. This means that we definitely need a much better understanding of what‘s behind “technology” or TFP if we are really to get to grips with the causes of growth differences across different countries.

The main problem of the neo-classical models as so far discussed is that their treatment of technological progress is seriously incomplete: the models take as given the behaviour of the variable that they identify as the driving force of growth. In short, they seek to model and explain growth by assuming the level of the main variable that determines growth! Why is this so? The answer is as follows. Because in the neoclassical model the payments made to acquire the inputs of labour and capital exhaust (fully use up) total output, nothing is left to compensate for any technological development. Hence, the model cannot capture the profit seeking activities related to research and development (R and D). Questions such as: "who produces technological progress and why" cannot be addressed by the Solow growth model, as it is. The realism of the processes involved in technological change in this augmented model remains deeply unsatisfactory.

This means that the assumption of perfect technological diffusion must be, somewhere, relaxed. If we relaxed it at this stage, allowing technology simply to evolve at different rates, one would obtain different growth rates of per capita output in the steady state. But, as Easterly has put it recently ...” to say that countries have different growth rates because they have different rates of technological progress for some mysterious non-economic reason is not very satisfying. This is just answering the question of why growth rates differ by saying that growth rates differ..” (Easterly [2002], pg 57).

The question of technological diffusion cannot be conveniently addressed without a previous and better understanding of the processes involved in technological change itself.

The following sections in Part II address, precisely, the need to learn more on what is behind this parameter that we have so far called “technology”. In doing so, we categorize differences in “technology” or TFP as being determined by two sources:

- Differences in the effectiveness with which factors of production and a *given technology* are combined to produce output. We categorise these differences as differences in “efficiency”. This direction of analysis will be explored in some depth in Chapter 8.
- Differences in the *adoption* of *more advanced technologies*, that is, the way in which factors of production can be better combined to produce output. This direction of analysis will be explored in Chapter 9.

CHAPTER 8. THE ENDOGENOUS GROWTH MODEL

"And thus a new view emerged, a new theory of growth. The key idea is quite simple: technology is probably not exogenous. The more capital workers have to work with, the more computers and so on, the more efficiently they will use the capital: they will learn by doing. If the dependence of technology on the capital/labour ratio is described in a particular way, then as Paul Romer showed – you probably guessed it – the capital /output ration turns out to be constant after all as assumed by Harrod and Domar" Thorvaldur Gylfason, *Principles of Economic Growth*. 1999, pg 29.

8.1. Introduction: Getting rid of diminishing returns

As was explained in Chapter 7, if there are diminishing returns to the reproducible factors - such as physical and human capital – taken together, then factor accumulation cannot by itself explain the long-term growth of per capita income. For this reason, growth in the neo-classical model is achieved by postulating an exogenous rate of technological progress. In this chapter it is shown that, by getting rid of diminishing returns, one can obtain continuous growth of per capita output *without* the need to introduce technological progress in such an unsatisfactory manner.

The problem with such an approach is that the assumption of diminishing returns plays a very central role in economic thinking. Hence, one needs a convincing theory to justify throwing it away. The following sections describe alternative theories and models that have been proposed to motivate the abandonment of diminishing returns as a key element of formal models of economic growth. Although none of these approaches should be seen as a centrepiece model, they all offer us various reasons why diminishing returns is not always the best assumption when we are searching for explanations of real world economic growth. These sections also stress alternative mechanisms through which policy actions, enhancing or reducing aggregate efficiency, may be beneficial or detrimental to growth. At this stage, however, we simply evaluate the implications of abandoning that crucial assumption of the neo-classical growth model.

8.2. The AK model

8.2.1. The basic AK model

Consider first a closed economy similar to that described in Section 7.1.2 - e.g, by equations (6.3.3) to (6.3.6) - except that production is now a linear function of the capital stock (K):

$$Y_t = AK_t \ , \ A > 0 \qquad (7.2.1)$$

Comparing (7.2.1) with (6.3.1), we see that now production depends only on the reproducible factor and that there are no diminishing returns to this factor. The reader may get suspicious about this formulation. Doesn't labour have any role in production? What would be the factor income shares in this case? In order to keep things simple, for the moment we simply appeal to the extreme case of the MRW model, with $\theta = \alpha + \beta = 1$ (see Footnote 18 in Section 7.3). In that case, K can be interpreted as a broad measure of capital including physical and human capital. In later stages, we will describe other theories that have been developed to motivate a production functions of this form.

As in the basic Solow model (Section 7.1), the parameter A, which captures the level of technology and efficiency, is assumed constant. Dividing (7.2.1) by *N*, we obtain the relationship between per capita income and the capital labour ratio:

$$y_t = Ak_t \qquad (7.2.10)$$

As before, we denote the propensity to save as "*s*". Using (6.3.4), (6.3.5) and (6.3.6), the following fundamental dynamic equation is obtained:

$$\dot{k}_t = sy_t - (n+\delta)k_t \qquad (7.2.11)$$

This equation is similar to (6.3.11), with the difference that now $\beta=1$.
Since output is now linear in the capital stock, output and capital are fated to grow at the same rate. This holds at each moment in time and not just in the long run, as in the Solow model. Dividing (7.2.11) by k, one obtains:

$$\gamma = s\frac{Y}{K} - (n+\delta) \qquad (7.2.15)$$

This equation is more often encountered as the Harrod-Domar equation of which more later.

The distinctive feature of the model developed in this section is that the average productivity of capital (Y/K) is constant over time (note the contrast with the neo-classical model where Y/K varies as we move along the neo-classical production function). Hence, the growth rate of per capita output is also constant and equal to:

$$\gamma = sA - (n+\delta) \qquad (7.2.16)$$

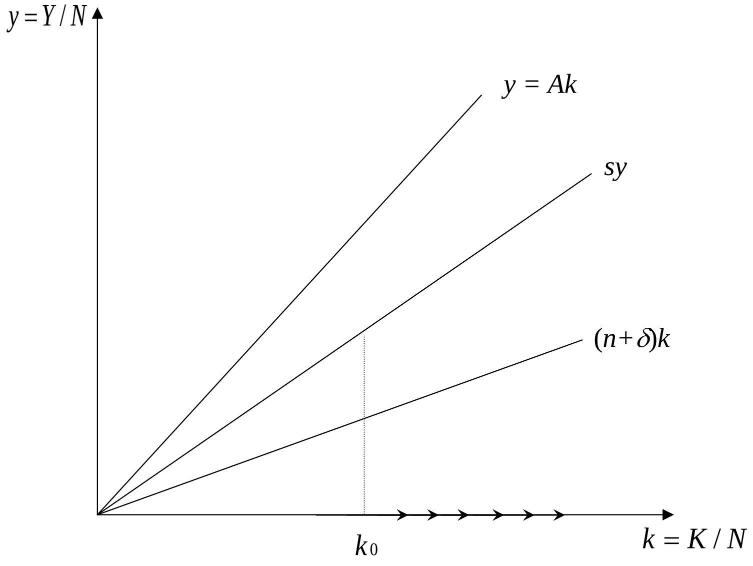
This equation states that the growth rate of per capita income rises with the efficiency level (A) and the saving rate (s) and declines with the "depreciation" of the capital-labour ratio (n and δ). Further, because the growth rate of per capita income depends on parameters that can be influenced by policy (s, A), this model can more easily embrace the numerous possible links between policy and growth. It is commonly labelled a model of *endogenous growth*.

8.2.2 A Graphical Illustration

Figure 8.2.1 shows the dynamics of this model. The horizontal axis measures the capital labour ratio (*k*). The vertical axis measures output per capita. The top line shows the path of output per capita as *k* increases (this is the production function in the intensity form, 7.2.10); the middle line shows the corresponding path of gross savings (the first term in the RHS of 7.2.11); the lower of the three lines shows the path of the break-even investment line, defined as the one that just preserves a constant *k* (the second term in the RHS of 7.2.11).

Because the production function is linear in k, the locus representing gross savings never crosses the break-even investment line (compare this with the Solow model, in Figure 7.1.1). This means that there is no steady state. As long as $sA>n+\delta$ in Equation (7.2.16), per capita output will grow forever[20]. Note that this conformity with real world experience (the stylised facts) is now achieved without the need to postulate any exogenous technological progress, as was done in Sections 7.2 and 7.3.

Figure 8.2.1: The AK model



8.2.3. Now what happens if the saving rate rises?

To next see how changes in the parameters affect growth, consider first a rise in the saving rate (in Figure 8.2.1, this leads to an upward shift of the saving schedule). Since all the remaining parameters of equation (7.2.16) are unchanged, this means that the growth rate of per capita income rises permanently.

Figure 8.2.2 compares how the paths of per capita income would differ in first the Solow model with exogenous growth and second in the AK model, following a once-and-for-all rise in the saving rate at time t_0 (the case with the Solow model was already discussed in detail in Section 7). The top part of the diagram shows levels (in logs) and the bottom part shows growth rates. Comparing the two models, one observes that:

- In the Solow model the rate of growth of per capita income rises instantaneously at the time when the saving rate rises, but then it declines over time, until the previous growth rate (given by the *exogenous* rate of technological progress) is reached (t_1). Because of diminishing returns, the long run growth rate of per capita output in that model is independent of the saving rate.

---

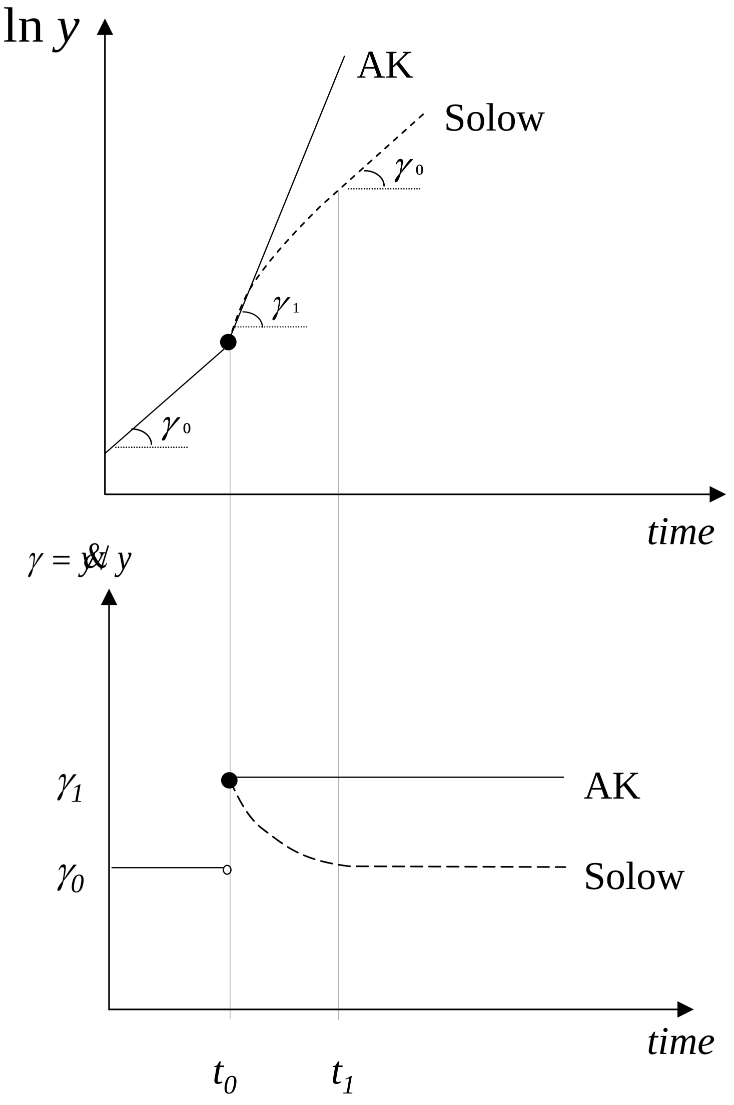
[20] Note that $k=0$ is the only steady state of this model. It is an unstable equilibrium, because if it happens to be disturbed, the economy will engage in a never ending growth process (it would be a stable equilibrium if $sA<n+\delta$).

- In the AK model, the rise in the saving rate has a *permanent* effect on growth, as there is no longer any tendency for the growth rate of per capita income to decline as time goes by. The growth rate of per capita output is, each moment in time, proportional to the saving rate.

Thus, the AK model goes far beyond the neo-classical model in stressing the relationship between capital accumulation and long-run growth. An implication is that all kinds of taxation and other policies that can affect the consumption-saving decision can also affect the accumulation of physical capital and hence the growth rate.

Note however that it is not only changes in the saving rate that affects growth permanently. Changes in the parameter A impact on long run growth, too. This suggests that differences in growth rates can also be explained by differences in aggregate efficiency, as embodied in "A" and irrespective of how this is achieved.

Figure 8.2.2: The AK model and the Solow model compared for a rise in the saving rate



8.2.4. The Harrod Domar equation

To further compare the AK model with the Solow model, let us use the Harrod Domar equation, (7.2.15) and compare it with equation (6.4.15). Although the two equations look similar, they differ in respect to the parameters that are exogenous and endogenous. Specifically:

- In the Solow model, a rise in the saving rate leads to a higher level of capital per worker, *k*, in the steady state and, hence, to a lower average productivity of capital. That is, Y/K declines (remember Section 6.4.6).
- In the AK model, *Y/K* is constant and equal to *A*. Hence, a rise in the saving rate can only be accommodated in the model by an increase in the growth rate of per capita income, γ.

Summing up, in the AK model, *Y/K* is exogenous and γ is endogenous. By contrast in the Solow model, γ is exogenous and *Y/K* is endogenous.

8.2.5. No convergence

Another feature of the AK model is that it does not predict convergence, even for similar economies. According to (7.2.16), two economies having the same technology and savings rates will enjoy the same growth rate regardless of their starting position. This means that their per capita incomes will remain in constant proportions to each other (evolving in parallel) and there will be no tendency for the poorer economy to “catch up”.

Moreover, since changes in technology (A) and in the saving rate (s) affect the growth rates permanently, the over-time series of per capita income any two countries may drift apart.

It is easy to see why this far less “certain” set of results is more in keeping with the ideas of the early development economists than are the highly structured and definitive statements about growth that emerged from the Solow model.[21] Box 8..1 illustrates another popular proposition of the early development economists that low level equilibrium traps and vicious circles are an intrinsic feature of the development situation..

Box 8.1: Low-Level Equilibrium Traps and Multiple Equilibria

The Solow neo-classical and the AK models result in *different* predicted statements about growth rates. But both models in the absence of specific disturbances suggest smooth trajectories of growth (e.g. of income per capita) over time. In order to generate the multiple equilibrium solutions (and low level traps) that are frequently seen in the literature some non-linearity needs to be introduced into one or more of the underlying functions.

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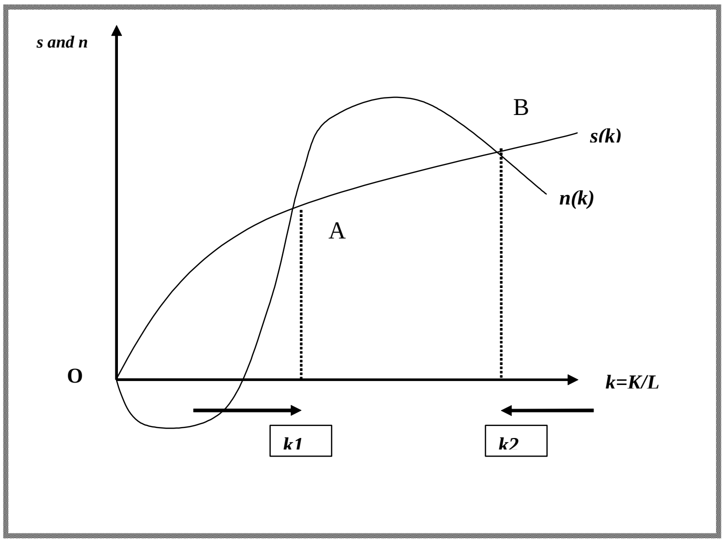
[21] However, one view of this as recently articulated by Jaime Ros (2006) is that whereas the neo-classical model predicts more convergence than is observed in the real world, the *unconstrained* models of endogenous growth predict too little convergence (i..e.. too much *divergence*). This problem is avoided in the AK model because it restricts the coefficient of capital in aggregate production to *unity* .However, until the value of this coefficient (i.e. unity) can be confirmed empirically, the propositions of the AK model need to be regarded largely as theoretical. The earlier economists Ros argues had models in which either convergence or divergence might be possible.

Malthus

The Malthus model as described in Box 7.1.2 above does this by assuming that the rate of population growth behaves differently at wage rates *below* the subsistence level (when population falls) and *above* that wage rate (when population increases). This can result in the low level trap described in Box 7.1.2 above. Something akin to the Malthus result can be generated by making both the savings rate and the population growth rate functions of k = K/L. For the savings function this idea is already familiar. For “n” it requires a non-linear function in which (i) population growth is negative when k is very low (ii) population growth rises beyond a certain critical threshold value of k and (iii) population begins to decline at high levels of k which imply high incomes. This case is illustrated in Figure 8.2.3. below where we see a low level equilibrium trap at point “A” when k= k1. The economy somehow needs to make the “big push” to point “B” to avoid this equilibrium trap. (Source: Burmeister and Dobell(1990)

Figure 8.2.3



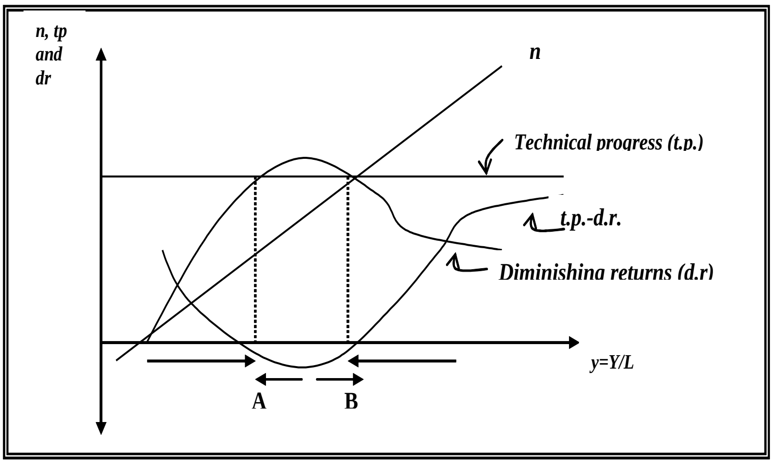
Inadequate rates of savings

A similar result can be achieved in a different way if savings rates at very low incomes are very low and also rise quite slowly as k rises. This is the idea behind the early Lewis and Rostow propositions about growth and it has gained a recent new lease of life – albeit with much controversy – in Sachs (2005). It means that at low incomes the savings response to higher “k” is below the response of “n” (which could now be linear as in Figure 8.2.4 below). Only when this positioning is reversed can the low-level equilibrium be escaped from.

Changing rates of Diminishing Returns

A similar result can be generated by assuming differential rates of diminishing returns to land as incomes rise. At low levels of income food consumption is very important in household budgets and so any increase in income gives rise to large increases in food consumption that challenge the ability of the economy to produce enough extra food on the fixed supply of land. But beyond a certain income level this effect becomes progressively less important (the income elasticity of the demand for food is less than one) and also starts to be dominated by the constant annual rate of technical progress. This all works without introducing any non-linearity into the population growth function as illustrated in Figure 8.2.4 below. This model generates a low-level equilibrium trap at point “A” which is relieved only when the economy (somehow) makes it to point “B”. Source: Hahn and Matthews (1965).

Figure 8.2.4



Finally it is worth noting that none of these three approaches to modelling low level equilibria enjoy much empirical support as *general propositions.* They may might apply to some individual countries but not to developing countries *in general*. To find the more general statements about why some groups of countries (e.g. the HIPCs) fail to escape from low incomes we do better to embrace more recent analysis and institutional literature which focuses on determining factors such as military and civil conflicts, natural resource problems and weak governance (see Part IV).

8.2.6 Transpiration (effort and sweat) responds to inspiration!

Thus far, the saving behaviour in this economy has been assumed exogenous. In this section we show that, when the model is modified so as to allow individuals to optimally choose the saving rate, a second channel linking efficiency to growth is opened up.

The optimal saving rate is the one that achieves the desired balance between today's sacrifice of permanent consumption and the higher growth prospects in the future. A model that captures this makes use of the optimal consumption rule:

$$\gamma = r - \rho \qquad (7.2.17)$$

In (7.2.17), ρ is the rate of time preference. If factors are paid their marginal productivities (remember equations 6.3.8 and 6.3.9), then the user cost of capital will be such that:

$$r + \delta = A \tag{7.2.18}$$

Substituting (7.2.18) in (7.2.17) and rearranging, one obtains the growth rate of per capita income as a function of the rate of time preference:

$$\gamma = A - \delta - \rho \tag{7.2.19}$$

Equation (7.2.19) shows that a lower rate of time preference (a change in consumption preferences in favour of more future and less present consumption), by raising the economy's current saving rate, also implies a higher growth rate of per capita income.

Comparing (7.2.19) to (7.2.16), we observe that the impact of *A* on growth is now much higher than with an exogenous saving rate. For a saving rate of, for example, 20%, according to (7.2.16) the impact of a unitary change in *A* on growth is 0.2. In (7.2.19) the impact of a unitary change in A is 1, that is, four times more.
What makes the assumption of endogenous saving so powerful is that it can alter so dramatically the relationship between efficiency and growth?

The reason is that, when *A* rises, there are now two things happening:

- First, as *A* rises for a *given s*, the growth rate rises, just as in (7.2.16);
- Second, when A rises, there is now an additional effect through the interest rate, *r*: as the marginal productivity of capital rises, this leads to a higher interest rate and hence to a higher saving rate, for a given rate of time preference. And if the saving rate rises, the economy grows faster.

This finding is of the utmost importance for understanding the mechanics of endogenous growth models. A typical assessment based on equation (7.2.16) is that a country may either grow through "inspiration" (A) or through "transpiration" i.e. sweat and hard effort. But as we just saw the "transpiration" effect can also respond to "inspiration". If the economic environment is favourable to a more efficient resource allocation, the marginal productivity of capital will be higher, the return on investment will be larger, and this in turn will induce a higher savings rate.

With this finding, one may rewrite equation (7.2.16) in the following form:

$$\gamma = s\left(\overset{-}{\rho}, \overset{+}{A}\right)A - (n + \delta) \tag{7.2.20}$$

Equation (7.2.20) gives the efficiency term, A (and hence any economic policy that can influence "A"!) an enormous responsibility.

8.3. The financing gap

8.3.1. Historical context

The true predecessor of the AK model was developed by Roy Harrod (1939) and Evsey Domar (1946) in the aftermath of the Great Depression, as a dynamic extension of Keynes' general theory. Harrod and Domar independently explored the logical consequences of a linear relationship between output and capital. The linearity was achieved in part by assuming that the labour market is always characterised by excess supply so that wages do not need to change in order to correct any imbalances between labour supply and demand.

Their work preceded that of Solow by several years and so obviously it was not motivated by any explicit intention to improve on the Solow model. Instead, both Harrod and Domar used their models, largely inspired by the Great Depression, to discuss business cycles in the U.S. economy. However, following a seminal extension by Sir Arthur Lewis (1954) to discuss the obstacles to growth in economies with high open or disguised unemployment, the model rapidly became a benchmark in the high development theories of the early years.

The assumptions of the basic model are extreme. But their simplicity provided them nevertheless with a great deal of residual appeal to policy-makers. Since this appeal persists, this model and variants of it need to be a part of our own deliberations. As discussed at the end of the chapter, aid donors have often used the linear assumption (i.e. a specified amount of extra K will achieve a predictable amount of extra Y) when they have sought to calculate how much extra capital a country may need to achieve any particular growth rate. This has commonly been the approach for example used to work out the volumes of foreign aid needed to achieve any particular growth target. Since the year 2000 it has been adapted for the calculations of the aid needed to help achieve the Millennium Development Goals by 2015.

8.3.2 Surplus labour

To motivate the following discussion, consider a developing economy with two coexisting sectors, a large "traditional" sector (say, agriculture) and a "modern" (formal) sector (say industry including mining). Assume that the traditional sector basically uses non-reproducible factors, such as labour and land, and follows the Malthusian rule that wages evolve over time close to the subsistence level with any improvement in technology being matched by population expansion. The "modern" sector, in turn, also employs a reproducible factor (capital) and may draw any amount of labour from the traditional sector. It will typically make use of some more advanced technologies. Economies of this type are called *dual economies.*

Assume also as did Lewis (1954) that population is so large relative to the available land that the marginal productivity in the traditional sector is zero: that is, one could reduce the number of workers in agriculture without affecting the total level of agricultural output. This situation is referred to as one of *disguised unemployment* and has been much researched especially to test its empirical validity in particular countries. (See, for example the survey on this topic in Eicher and Witt (1964)
Does this mean that wages in agriculture should be zero? No that would be unlikely at least in general. True, in a modern society a profit-maximisation firm, that will regard all wage bills as a cost, would hire labour only to the point where its marginal productivity equals the wage rate (remember equation 6.3.8). In traditional societies, however, values are not necessarily the same and workers with zero marginal

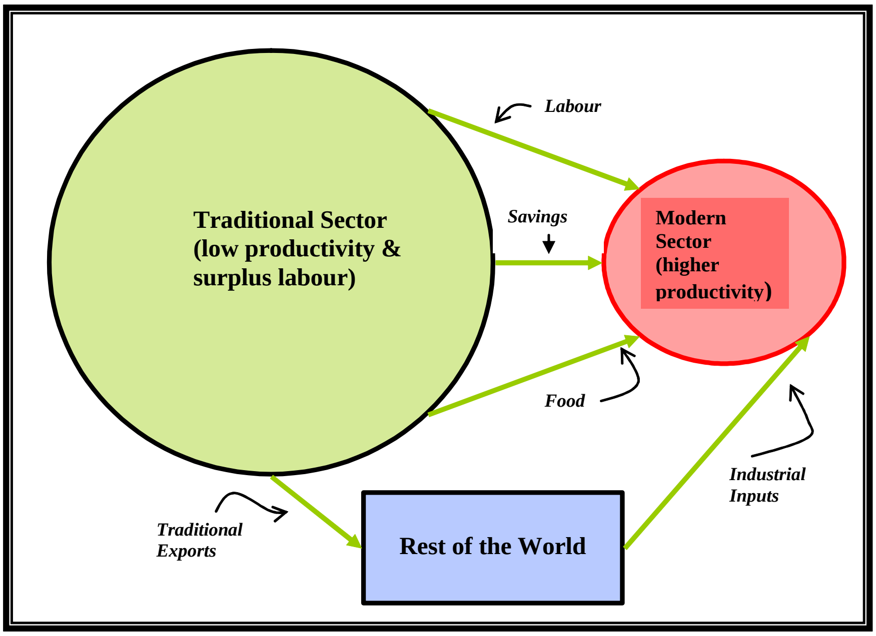
productivity will usually receive some in-kind payment especially if they are a part of a family productive unit. In many low-income countries significant numbers of farmers are landless, tilling the landlord's land under share-cropping arrangements, in which the landlord gets a large slice of the output. The family farm, in turn, may value the incomes received by each of its members. One possibility is to share the output equally among the family members. In that case, wages will be linked to *average* rather than marginal productivity. Even if the family size is so large that some child workers could be freed from working on the family farm entirely without affecting total production (i.e. their marginal productivity is zero), parents may not do that.

Box 8.1 provides a graphical description of the main features of the Lewis model and how it translates into growth.

Box 8. 1: Key Features of the Lewis Model with Surplus Labour

Labour is Released

The development of this economy relies on the fact of *surplus labour* in the initially large traditional sector which means that LABOUR can be released from this sector with only a small or even a zero loss of traditional (e.g. agricultural output). So the modern sector where productivity is much higher can obtain this labour at low cost even though the wages paid there will be higher than the incomes that the migrants leave behind when they depart from their traditional sector jobs. The process slows as that surplus labour is gradually drawn down..



Food is Supplied

However, as the Modern Sector expands it needs increased food supplies food supplies even though there are increasingly fewer workers now producing food. Here again the assumption of a low or zero marginal product in the traditional sector plays a key role. If this assumption is correct there need not be any loss of agricultural output as the migration to the modern sector occurs. However something does need to happen to organise the delivery of food to new locations (e.g. private trading or forced deliveries as for example during the Soviet push for industrialisation under Joseph Stalin in the 1930s).

Foreign Trade Balance

A third role is played by the traditional sector in delivering part of its output for exports to international markets. The foreign exchange so earned can be used in part to purchase the essential inputs into the expanding modern sector that cannot be produced domestically.

Hidden Savings

Finally the economy benefits from this form of transformation in that the work-effort of those workers released from the traditional sector are in effect converted into savings. To see this note that these workers were previously producing little or nothing at the margin but were still consuming food etc. (probably at something like the subsistence level). In the modern sector they are producing a positive contribution to output and so long as their consumption levels do not rise disproportionately, they will be providing a new form of savings to the economy.

Contradictions

The reader is encouraged to look for a number of tendencies in this type of economic transformation that clash with each other in ways that can eventually halt the successful development as described above.

8.3.3 Rural-Urban migration

In many countries, the transfer of labour from the traditional sectors to the modern sectors translates into an increase in the urbanization rate. But the relationship is not necessarily proportional. The reason is that, when workers move from rural areas to cities, they are not necessarily blessed with a formal job. The higher wages in the modern sector sometimes attract much more migrants than what the modern sector can absorb, resulting in high rates of urban unemployment. In these cases, workers just move from an informal activity in the rural area to another informal activity in the urban area, with lower quality of life[22].

8.3.4 Complementary inputs

For the purposes of our discussion, it does not matter whether excess labour comes from rural areas or from urban unemployment. The main point is that the labour surplus cannot be immediately absorbed by the modern sector because the scale of the later is limited by the supply of capital. Thus, the only way of improving production in this economy is by expanding the stock of physical capital. In such an economy, capital accumulation in the modern sector is the engine of growth.

To put this formally, assume that capital and labour are complementary inputs, rather than substitutes in the production function. In this case, factor prices play no role in promoting full employment. The implied production function is a so-called "Leontief" of fixed coefficient function[23]:

$$Y_t = \min\left\{\frac{K_t}{v}, \frac{N_t}{u}\right\}. \quad (7.3.1)$$

In (7.3.1), *v* and *u* are fixed coefficients.

To illustrate, we depict in Figure 8.3.1 a case in which *v=1* and *u=2*. Think, for example, that *Y* is a restaurant meal involving one steak with two eggs. To produce one meal (one unit of *Y*), you need at least one steak, *K*, and two eggs, *N* (Point A). If an economy has one steak and 8 eggs, production will still be equal to only one meal (point B), but in that case there will be unemployment of eggs (at point B, 6 eggs will go to waste). Even though eggs prices were to decline, since the producer cannot substitute eggs for steak, such unemployment will not be absorbed, unless more steaks also become available. If we managed to raise the number of steaks in production to *K=2*, the output level would jump to *Y=2* meals (at point C the eggs going to waste is now reduced to 4 eggs). Raising production by employing more steaks (*K*) in an economy with surplus eggs (*L*) is basically how the model works.

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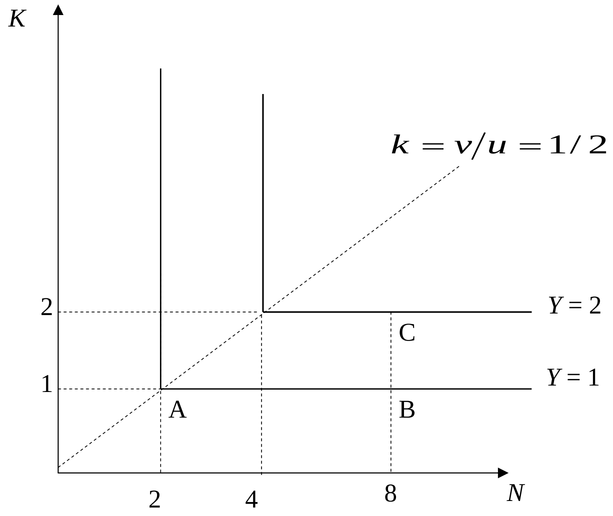
[22] This means that the decision to migrate should depend on the *probability* of finding a formal job in the modern or urban economy. A theory of rural-urban migration addressing such complications was first developed by Harris and Todaro (1970). It suggest an equilibrium in which the urban:rural wage differential is associated closely with the rate of urban unemployment.

[23] This is after Professor Wassiliy Leontief the Russian economist and Nobel Laureate (1973) who spent much of his professional career at Harvard University and who is one of the pioneers of input-output analysis and its use in economics.

Figure 8.3.1: The Leontief production function



8.3.5 The Harrod-Domar model

Assume that initially we have a surplus of labour for reasons that may include those just described. In Figure 8.3.2, the initial position of the economy is represented by point A (note that the capital-labour ratio at point k_A, is lower than the full employment level, $k = v/u$). (NOTE to self – position of "A" is wrong needs to move to right)

In this case, the relevant segment of the production function is:

$$Y_t = \frac{1}{v} K_t \tag{7.3.2}$$

This function is linear in K - note the similar structure to (7.2.1). Thus, the model solves exactly as the AK model.

As before, assume that a constant fraction of income is devoted to capital accumulation:

$$sY = \dot{K} + \delta K \tag{7.3.3}$$

The growth rate of per capita income and capital per worker is:

$$\gamma = \frac{s}{v} - (n + \delta) \tag{7.3.16}$$

Since *v* is exogenous, a rise in the saving rate leads to a rise in the rate of economic growth. Just as in the basic AK model, the model assumes that growth is constrained by the availability and productivity of capital. All we have done is to replace the generalised measure of productivity "A" in the AK model by the term *1/v* in Equation 7.2.1.

8.3.6. The financing gap

One of the reasons why the Harrod Domar equation became so popular is that it offers a simple formula to forecast economic growth. All we need to know is the economy's saving rate, a depreciation rate and a value for the output-capital ratio. Since data on the stock of capital are not usually available, a common procedure is to proxy the marginal productivity of capital (A) by the ratio of net investment to the change in real GDP over two consecutive years. Specifically,

$$ICOR = \frac{\Delta K}{\Delta Y} = \frac{net \quad investment}{change \quad in \quad GDP}$$

This is the so-called "Incremental Capital-Output Ratio", ICOR. As an example, consider a poor economy where the ICOR = 4 and the observed savings and investment ratio is 4%. This implies that output will grow at 1% (i.e. 4%/4). Now suppose you are, say, a World Bank economist for that economy, charged with advising on poverty alleviation. You may well regard the predicted growth rate as too low. If the population grows at 2%, this means that per capita income will actually decline at the rate of 1% per annum.

You may, then, use the HD equation the other way around. If you assume that the productivity of capital is constant, then to achieve a faster growth rate you only need to increase the level of savings. And the question is what would be the investment rate necessary to reach a given target for output growth?

Suppose you want output per capita to grow at 2%. With the population rising at 2% and a measured ICOR equal to 4, according to the model, you need a net investment amounting to 16% of GDP (i.e. (2%+2%)x4). Since domestic savings are only 4%, you will need to ask international donors to fill the "financing gap" of find some way to engineer policy changes that can help achieve a higher savings rate.

8.3.7. Growth Engineering

Economists in international institutions, such as the World Bank, the IMF, the Inter-American Development Bank, the European Bank for Reconstruction and Development used or still use models based on the HD equation to estimate the amount of savings (and/or aid) necessary for poor countries to achieve a minimum rate of economic growth[24]. This philosophy is supported by the understanding that people living near the subsistence level cannot save the same as people enjoying a high living standard. Foreign aid could fix this. If the external aid succeeds in raising per capita output, then probably the domestic saving rate would respond, allowing the country to engage in higher self-sustained growth. In short the support from aid need only be temporary[25].

This interpretation of the HD equation was seriously criticised by William Easterly (1999) in an insightful paper called "The ghost of financing gap". The author noted that, over the past four decades large amounts of financial assistance of western

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[24] The World Bank's long-established model in this tradition is referred to as the Revised Minimum Standards Model (or RMSM). It is explained in detail in Mohsin Khan et al (1990)

[25] We invite the reader to adjust the Harrod-Domar model so as to analyse the implications of having a saving rate that depends positively on per capita income.

economies to the developing world did not translate into faster economic growth. Using a sample of 146 countries for the period from 1950 to 1992, the author failed to find a robust positive linear relationship between the amounts of aid received and countries' differential rates of GDP growth.

Does this mean that the HD equation is wrong? Not necessarily. But certainly one should not put too much trust in the historical value of "A" – as it comes out in the ICOR formula - to apply also to all new investment and still remain constant, irrespective of the economic conditions in place.

External aid is channelled through complex political systems that may deviate significantly from that of the theoretical benevolent planner. Sufficiently poor economic management on the part of the beneficiary governments may render foreign aid ineffective. If, for example, price distortions, directed investments, or other administrative interventions prevent resources from being allocated efficiently, or if part of the external aid is diverted into unproductive uses (frivolous expenses, corruption fees), then part of the incremental capital will be wasted. In terms of the HD equation, this means that the output-capital ratio will decline (probably to zero, at the margin), instead of being constant, so that the higher (augmented) saving rate will be offset by a lower A.

Moreover, since poor policy environments provide weak incentives for investment, it may be the unintended consequence that foreign aid to a bad-policy country will crowd out domestic savings: in the end, *s* may not increase at all even when aid is added in! To this, one may add the possibility that large amounts of financial aid to a country with poor economic institutions may **encourage aid-dependence, enrich the elite and perpetuate bad governments in power,** retarding the reform. This range of issues on which there is a huge literature will be the subject of more in-depth discussion in Part IV of the book.

8.3.8. Conclusions

The Harrod-Domar model is the earliest incarnation of the AK model. Because it offers a simple and appealing formula to help forecast economic growth, the Harrod Domar model has been widely used by international institutions to ascertain whether the domestic and external financing available to a particular country is adequate to achieve any given target for economic growth. Growth targets in turn have more recently been deemed necessary to help poor countries achieve the specific anti-poverty targets of the MDGs. Whenever the available resources were insufficient, the model could then be used to compute the amount of external aid a particular developing countries would need to achieve the desired rate of economic growth.
Empirically, however, there is little evidence of any positive relationship between aid volumes received and growth. This suggests once again that capital availability should not be overstated as the main driver of economic growth. The alternative message is that efficiency in resource allocation probably matters at least as much if not more.

8.4. Externalities on Capital Accumulation

8.4.1. Introduction

We return now to the problem of the insufficiently large role for capital in the Solow model as posed in Section 7.3 above.

One possible way of accounting for a larger role for physical capital in production than that implied by the capital income share (β) of the Solow model is by recognising the existence of externalities. Externalities are present whenever an individual takes an action that directly affects others but for which he or she neither pays nor is paid a compensation. In a famous paper in 1986, Paul Romer proposed an important role for externalities associated with investment in physical capital. A related work from Robert Lucas in 1988 emphasised the role of externalities associated with investment in human capital. These externalities they both argued may lead to non-declining marginal productivities of physical and human capital in the economy *as a whole*, even though marginal productivities are decreasing at the level of the individual firm. This in turn can lead to unceasing capital accumulation rather than to accumulation truncated by declining marginal returns as is the case with the basic neo-classical production function.

8.4.2 Learning by doing

Romer in his 1986 paper combined the assumption of externalities associated to capita accumulation with the theory of “learning by doing” developed much earlier by Kenneth Arrow (1962).

The theory of Arrow (1962) was the first rigorous attempt to endogenize technological progress. Arrow (1962) was inspired by the concept of a “learning curve”, a systematic relationship between cumulative production experience and average costs. The idea is that learning about how to use any new equipment and adapting existing production processes so as to extract full profit from the new opportunities will often take time. So as workers become more accustomed to the new capital good, the firm’s stock of technical knowledge increases. Arrow (1962) formulated this by assuming that learning by doing was an unintended by-product of investment in physical capital. That is, when a firm acquires a new capital good, it also buys a new production *technique*. Thus, in his model, technical change involves no deliberate economic decisions. Instead, it occurs as an inadvertent by-product of production and the acquisition of new equipment.

Romer (1986) added to this mechanism the idea that *knowledge leaks*. In other words people have an incentive to observe what others are doing and to imitate the best practices of the day. With this combination, Romer (1986) proposed a key to generate economies of scale while preserving perfect competition at the firm level: each firm, perceiving a CRS production function, buys new capital equipment until the marginal revenue generated equals its user cost. By buying new capital, the firm will inadvertently increase its stock of knowledge, but this effect may be small. However, because knowledge leaks, the acquisition of physical capital by each individual firm will add to a *common* stock of economy-wide knowledge, and this in turn can impact positively on the productivity of all firms. In the aggregate, each firm will be more productive, the higher is the stock of capital in all the other firms. While at the firm level there are diminishing returns on capital accumulation, at the aggregate level there might be increasing returns.

Box 8.2 describes a case study for this theory identified and described by Willam Easterly

8.4.3. Individual and aggregate production functions

These ideas can be formalised by assuming that there are many producers in this economy. The production function for the individual firm *i* is given by:

$$Y_{it} = BK_{it}^{\beta}\left(N_{it}\lambda_t\right)^{1-\beta} \qquad (7.4.1)$$

The subscripts "*i*" and "*t*" denote, respectively, firm *i* and time *t*, and the other variables are defined as before. For example, Y_{it} denotes the production of firm *i* at time t.

In the Solow model, the effective labour input per worker, λ, grows at an exogenous rate. In the Romer (1986) model, this variable depends on the aggregate capital stock. Specifically, it is assumed that:

$$\lambda_t = Ck_t \ , \qquad (7.4.2)$$

where $k = K/N$ and *K*, *N* stand for the aggregate levels of capital and labour. According to (7.4.2), the efficiency of labour in a particular firm depends on the prevailing capital labour ratio in the economy as a whole. This captures the external effects associated with investment in physical capital[26].

If all firms are identical, the aggregate production function becomes:

$$Y_t = AK_t \text{, with } A = BC^{1-\beta} \qquad (7.4.3)$$

Hence, the aggregate production of the whole economy becomes linear in *K just as in the basic AK model introduced earlier.* . As in the simple AK model, the growth rate of this economy is given by (7.3.15). Note how the basic structure of the simple AK model can be used here as well even though diminishing returns at the level of the individual firm still apply[27]. In short the model does not really get rid of diminishing returns at all. Instead it proposes an ingenious way to side-step the growth retarding effects of diminishing returns.

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[26] This section deals specifically with the case in which there are externalities associated to physical capital. But you may also interpret K in a broad manner, so as to include Human Capital.

[27] It is important to observe that the aggregate production function (7.4.3) is exactly linear in K, because the size of the externality is assumed to be exactly enough to overwhelm the normal process of diminishing returns on capital. Because neither Arrow (1962) nor Romer (1986) postulated such a convenient form, their models exhibit scale effects. We will return to these *scale effects* in chapter 9.

Box 8.2: Noorul Quader's Desh Factory

William Easterly in his recent book *The Elusive Quest for Growth* published in 2001, provided a nice illustration of how spill-over effects associated with learning by doing may induce economic growth.

The story starts in 1979, when Daewoo Corporation, a major world textile producer from South Korea, was looking for a new base to evade the US and European import quotas against Korean products. Since these quotas did not cover Bangladesh, the company created a joint venture there with a former government official called Noorul Quader to produce shirts. The new company, called Desh Garment Ltd, start producing in April 1980. Since there was no real experience of shirt production for export in Bangladesh, the 130 Bangladeshi garment workers including marketing and other management staff were trained in Korea. This familiarisation with modern production and marketing techniques allowed the Daewoo collaborative agreement to have long lasting effects in Bangladesh. Bangladesh too became a highly significant exporter of textile products. The following quotations are transcriptions from Easterly (2001), pp 148-149:

"Of the 130 Desh workers trained by Daewoo, 115 of them left Desh during the 1980s to set up their own garment export firms. They diversified into gloves, coats and trousers. This explosion of garment companies started by ex-Desh workers brought Bangladesh its $2 billion in garment sales today" .... "The story of the birth of the Bangladeshi garment industry illustrates the principle that investment in knowledge does not remain with the original investor. Knowledge leaks". ... "Why hadn't Bangladeshi already been making shirts on their own, before Daewoo volunteered its service? The answer is that Daewoo had learned something about how to produce shirts and how to sell them on the world market. ... and transmitted this knowledge to Desh workers". ... "Creating Knowledge does not necessarily mean inventing new technologies from scratch. Some aspects of garment manufactory were probably several centuries old. The relevant technological ideas might be floating out there in the ether, but only those who apply them can really learn them and can teach them to others".

8.4.4. Private and social returns to capital

The novelty in models such as Romer's with externalities is that there will be a divergence between private returns and social returns to investment. Thus, in a laissez-faire equilibrium (i.e. one with no government intervention), investment levels will be sub-optimal. To see this, note that factor incomes are determined at the firm level and each firm disregards how its decisions affect the other firms' profits. Analytically, each firm maximises profits taking labour efficiency (λ) as given. Firms therefore employ labour and capital until the "perceived" marginal productivities in (7.4.1) are equal to their respective factor prices:

$$w_t = \frac{\partial Y_i}{\partial N_i} = (1-\beta)\frac{Y_i}{N_i} = (1-\beta)y_t \qquad (7.4.8)$$

and

$$r+\delta=\frac{\partial Y_i}{\partial K_i}=\beta\frac{Y_i}{K_i}=\beta A \qquad (7.4.9)$$

According to (7.4.8) and (7.4.9), wages grow in line with per capita income while the interest rate is constant and equal to $r=\beta A-\delta$. The capital income share is β. These results are consistent with the stylised facts as presented in Chapter 5.
Note, however, that the "Social" marginal productivity of capital, including externalities is now *A*, not βA (equation 7.4.3). This means that there is a wedge between the actual marginal productivity of capital and the interest rate. In other words, the free market will not lead to the best possible outcome and the highest possible growth rate.

8.4.5. The social optimum

The wedge between social returns and private returns to capital accumulation constitutes a market distortion. To remove this distortion, the government should set the rental price of capital so as to make it reflect fully the social marginal product of capital. Specifically, the optimal interest rate, r*, should be:

$$r^*=A-\delta \qquad (7.4.9a)$$

An important implication of this model is that removing the distortion leads to a higher rate of economic growth. To see this, instead of taking *s* as exogenous, consider the optimal consumption rule (7.2.17), which we repeat here:

$$\gamma=r-\rho \qquad (7.2.17)$$

Substituting the user cost of capital that results in the competitive equilibrium, (7.4.9), one obtains:

$$\gamma=\beta A-\rho-\delta \qquad (7.4.10)$$

If the interest rate was changed so as to reflect the social contribution of capital (equation 7.5a), the growth rate of the economy would be higher at :

$$\gamma^*=A-\rho-\delta>\gamma \qquad (7.4.11)$$

How might government policy be used to establish the socially optimal (rather than the market) interest rate in order to extract this extra boost to growth? This could be done for example by introducing an investment tax credit at the rate $1-\beta$, financed with a lump-sum tax, so that private firms buy one unit of capital at the cost β. With such a policy, the rate of capital accumulation would be socially optimal and the growth rate of the economy would be much higher than in the decentralised economy.

This is just one example of how judicious government intervention might be used to establish the "right" prices to stimulate growth. But note too that the advocacy of such a course of action requires a high level of confidence about the magnitude of the external effect, as well as technically competent and honest government officials to implement the policy.

8.4.6. Externalities associated to Human Capital

Lucas (1988, 1990) extended the insights from Romer by stressing the role of externalities associated with Human Capital. The main idea here is that new knowledge is complementary to existing knowledge.

To understand this, ask yourself why economics graduates from Harvard, the LSE, MIT or your own university or college (if not one of those listed) may prefer to work in Wall Street or in the City of London – where economics graduates are plentiful – rather than in, say, Mongolia where they are in very short supply! The Harvard/LSE/MIT economists on Wall Street or in the City earn their high incomes in part because of the manner in which their own efforts are augmented by those of fellow well-educated economists.

This happens because individuals benefit from interacting with each other and exploring complementarities. Exchange of ideas and interaction with other professionals in the same field of endeavour can enhance the individual capabilities (and outputs) of each of them. If this effect is strong enough to overwhelm the normal diminishing returns to skills as skills get more abundant, then skilled labour will not necessarily be more valuable where it is scarcer: e.g. in Mongolia. Indeed working as a great expert in a location where few understand even the basic concepts of economics can be a daunting and ineffective experience. Inversely, the returns to skills for the individual will go up with the existing skill average in the society.

Thus, just as on an assembly line, where the value of each worker's effort depends on the other worker's efforts, if the best economists are *assembled* together, they are likely to have better ideas and will get a higher payoff from their skills. If, instead, they are partnered with poorly trained and ineffective colleagues, they will have a lower reward for any effort that they might individually provide. This creates an incentive for the best workers to stay together and a disincentive for good economists (for example) to take up one of the very few jobs for economists in Mongolia.

Note that this is exactly the opposite of the results that are predicted by the LDR. With diminishing returns, skills substitute for each other, so they become more valuable where they are scarcer – in Mongolia and not on Wall Street or in the City! Hence, under diminishing returns, while some labour might tend to migrate from poor countries to rich countries, skilled labour would tend to stay in poor countries.
By contrast when externalities are present, human skills have increasing returns and so skilled workers tend to migrate and cluster around other skilled workers. People who get educated in a society with little knowledge do not benefit as much as those in a knowledge-abundant society. The few Mongolian nationals trained in economics are more likely to seek work on Wall Street than are the Harvard/MIT graduates to move to Mongolia.

This story illustrates how the private returns to the skills of the individual may be inextricably bound up with the existing skills in the society. A recent example of this is described by Thomas Friedman in his recent provocative book entitled *The World is Flat* (2005). He describes that in the days before the Indian economic reforms of the early 1990s (see the Figure in Chapter 4 that indicates the consequences of these reforms for India’s growth), it was common for well-trained Indian IT and other specialists to queue for days to obtain visas to work in the USA. But the new attitudes and economic opportunities in India in the past 15 years have created the new IT-based and other modern industries that are now attracting thousands of those highly trained person back into the Indian market to seek work alongside a significantly larger proportion of the new Indian graduates

Lucas (1988) argued that the across-household externalities could explain why we often see migration of skilled labour at maximal allowable rates and beyond from poor countries to wealthy ones. But equally his analysis can help us make sense of the changing attitudes to international migration that are now very evident in the return-migration of India and some other more developed economies such as Ireland.

8.4.7. Cumulative causation

We can see from these examples that increasing returns can be a source of divergence: returns to capital, both physical and human are likely to be higher where capital is already abundant. In a nation where skill levels are already deep and well established, people in that nation will have strong incentives to invest in their own skills and stay put. But in poorer countries where the skill base is thin, the incentive of the individual to invest in human skills is also low. As in the case of good and bad assembly lines, this reality is likely to generate virtuous and vicious cycles. A country is rich because it started out rich, a country is poor because it started out poor. Significantly , this newer theory speaks to many of the same basic propositions articulated more than forty years aho by the “high development theorists” but without the benefit of similarly formalised models.

This story also makes it clear that the market itself will not necessarily create growth. Moving from the vicious cycle to the virtuous cycle may well require a conscious government intervention. For example, the public sector could get the economy out of the trap of low returns to capital by subsidizing investment in physical and human capital. In economies with sizeable income disparities, such an effort might be specially directed to poorer people or to segregated groups. The Indian reversal of skilled migration referred to above required both a large pool of already well-trained Indians (many of whom migrated to the USA or to Western Europe during the years of low Indian growth), as well as the new and more liberal policies of the early 1990s that made possible huge investments in modern IT and other important service industries especially to take advantage of the revolution in digital and related technologies. (Friedman (2005))

8.4.8. Other centripetal forces

Leaks of knowledge and human capital complementarities are two among a number of alternative mechanisms that may generate economies of scale at the level of the aggregate economy. This section describes other possibilities.

- The availability of larger markets for specialized inputs. In the simple neoclassical model, factor inputs are assumed to be homogeneous (as explained in Chapter 5). In the real world, however, some production processes are highly sophisticated and require very specialized skills. These skills are not easily available everywhere. This is why modern firms have an incentive to locate where such specialized human capital is available. The presence of a large pool of specialised inputs can be seen as an external scale economy for every single firm in that same location, since being closer to large factor markets enables firms to hire specific inputs at lower costs. On the other hand, a specialist in any industry will have an incentive to move to areas where more potential employers are located. This means a “cumulative causation” may apply to skilled workers: skilled workers go to where firms are located and firms go to where they can find the appropriately skilled (or trainable)workers are.

- Sharing costs. When various firms of the same sector are operating in the same location, it is possible to develop common infrastructures, such as training schools, a "regional" brand, an independent laboratory for quality control, promotional events, etc. So once again when a critical mass has been built, the incentives available will more readily help the cumulative development of that mass
- Infra-structures. The larger is the number of firms operating in a given location, the higher is the probability of that location being well served with public infrastructure, such as roads, ports, power supply, telecommunications treatment of waste, etc. Some government infrastructures are specific to particular industries, so that their external effects will not be uniform across industries. This form of externality is addressed in the next section.

In general, centripetal forces have been neglected by the neoclassical models and so by much of the formal development literature of the period during which the Solow model itself ruled the roost. Ironically, it was the 'father' of neoclassical economics himself, Alfred Marshall (1890), who first introduced the concept of agglomeration externalities. Some of these ideas have been used to explain regional divergences by the earlier development theorists such as Myrdal (1957), Hirshman (1958) and Kaldor (1970) but they are also central to the modern approaches to economic growth, geography and trade (see for example, Krugman, 1991, Krugman and Venables, 1995).

8.4.9. Summing up

The newer models described in this section provide us with an interesting set of implications. These include the following:

- The aggregate production function of an economy is likely to exhibit non-decreasing returns to capital (physical and human) even though we still see diminishing returns at the level of individual firms;
- The observed income share of capital in decentralized markets is likely to be much lower than its overall contribution to output once full account is taken of all the possible complementary effects
- Market equilibrium is likely to be characterised by underinvestment relative to the socially efficient outcome; the achievement of a more nearly optimal policy involves subsidizing capital accumulation.
- Positive policy incentives to capital accumulation, of various types can have a positive impact on the long run growth rate of per capita output. These may take the form either of directly targeted investment subsidies or the more dispersed incentives exampled by the liberalising Indian reforms of the early 1990s

8.5. Government services and growth

8.5.1. Introduction

We now move on from the possibilities opened up by the new models of endogenous growth to consider particular implications of these possibilities for pubic policy. In doing so we begin to touch on the issues of *institutional development* addressed in more depth in Part III of the book.

This current section focuses on one dimension of government policy intervention, which is the provision of *public inputs* to production.

By public inputs, we mean those expenditures that impact positively on the productivity of private businesses. This will typically include both a *physical* dimension - infrastructure, such as roads, highways and bridges - and an *institutional* dimension - essential “inputs” or supports to production such as the rule of law, national defence and public order. An insufficient provision of public inputs of both types implies higher costs on private business (for example, higher transportation costs, the cost of private security guards, more risk attached to any transaction than is necessary) and, hence, lower investment levels, everything else being constant.

The issue of contention arises primarily from the following opposing effects of taxation. On the one hand taxes on incomes or outputs reduce efficiency and harm growth, but on the other they provide resources for government-funded investment in public capital that helps to lower private business costs, enhances returns to private capital and hence stimulates investment. Therefore, the analysis of optimal taxation in such a framework entails a balance between its distortionary effects and its growth enhancing implications.

8.5.2. Public goods

Public goods are an extreme case of positive externalities. A “pure” public good is one that is non-excludable (i.e, if it is provided at all, it will be impossible to preclude anyone from benefiting from its availability). Additionally its consumption is “non-rivalrous” (i.e. the marginal cost of providing it to one additional person is zero (its consumption is non-rivalrous). A typical pure public good is national defence.

Even the most enthusiastic advocates of free markets recognise that these do not work at all well when goods are not excludable in consumption. Whenever it is impossible or difficult to preclude anyone from using a service or consuming a good, fewer people will go to the trouble of organising production of that good. This is because each individual will prefer *not* to pay and instead to take a free-ride on any eventual production that does appear. The result is that private markets will tend to under-supply public goods (a particular case of this is “knowledge”, as discussed in Section 7.2). Sometimes, voluntary associations emerge to collectively assure the provision of the public good. But these associations are in general fragile to the free-rider problem. They will also have limited resources to supply everyone’s requirements given their difficulties in collecting revenues to cover their costs of supply. The government has an advantage, in that it has the power to coerce citizens to pay the various taxes that can fund the public good..

8.5.3. Publicly provided goods

Many of the goods that the government provides are not *pure* public goods. A less demanding definition of a public good only requires goods to be non-rivalrous in consumption. As an example, consider a bridge that initially allows for free-flowing traffic with little congestion: it is a practical possibility to preclude people from (or discourage use by charging people for) crossing the bridge. This property makes the *private provision* of bridge crossings entirely possible. But, to the extent that the social cost of having an extra individual crossing the bridge is zero, excludability may not be socially optimal. It may also be politically unpopular and so hard to get accepted. The government can solve this problem by publicly providing the bridge.

However, as more and more individuals cross the bridge, traffic flow will begin to slow as the bridge becomes increasingly *congested*. With congestion, for a given quantity of available bridge crossings, the quantity available to any one individual declines as other users congest the facilities. The marginal cost of an extra individual crossing a bridge (defined, not only in terms of wear and tear in the bridge, but also in terms of the time lost in attempting to cross an overcrowded bridge) becomes positive, implying that charging for its use becomes desirable. Many governmental activities, such as highways, public security and courts are likely to face this type of problem in practice.

Other goods like education, health services and access to courts are not public goods in the narrow technical sense, because the cost of extending the supply to more users is significant[28]. But, because of the positive externalities involved (the community as a whole benefits from a higher education level, a lower incidence of diseases and a greater respect for the law) these services will be under-supplied in the free market equilibrium. In these cases, the private provision is feasible (because the good is excludable), but a government subsidy may still be desirable in order to boost usage to a level closer to the social optimum.

In practice, in the messy real world in which we all live, there is no clear cut distinction between goods that can *only* be provided publicly and goods that can *only* be provided privately. Because of this the adequate amount of public intervention is invariably a matter of some dispute and one that involves political as well as economic considerations.

8.5.4. Modelling the impact of public goods on productivity

Consider now an economy with a large number of equal firms with a constant population of such firms. Each firm at time t produces a homogeneous consumption good according to the following production function[29]:

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[28] When, in alternative, consumption is rivalrous but exclusion is impossible (like fishing in a coastal area), we still have a market failure, requiring intervention, but technically not a public good.

[29] The discussion is based on Barro (1990).

$$Y_i = A\left(\frac{G}{Y}\right)^{\frac{1-\beta}{\beta}} K_i \qquad (7.20)$$

where *G* refers to the provision of public services and *K* refers to private capital (which may include human capital, along the lines of the model presented in the previous section). This is the AK production function modified so as to account for the fact that public capital as we now recognise can enhance the productivity of private capital.

In (7.20), the output of the firm *i* rises with the size of the public infrastructure. The later is however, defined relative to the size of the economy (*Y*), which means that the average firm enjoys only its share of the total public capital. In other words, in this model the public good is subject to “congestion”.

8.5.5. Aggregate production

An implication of (7.20) is that publicly provided goods exhibit decreasing returns (that is, for example each extra road, bridge or mains water pipe has a positive impact on the marginal productivity of private investments that is lower than that of the road or water pipe before). To see this, sum (7.20) across all firms and solve for *Y*, obtaining:

$$Y = A^{\beta} K^{\beta} G^{1-\beta}\,. \qquad (7.21)$$

This (aggregate) production function exhibits constant returns with respect to the reproducible factors both private and public. If public expenditures on public services are able to grow at the same rate as physical capital, then this property allows the economy to evolve along a balanced growth path.

8.5.6. Intervention trade-offs

The discussion above made the point that non-excludability prevents the market mechanism from efficiently providing some goods. As is well known from the economics of public finance, the government can solve this problem by *publicly* providing these goods or alternatively by subsidising their acquisition. The problem is that public expenditures are financed with taxes, which are distortionary.

This means there is invariably a trade-off between the benefits and the costs of intervention. On the one hand, a larger provision of public services increases efficiency by correcting the market failure; on the other hand, the mechanisms of taxation needed to raise funds will generate distortions which will have a negative impact on efficiency. Beyond some point, the combined effect will be detrimental to aggregate efficiency and, therefore, to growth. The following model illustrates this point.

8.5.7. The costs of intervention

Assume now that the provision of the public good is financed by using an exogenous income tax levied at rate τ. However, not all tax proceeds translate into the production of public goods.

Because of excess bureaucracy, badly designed contracts, the corrupt misappropriation of public resources, or other inefficiencies, taxes are often larger than the level strictly necessary to assure the provision of “productive” government services. To capture this point, we assume that a fraction ϕ of the total tax burden is wasted in unproductive uses. So:

$$G = \tau(1-\phi)Y \qquad (7.22)$$

A positive ϕ means that government actions and their management systems could be somehow reformed to allow for a higher provision of public services out of the same tax proceeds.

The government budget constraint (7.22) implies that the public good and total national output grow together.

8.5.8. Intervention trade-offs in the model

Substituting (7.22) in (7.21) and solving for Y, one obtains the aggregate production function of this economy as a function of the tax rate:

$$Y = A[\tau(1-\phi)]^{\frac{1-\beta}{\beta}}K \qquad (7.23)$$

Assuming that individuals save a fixed proportion of their net income (that is, solving the model with exogenous saving, as in Section 7.2.2), the growth rate of (per capita) output will be:

$$\gamma = s(1-\tau)A[\tau(1-\phi)]^{\frac{1-\beta}{\beta}} - \delta \qquad (7.24)$$

Comparing this with the simple AK model, we see that now the "efficiency term" or “A” is now influenced very explicitly by the size of government but through two different channels.

(i) First, a higher tax rate reduces the disposable income and hence the amounts of saving and investment for each level of output.

(ii) Second, a higher provision of public services raises the productivity of each unit of private investment.

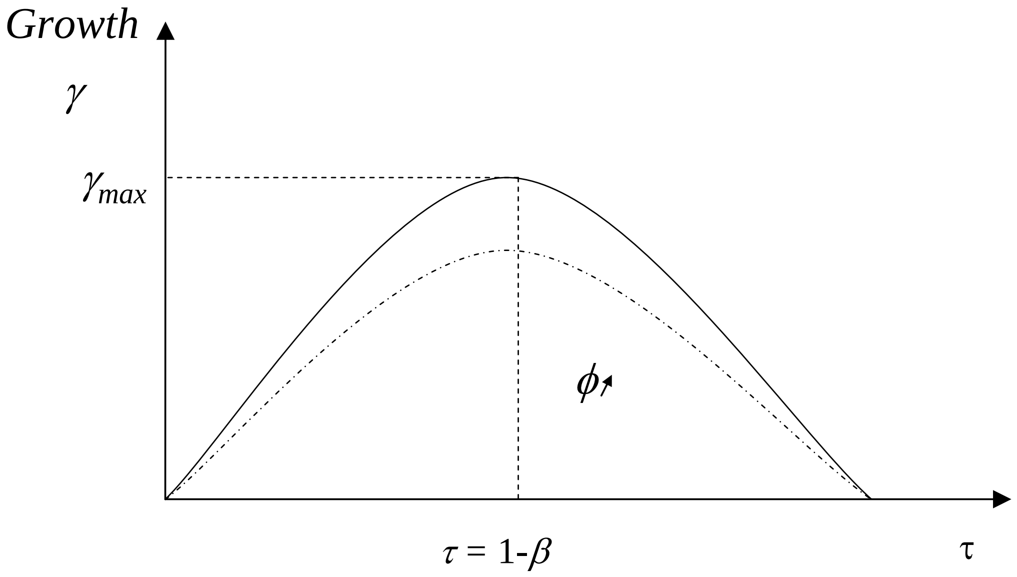
Equation (7.24) also shows that a rise in government profligacy or inefficiency, ϕ, is equivalent to a *decline* in the private saving rate, reducing the rate of economic growth. It follows that government reforms that can reduce profligacy and so improve efficiency will also provide a low-cost route to improved growth,

8.5.9 A graphical illustration

Figure 8.5.1 plots (7.24) as a function of the tax distortion for two different levels of ϕ. The dashed line corresponds to a higher level of ϕ .The rate of economic growth declines proportionally for each level of τ. For a given ϕ , each curve represents the relationship between the size of government and growth.

At lower values of τ, the positive effect (ii) above dominates the negative effect (1), so that increasing the size of the government improves the rate of economic growth.
However, as the size of the government rises, the benefits of further expanding the provision of public goods declines, while the negative impact of taxation (i) rises.
At the higher levels of taxation, effect (i) dominates (ii), so that a further rise in τ decreases the rate of economic growth.

Figure 8.5.1: The optimal provision of public services



8.5.10. Optimal intervention

The tax rate that maximises the growth rate in this economy may be found by setting the derivative of γ with respect to τ equal to zero. The result is independent of ϕ and is given by:

$$\tau^* = 1 - \beta$$

That is, the growth maximizing tax rate is equal to the output elasticity of public capital. To interpret this, consider again the aggregate production function in the form of (7.21). The marginal product of public services is equal to $\partial Y / \partial G = (1-\beta)(Y/G)$. However, (7.22) says that one unit of public services costs the same as one unit of output, so that the natural efficiency condition for the size of the government is $\partial Y / \partial G = 1$. Using the two conditions, the result above is straightforward.

The main interest in this version of the AK model is that it explicitly recognises the potential growth-enhancing effects that can come from the public provision of crucial infrastructure. But the model can nonetheless demonstrate that there is no assurance that the level of public provision (size of government) actually chosen by any particular country will be “correct” if the objective of government is to enhance growth. Beyond a certain point the public interventions are likely to become counter-productive

8.6. Generalizing the AK model

8.6.1. Introduction

By examining alternative manifestations of the AK model, we have seen that growth depends critically on the efficiency parameter, A. We have also explored and illustrated various different mechanisms through which policy may influence this parameter. In particular, the models already examined emphasise the need to reduce unemployment, correct externalities and provide a fair balance between public provision and taxation. But this is only part of the story. In general, the amount of output that an economy gets out of its resources depends on a much wider range of factors than we can examine individually. Not surprisingly, the AK model has been extended in many other directions, so as to stress the role of those factors that, by affecting aggregate efficiency, impact on economic growth. This section selectively broadens the discussion of the earlier sections, so as to highlight a number of further links between policies and economic growth.

8.6.2. An extended AK/HD model

Consider again the simple AK production function:

$$Y=AK \qquad (7.8.1)$$

In light of the earlier discussion let us interpret *K* as including both physical capital and human capital. The efficiency parameter *A*, in turn, reflects the existing externalities, the amount of public services, price distortions and so on.
The role of those impediments to growth that operate through capital accumulation, are addressed with a slight modification of the equality between savings and gross investment:

$$(1-\phi)sY = P_I\left(\dot{K}+\delta K\right) \qquad (7.8.2)$$

The left hand side of equation (7.8.2) measures the amount of resources devoted to investment. In (7.8.2) the saving rate can be analysed as though it were exogenous. However, in the light of the discussion in Section 8.2.3, you may think of it as also depending on the return of capital, and hence, on A.

As in the model with public goods, we assume that a fraction ϕ of income is wasted and so detracts from savings. But you can also interpret ϕ in a broader sense. For example, it can also capture all sorts of inefficiencies in financial intermediation (that is, the transformation of savings to investment) or in government services (transformation of taxes into productive expenditures). This parameter can measure at the same time excess bureaucracy, bribes, corruption fees, deviation of resources to directly unproductive uses, excess margins in banks due to financial repression, the technical inefficiencies of financial institutions or insufficient competition in the banking system.

The term P_I is the relative price of capital. It captures all sources of divergence between the price of output and the price of capital, including indirect taxation, imperfect competition in equipment production, transport costs. A rise in P_I means that a lower increase in the capital stock will be obtained from any given amount of savings.

The depreciation rate δ determines the amount of investment that is needed to replace the capital goods that deteriorate or become economically obsolete. This parameter may be seen as depending on the quality of the installed equipment (remember the discussion on growth engineering) and on how fast technological progress renders obsolete the economy's earlier investments in physical and human capital.

Using (7.8.1) and (7.8.2), the growth rate of per capita income becomes:

$$\gamma = \frac{s(1-\phi)A}{P_I} - (n+\delta) \qquad (7.8.3)$$

This equation states that economic growth depends positively on the level of efficiency (A) and on the saving rate (s), and negatively on the depreciation rate (δ), the relative price of capital (P_I), corruption fees, financial sector inefficiencies and taxes (ϕ). Equation (7.2.15) that we considered at the beginning of this chapter can now be interpreted as a particular case, with $\phi=0$ and $P_I=1$.

According to (7.8.3), although a higher saving rate may be conducive to growth, this effect may be offset by other factors affecting the amount of income that translates into capital accumulation. This more general formulation can now be used to discuss examples of alternative channels through which government policies may influence economic growth. In the rest of this section we provide brief discussion of a number of specific examples some of which are developed more fully in later parts of the book.

8.6.3. International trade

In general, free trade and open competition by allowing an economy to explore the benefits of comparative advantage and to produce more of their goods and services at lower costs, tends to improve *A*. At the microeconomic level, the enlargement of the market favours worker's specialization (the division of labour, as it was labelled by Adam Smith, 1877). Workers avoid the time lost in switching from one production task to another and have a better environment for invention through learning by doing. At the same time, effective competition is one major factor that forces firms to search for more efficient ways of producing goods and to seek out the newest technologies. Thus, reasonably open trade can increases the permeability of the economy to the technological progress occurring abroad and this can increase A over time. For all these reasons, economies that are open to free trade might reasonably be expected to grow faster.

In this model, high rates of trade protectionism reduce the benefits of specialization and give undue incentives to local firms to produce goods that could be obtained at lower cost elsewhere. Moreover, trade tariffs (or quotas) are often imposed on imported equipment raising the relative price of capital goods P_I. Finally, to the extent that protectionism may benefit some specific groups, it creates the conditions for these groups to become organized and engage in lobbying activities to retain or extend tariffs even where they are demonstrably inefficient. When trade barriers are lifted, domestic producers have incentives to shift from their formerly protected activities to other and more productive as well as innovative activities in order to achieve and sustain international competitiveness.

Admittedly a simplified model such as this cannot possibly reveal all the messy complexity of trade reform in real world situations: in particular the large potential *adjustment costs* to formerly protected firms and jobs. But it does give us a way to integrate the essentials of trade theory with the mainstream of growth modelling.

In term of the model, protectionism leads to a lower value of A and a higher value of ϕ, reducing the rate of economic growth. Trade liberalisation, if the transitional adjustment difficulties can be managed, provides one possible way to achieve a lower value for ϕ and so a higher rate of growth.

8.6.4. High inflation

The institution of money is an important input to production. By lowering the costs of payment transactions, it helps to increase specialization in the economy and also to reduce uncertainties regarding the value to be obtained from trading ones own production. So an effective money can also contribute to a higher efficiency level, “A”. However, when a country faces or has a past record of high inflation, people tend to move away from money: the uncertainty about its true purchasing power offseting the reduced uncertainties associated with using money to make payments. This is a source of economic efficiency and one that will be explored in much greater depth in Part IV. Moreover, in episodes of very high inflation, a lack of synchronisation in price revisions may cause significant misalignments in some relative prices, confounding the situation of those economic agents buying or selling the products that are affected. All this impacts negatively on A. The uncertainty concerning real returns on financial assets held over time also may affect negatively the saving rates (or positively the rate of time preference), further reducing growth.

Sound monetary and fiscal policies, by bringing the inflation rate down, can play an important role in the creation of a favourable environment for economic growth. A negative relationship between inflation and growth has been detected in many cross-section studies. A good and much cited example is Bruno and Easterly, 1998.

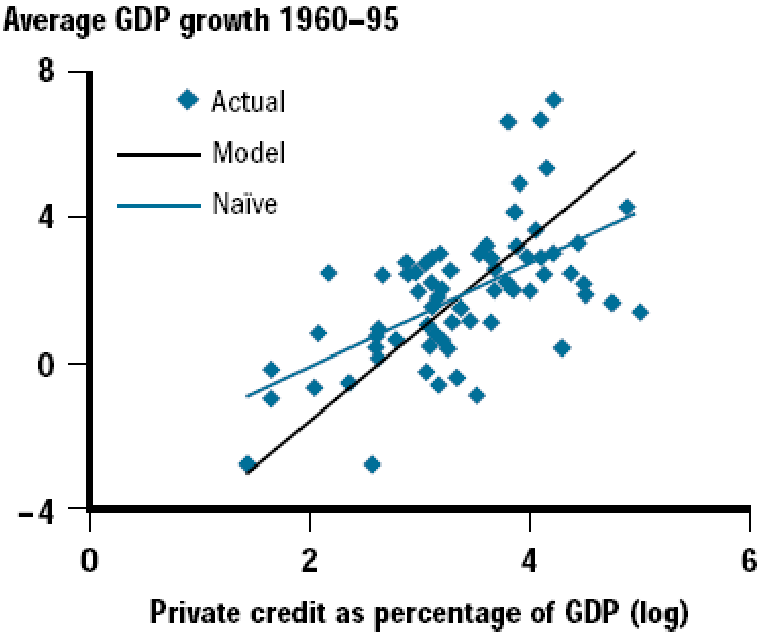
8.6.5. Financial Markets

In the past two decades economists have recognised increasingly that a fundamental reason for low returns to capital in developing countries is the lack of developed financial markets that can allocate capital efficiently as between savers and investors. The financial system has a crucial role in allocating many small and often short term savings into large and long term projects. J.R Hicks argued in a book published in 1969 (Hicks, 1969) that the UK’s industrial revolution only became possible once the *financial* technology had been developed to move the funds of many thousands of savers to fund what he termed “the immense capital works” that that revolution involved. More generally, if economic agents have appropriate incentives and the necessary financial technology to allocate their capital resources efficiently and to diversify the risks, then this too will improve the nation’s productivity parameter, *A* and also the volume of savings that will be achievable..

However, when financial markets are small and/or inefficient, due, for example, to high reserve requirements, imperfect competition in the banking sector, poor financial products and technologies and financial repression, less resources will be allocated to borrowers out of any given level of resources. In terms of our model, the fraction of total savings lost in the process of financial intermediation is captured by the parameter φ□□ (see Pagano, 1993).

Beck, Levine and Loyaza (2000) and Levine, Loyaza and Beck (2000) are recent examples of empirical research that find positive correlations between growth and financial market developments in cross–country data. Some of the results from the first of those papers is reproduced below as Figure 8.6.1. In this case the size of the financial system is proxied by the size of *private credit outstanding* relative to GDP[30]. The results suggest a striking impact of financial sector depth on growth. For example, the regression results summarised in Figure 8.6.1 suggests that a doubling of the ratio of private credit (say, from 19 percent of GDP to the sample average of 38 percent) is associated with an average long-term growth rate almost 2 percentage points higher.

Figure 8.6.1: The Impact of Larger Financial Systems on Growth



Source: Levine, Loayza, and Beck (2000).

8.6.6. Other Institutions

In general, the parameter *A* depends on the way that agents are organised in their economic and social interactions. This in turn depends on institutions. Institutions determine the economic environment in which individual agents invest and produce. A political and institutional framework will be favourable to growth, if it provides an

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[30] The use of “private credit” instead of other possible measure of financial depth by Levine et. al. reflects the fact that credit to government does not much involve the functions of allocation, monitoring, and risk management. It is exactly these functions that contribute the efficiency boost that we are discussing in this section..

environment that induces effort, capital accumulation and the adoption of new technologies[31]. For example, by providing the Rule of Law and its effective enforcement, the government helps to lower the transaction costs facing private business and hence contributes to enhanced efficiency. Also countries where property rights are well defined and guaranteed are more attractive sites for investment than countries with high expropriation risks. In countries with large bureaucracies and where the system is favourable to corruption or rent seeking activities, there is likely to be a diversion of resources from production to directly unproductive activities. These various effects may also be captured by the parameter ϕ□.

8.6.7. Geography

Many authors argue that geography is yet another crucial variable that can help explain economic growth or the failure of some countries to grow. The rationale for the geography hypothesis can also be discussed in terms of our generalized AK model.

Specifically, countries that are located in the periphery of large population blocs face higher transport costs. Transport costs in turn will affect the relative price of tradable goods. For example, a remote developing country producing agriculture goods and raw materials and importing capital goods, will face a higher relative price of capital goods imports while the net prices received from selling its exports are lower, than for a better located country. This means also that a greater fraction of that country's income needs to be devoted to savings in order to achieve a similar rate of capital accumulation. In terms of equation (7.8.3), a higher price of capital goods implies a lower growth rate. This effect is also likely to be strong in regions which are landlocked (i.e. no easy sea routes to distant markets or sources of supply) or surrounded by forests and mountains (high costs of road or rail transport). This is one of the crucial arguments recently used by Paul Collier (2007) to account for the exceptionally poor performance of many countries in Sub-Saharan Africa.

Further, countries located in tropical areas are subject to tropical diseases, that are endemic. This reduces labour productivity especially in particular seasons. In terms of equation (7.3.16), this is captured by the parameter measuring the productivity of capital, (A). At the same time, countries located on the periphery are less exposed to foreign direct investment, technological spill-over and agglomeration effects. In terms of equation (7.3.16), this is captured by the parameter measuring the productivity of capital, (A).

Overall it is difficult to find reasons why a remote location would be helpful to economic development in terms of the models so far considered.
Some authors have noted that also that geography can influence policy choices through some or all of the following channels:

- Revenue-maximising sovereign countries are more likely to choose protectionist policies in landlocked economies, where the elasticity of output with respect to tariffs is lower (Gallup et al., 1999).

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[31] The role of institutions has been stressed by historians for a long time (see, for example, North, 1990). Recently, many authors have found positive correlations between measures of institutional dvelopment and growth.

- The propensity to invest in human capital, rises with the life expectancy. So in tropical countries, where endemic diseases, such as malaria, are widespread, people will optimally respond by investing less in human skills (Cohen and Soto, 2000).
- Geographical conditions may even shape the nature of institutions, which, in turn, can influence economic growth (Acemoglu, Johnson and Robinson, 2001).

Overall these various points suggest that when growth is inherently low because of adverse geographic factors, policy and individual choices may be such as to intensify these negative effects and so generate vicious cycles .

We will discuss further the role of geography in shaping the economic landscapes when studying the more fundamental forces that drive economic growth in Chapter 9.

8.6.8. Getting the prices right

In his seminal book *Wealth of Nations*, Adam Smith (1776) used the metaphor of the "invisible hand" to argue that the public interest would be best promoted by individuals pursuing their own self-interest. In a laissez faire world, he argued that resources would not be wasted and the economy would operate at its maximum level of efficiency. In terms of the AK model, this would mean a higher efficiency parameter (A) and, hence, a faster per capita income growth. In terms of the neo-classical growth model, this would mean a higher level of per capita income.
With no question, the "invisible hand" argument still has great appeal and we will examine it further in Part III of the book. In general, there is a much-supported proposition that greater economic freedom is related to higher per capital income and higher growth. But the economics basis of this discussion has progressed a lot in the last two centuries. Today, the economics profession is well aware that an economy without government intervention will hardly work at all. So fully-fledged laissez-faire is definitely ruled out.

A first area where there is a broad consensus in favour of some government intervention arises in relation to the need in a free economy to set up a coherent system of (individual and corporate) property rights and the enforcement of contracts. If private property was not protected and contracts freely entered into could not be enforced, the incentives to invest and to conduct many types of beneficial trade simply would not exist. So property rights and contract enforcement may be seen as the foundations on which all market economies rest.

Secondly, as it is well known, the free market is likely to produce too many undesirable outcomes, such as pollution and too few essential goods and services, such as public order, roads and defence. Economists refer to these problems collectively as "market failures"[32]. Market failures – to be discussed more fully in Part III - include inadequate provision of public goods, externalities leading to too much or too little production of certain goods, imperfect competition, missing markets, incomplete markets and information failures. When there is a market failure, it is understood by all economists that the market mechanism does not produce the most efficient outcome.

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[32] It is also true that the market mechanism produces too much of income inequality. However, policies aiming at reducing inequalities weaken economic incentives and impact negatively on the efficiency parameter, *A*. The trade-off between efficiency and equity requires other tools than those used in this part of the book. We will addressed this question in Chapter XXX.

The existence of market failures is one necessary condition that can justify some role for government intervention to try to enhance economic efficiency. Governments can obviously do things private institutions cannot do – at least in principle. For example, they have the right to force citizens to pay taxes. Governments have also the right to create rules that regulate or otherwise restrict private activities to try to minimise the incidence of undesirable market outcomes (e.g. excessive pollution of rivers by nearby mining companies, reckless lending by bankers etc.). Intervention mechanisms can include the public provision of goods and services, interference in the price system, through taxes and subsidies, regulation (e.g. of banks and utility companies) and the establishment of otherwise missing but supportive economic institutions..

If the intervention is successful, private incentives will become better aligned with the social interest. This, in turn, will induce a more efficient allocation of resources to emerge. In general, as claimed by the Nobel Laureate Douglas North (1990) “getting the prices right” (that is, when individual returns reflect their contribution to social welfare) is good for growth. But obviously they are not sufficient of themselves. Later sections of this present Chapter and Part III of the book address the question of whether certain particular types of government intervention in the economy may be beneficial or detrimental to growth.

8.6.9. Levels or changes?

As shown in Sections 7.2.4, the AK model differs dramatically from the Solow model in terms of the relationship it establishes between the investment rate on the one hand and the rate of economic growth on the other. In particular:

- The AK models predict that a rise in the investment rate can have a *proportional* effect on the growth rate. So according to that model, countries with high investment rates should exhibit faster growth rates of per capita output.
- In contrast, in the Solow model, where because of diminishing returns, a developing country that succeeds in permanently raising its saving rate will have a higher *level of output per worker* in the long run, but it will experience faster growth only temporarily.

In order to assess which one of these models has more credibility as a description of the real world, the critical question to ask is whether a rise in the investment rate has permanent or only temporary effects on the growth rate of per capita output.
Unfortunately there is a major difficulty in distinguishing empirically whether the true model is the Solow model or the AK model.

This difficulty arises because the two models can be observationally equivalent for quite long periods of time. Indeed, the Solow model predicts a positive relationship between investment and growth while the economy moves from one steady state to the other. Since this transition process can be quite long – lasting (in the MRW formulation, for instance, half of the transition dynamic may take as long as 35 years) - there is little scope to disentangle whether changes in the investment rate have long run *level effects* or *growth effects*. Using the most reliable dataset with comparable data for a large sample of countries, the Penn World Tables, starting in 1950, the same evidence that fails to reject constant returns to scale will also fail to reject slight decreasing returns.

Nevertheless, if any trend is evident in the still contentious literature on this matter, this is the conclusions that country characteristics, such as the saving rate and aggregate levels of efficiency are more likely to influence the *levels* of per capita income (and their differences across countries) than *growth rates*. This trend in the literature has been called the neo-classical revival (Klenow and Rodriguez-Clare, 2004).

Does this means that the AK model is less useful in the analysis of development and differences as between countries than the argument of this section has suggested? Not al all. Remember that the important link between efficiency and growth is also present in the neoclassical growth model. The only difference if that, in the context of diminishing returns, growth effects will be purely temporary in that model. The AK model being much simpler to solve, still allows us to stress in a simpler form the relationships between policy, efficiency and growth. Using the AK model is also more convenient from the expositional point of view. Furthermore we always retain the option to spell out the conclusions of the AK model in terms of transitory growth effects, if we wish to interpret the conclusions in terms of the Solow model.
Moreover, with half of the transition period between steady states taking as long as 35 years (as MRW conclude), from the *policy* point of view, the distinction between the two classes of model may not be less important than the academic literature may imply Whatever the “true” model is, the main message is that government indeed has a role - and quite a large number of possible routes – to help promote faster economic growth.

8.6.10. Conclusions

So far, the discussion has concentrated on a particular component of the productivity parameter “A”, which we labelled “efficiency”. Less attention has been devoted to the second critical element contained in A, which is “technology”. In Chapter 9, we will redress this imbalance and discuss alternative theories that have been developed to explain the accumulation of technical knowledge and how this also impact s the rate of economic growth. This analysis will also equip us with a further set of arguments as to why judicious government interventions in the economy may be necessary to stimulate a higher rate of growth.

CHAPTER 9. TECHNOLOGY AND GROWTH

"The analysis of technology-related issues by economists has changed significantly over the past fifty years. Prior to the 1960s, technology and technological change were …. treated as "manna from heaven. In the 1960s and 1970s the endogenous nature of technological change was increasingly recognized and a variety of micro-economic models sought to identify the determinants of technological change." Sonali Deraniyagala in Jomo and Fine (2006) pg 124

9.1 The Role of Research and Development

9.1.1 Introduction

In the extended versions of the neo-classical model and also in the learning by doing model, it is assumed that technology spills over instantaneously across firms and country borders with no cost. This assumption is, however, easy to contest: just think how nice it would be if the discoveries of multi-national drug companies (e.g. of anti viral treatments for HIV/AIDs) could be transferred costlessly into use in poor countries as many activist organisations advocate they should be. …

It should be noted that no economic model states explicitly that the level of technology has to be the same across firms and country borders. Because it assumes perfect competition, however, the basic formulation of the neo-classical model *assumes* that this is indeed the case. Such a simplification of reality may be justified when the aim of the analysis is to discuss cross-country technological interdependency along secular trends (remember our discussion in Section 6.4.7). However, it is certainly not appropriate when the aim of the analysis is to explain the pace of technological progress itself.

In the real world as we know vast resources are spent in systematic efforts to create new products and production processes. Most of this effort is conducted by economic agents (often large corporations) seeking to maximise profits. These agents would not engage in such an effort unless they had the expectation of capturing some of the gains to the society, after they create the invention. Their failure to hand over their findings freely to low-income countries is obviously explained by the considerations of profit that motivate them. This section deals specifically with the question of what are the forces driving the agents' incentives to engage in *research* (the search for new ideas or products) and *development* (improving existing products so as to make them more marketable).

9.1.2 Imperfect technological diffusion

In real life many factors prevent technology from spilling over instantaneously across people and country borders. To motivate this point, consider the following examples - four of the most important inventions of the Human race:

1. ***The wheel:*** the wheel was discovered in the region of the Black Sea by the year 3,400 B.C. You may think of this idea as almost a public good: once an agent becomes aware of the concept, nothing much prevents him/her from using it for their own benefit. Nevertheless, this simple idea took some centuries to spread around Europe and Asia. In the New World, people had to wait until the XV century before

enjoying the benefits of the wheel in transportation[33]. This example suggests that *geography* may have a role in determining –and possibly delaying - the pace of technological diffusion. We consider this possibility more fully later in this Chapter.

2. ***Making fire***: because of its somewhat more complex nature, this technology is somewhat easier to hide from imitators than is the wheel. Probably, the people who first discovered how to make a campfire, somewhere around 1,4 million years ago, tried to keep it secret, so as to have an advantage against their competitors. But, either through disclosure or through independent discoveries, the truth is that the ability to make fire became *universally* known way back in human history. In this example, the passage of *time* played a role in eroding the barriers to technological diffusion[34].
3. ***Writing***: this technology was invented in Mesopotamia around the year 3000 B.C. But it was also independently discovered in Central America before 600 B.C. This technology differs from that of making fire because of the much greater complexity involved. Even though modern societies spend large amounts of resources to make this technology universally available, many people still did not achieve such a skill even by the 21st century. This example shows that some knowledge requires considerable amounts of *individual efforts* to be transmitted universally. People will engage in such an effort only if they perceive it to be worthwhile. Not surprisingly, after this technology was invented, it rapidly spread through societies with a minimum level of organization, but it was unable to penetrate in hunter-gatherer societies, where the economic incentives to adopt it were not sufficiently strong because of the nature of the prevailing economic activity.
4. ***Democracy***: democracy was first implemented in the ancient Greek city-state of Athens, in the year 508 B.C. Implementing this “technology” depends on collective actions and requires a minimum set of complementary institutions. Even when the technical conditions existed to create these institutions, the move from dictatorship to democracy was often blocked by those who benefit from the non-democratic *status quo*. In Athens, the genesis of the democracy was the need to provide incentives to peasants engaged in highly productive investments in preparing the fields to cultivate olives with a political system that minimised the expropriation risk. A failure to have done so would have discouraged the necessary investments (Fleck and Hansen, 2006). This example suggests that the lack of *complementary technologies* and certain necessary *incentives* also have a role in delaying the pace of technological diffusion.

Taken together, these four examples remind us that, although knowledge is, in principle, infinitely expandible, knowledge spill-overs do not happen automatically. Knowledge spill-overs tend to be concentrated in spatial, industrial and political clusters and to flow through specific mechanisms. Because of various combinations

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[33] The Mayans and the Aztecs actually had discovered the “wheel”, but had only used it in toys.

[34] As a contemporaneous example, take the battle against the diffusion of the atomic bomb, since it was invented at the time of WWII.

of geographical distance, secrecy, lack of complementary skills, bad incentives or cultural idiosyncrasies, knowledge is differentially known in different spatial and other situations and involves different costs in use.

9.1.3. Innovation trade-offs

In today's world, much competition between firms takes the form of firms trying to develop new and better products or less costly methods of producing existing products. In doing so, firms employ resources that otherwise could be allocated to production. A difficulty exists, however, in that non-excludability reduces the incentives to invent and otherwise develop new technology.

A simple way of illustrating the trade-offs involved in allocating resources to R&D is to consider an individual firm that splits its employees into two groups: those workers producing output and those workers engaged in R&D. Formally, let μ be the fraction of labour devoted to the production of knowledge (λ) and $1-\mu$ the fraction of labour devoted to the production of output (*Y*). Assuming that the production function has the usual form, the firm output level will be determined according to:

$$Y = AK^{\beta}\left(\lambda N_Y\right)^{1-\beta} \qquad (8.1)$$

where $N_Y = (1-\mu)N$ is the amount of labour engaged in the production of output and λ is the effective labour per worker. Workers not engaged in output production are devoted to the production of knowledge.

The relationship between the resources allocated to R&D and the incremental knowledge achieved is not easy to model. In part, because "knowledge" itself is not measurable. On the other hand, technological progress may take different forms, including the development of new technologies to produce existing goods, improvements in the quality of existing goods and the expansion in the number of goods available for consumption. It also happens that researchers may not succeed in developing a new technology: sometimes, a discovery is a matter of luck. This makes the relationship between the production of ideas and the resources allocated to such endeavours much less certain than for normal goods.

In what follows, we adopt a very simple specification, which nonetheless is consistent with some alternative theoretical models of R&D. In particular, it is assumed that the research effort impacts proportionally on the firm's efficiency of labour, λ, according to:

$$\dot{\lambda} = b\mu N \qquad (8.2)$$

In (8.2), the parameter *b* measures the arrival rate of new technology and is assumed exogenous in respect to the choice of μ . According to this specification, the larger the number of workers devoted to R&D, the greater the advances achieved in technology.

Equations (8.1) and (8.2) stress the trade-off involved in the allocation of resources to output production or to knowledge production: if the firm commits a larger proportion of the labour force to R&D (μ rises), the first impact is a fall in its output level, because less working time is devoted to production (equation 8.1). But the second effect is to increase the pace of productivity growth (equation 8.2), allowing the average costs per unit of output to decline faster along time.

9.1.4. How much effort?

The model above stresses the trade-off involved in allocating resources to production or to R&D. This trade-off resembles principles embodied in the Solow model, in the choice between consumption and saving and it suggests a corresponding golden rule. In this case, however, the optimal value of μ from the firm point of view depends on how excludable the knowledge created is.

Specifically, whether any additional research effort translates into a real competitive advantage or fails to do so, depends crucially on the extent to which the technology created becomes available to the other firms or not:

- If other firms have *immediate* access to the knowledge created, the innovating firm will gain no new competitive advantage. In that case, the optimal level of μ would be zero. This case was underling the discussion in Section 6.4 (if this model represented the whole story no high-tech firm in a competitive industry would ever give away its technological findings.
- If on the other hand only the innovating firm had access to the new technology - at least for an assured period of time – that firm would obtain lower average costs and hence an advantage against its competitors. This would allow the firm to achieve extra-profits[35]. The present value of these extra-profits over the period during which the technological advantage materialises may be seen as the return of the research effort.

This simple model suggests that the optimal level of μ (that is, how much the firm should spend on R&D) depends on how much advantage the firm can gain and on how long those gains can persist. This advantage, in turn, increases with the degree of excludability over the technology that is created: the lower (or the slower) the transfer of technology from the innovating firm to its competitors, the greater will be the market incentives to produce new technologies.

Another important determinant of the research effort is the size of the market. Because R&D constitutes a fixed cost (the “idea” underlying each new product only needs to be created once), the larger the market, the lower will be the R&D cost per unit of output and hence the higher will be the incentives to engage in R&D. A corollary is that openness to trade – and access to the large global market - is good for innovation.

The example also illustrates why private R&D is inherently linked to imperfect competition. Industries where technological change is important typically face high fixed costs – costs related to R&D, that do not change when output increases. To reward these fixed costs, firms must achieve some form of monopoly power over the technology created. Moreover, the size of these fixed costs determines how competitive the industry has to be. The greater the fixed costs, that is, the more relevant R&D expenditures in a given industry are, the more likely is it that there will

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[35] Extra profits may either be generated by an higher margin or by lowering the prices so as to obtain a dominant position in the market and then explore the monopoly power. As an exercise, you may verify that the average cost function corresponding to (8.1) is invariant with the output level, Y, and inversely related to the level of technology, λ.

be few firms and more limited competition. This helps to explain the industrial structure in industries such as pharmaceuticals where the research costs of new discoveries are extremely large. The computer software and IT industries by contrast where important discoveries have been achieved at relatively low cost have much more open and competitive structures.

9.1.5. How can firms achieve Excludability?

The discussion above emphasises the idea that entrepreneurs innovate as long as they can capture a rent from their ideas. This, in turn would not be possible if technology spilled over instantaneously to become available to all firms. This section deals more specifically with the mechanisms on which innovating firms rely in order to ensure a return on theirs own inventions.

The first and most obvious mechanism of knowledge excludability is the *trade secret*. By not disclosing the details of an invention, its owner may manage to keep its competitors away. This has been the case, for example, of the famous (but not known) formula for Coca-Cola for more than one hundred years.

Not all inventions, however, are suitable to be protected as trade secrets. An obvious example is the wheel, discussed above. Even complex ideas are difficult to hide from others in our days. Many ideas are embodied in the human capital of each worker hired and trained by the innovator. In these cases, an obvious risk exists that your workers will move away to start a competing business independently.

One important way of dealing with this risk involves taking the opportunity of the *lead time*. Knowledge leaks gradually. The time length that competing firms take to assimilate new ideas and then incorporate them into their own business provides the innovating firm a “first-mover”-advantage. Moreover, the firm that first enter the market with a new product or process has the time to explore the benefits of experience (*learning by doing*) and to build up costumer loyalty and a reputation. Provided that these advantages are large enough, there will be private incentives to develop new technologies, even in the absence of patent protection.

It follows that whenever the risk of copying is high and the potential benefits of lead times are not large enough to compensate for the fixed cost of R&D, inventors may prefer to buy some form of official/legal protection. There are different ways of enforcing secrecy legally: employment contracts, disclosure agreements, no-compete clauses and registering property rights. The systems of *patents and copyrights* represents the use of the legal system to influence the degree of excludability over the inventions achieved.

Box 9.1. What is a patent?

The patent system was designed to create incentives for innovation activity. Patents are a legal mechanism that establish private claims on intellectual property rights, permitting innovators to restrict unauthorized use of their ideas. A patent grants the inventor exclusive right to its discovery for a definite time length (20 years in Europe and in the US, from 14 to 21 years in the UK). During this period other producers are precluded from making use of the invention without permission of the patent holder. Patent holders can sell to others the right to use their invention in exchange for a payment called a *royalty*. When the patent expires, other firms are allowed to enter the industry (note that this will not happen with a well maintained trade secret!). The patent coverage only applies to the patented output. The *information* in the patent, that is, the technical details of the invention, can be used for free to support the additional R&D carried out by rival firms. Although legally distinct, copyrights and design rights serve the same economic function as patents: they all provide mechanisms of intellectual property protection.

9.1.6. Static and dynamic efficiency

In effect, a firm with a patent is granted a form of government-enforced monopoly. The existence of such a legal device looks at odds with what we learn in introductory economics. Indeed, the classical economic theory tell us that monopolies are bad for welfare: under monopoly, prices are likely to be higher and output levels lower than under perfect competition. In order to avoid the welfare loss caused by monopolies, governments are recommended to intervene by, for example regulating prices. In the case of knowledge, a further reasoning exists to back up this basic economic principle: since the social cost of having an extra individual sharing a given idea is zero, does it make sense to exclude other people from using that idea?
The problem is that without exclusion there are no incentives to innovate. As with many other problems in economics, this case involves a difficult trade-off. This is the trade-off between, on the one side the deadweight-loss implied by precluding other agents from having access to the new technology and on the other side the incentives that excludability provides. Some excludability may be less than efficient from the narrowly *static* point of view, but it may provide the incentives for private agents to develop more ideas and so have advantages in *dynamic* terms. This trade-off led one of the pioneers of modern development economics, Joseph A. Schumpeter (1883-1950) to argue that “static” efficiency and “dynamic” efficiency do not necessarily go along side by side.

The regulation of property rights has a difficult task in weighing the *ex ante* private incentives for individual agents to create knowledge against the *ex post* social inefficiency involved in preserving private monopoly over that created knowledge. The key to effective regulation is to choose a patent duration (length of life) and a breadth for patent protection that achieves an appropriate balance between the activity of innovation and its rights to earn a return on the R&D investment and the benefits that will accrue to consumers once the patent expires and additional competition emerges.

However, finding that appropriate balance is not easy. Some authors have criticized the patent and copyright systems on the grounds that the large ex-post monopoly distortions associated with patents are too costly[36]. These authors argue that purely private excludability mechanisms, such as the first-mover advantages, lead times, secrecy and imitation delays can often provide ample protection for innovation and preserve a better allocation of resources.

In practice, patents are an important source of rent appropriation in industries such as drugs, plastic materials, inorganic materials, organic materials and petroleum refining (Levine, Klevorick, Nelson and Winter, 1987). In other words they enable firms to realise profits well in excess of the norms that would prevail under competitive conditions. However, aside from the pharmaceutical industry, where revelation is obligatory (thus the trade secrets approach cannot prevail), trade secrecy is probably more important in practice than are formal patents.

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[36] Kremer (1998), Boldrin and Levine (2002, 2004), Kelly and Quah (1998).

Box 9.2: Joseph Schumpeter

Joseph A. Schumpeter (1883-1950) is sometimes referred to as the “father of economic development”. In two famous books, *The Theory of Economic Development*, published in 1911, and *Capitalism, Socialism and Democracy*, first published in 1943, Schumpeter argued that the process of economic development resembles Charles Darwin’s theory of evolution. Schumpeter argued that the introduction of new consumer goods, new methods of production, and new forms of industrial organization by a newer firm or energetic older firm will undermine the marketability and the value of existing designs and production techniques of other incumbent producers. This allows the inventing firm to achieve a new dominant position in the market and, by then using that position, to reap a return on their research effort. However, that dominant position will not last for long, as other firms will enter the market with new designs and production techniques. According to Schumpeter, this process of *industrial mutation* or *“creative destruction”* through which innovations incessantly revolutionize the economic structure from within, challenging the existing industrial structure, creating new businesses and destroying old businesses, is the essential mechanism through which the market economy adapts to technological progress.

9.1.7. Financing constraints

We saw earlier in this section that, whenever “natural barriers” to technological diffusion – such as secrecy, lead-times and learning by doing - cannot provide the required incentives for technological development, there is scope for government intervention. Governments in other words have some role in promoting *ex ante* incentives to R&D by establishing and enforcing a system of property rights over the discoveries realised by that R&D.

Insufficient *ex ante* incentives do not constitute, however, the only market failure affecting R&D. Even when incentives are large enough, some of the firms engaged in research and development may face difficulties in raising capital from banks or from other potential investors.

A major reason is that many research projects fail: the probability of this happening is high. Inventors are often overly optimistic about their ideas and many are also unworldly as regards commercial realities. And in many cases involving strenuous research nothing much of relevance is discovered. Even when a new discovery is made, the possibility exists of the invention being beaten by a competing firm’s product or process in the patent office. In other words the risks involved in engaging in R&D activity are high for several different reasons.

Another problem arises from information asymmetries: investors do not in general fully understand what is envisaged by the researcher. This may occur because of the technical complexity of projects or because of insufficient disclosure (researchers do not reveal all the details of their project to investors, because if they did, investors would no longer need to buy the idea). Another problem is lack of collateral: when a bank makes a loan for a building, if the borrower defaults, the bank ends up with the building. If the bank lends for R&D and the research project fails, the bank may end up with nothing. So for many reasons, the financing of R&D is also perceived to be a risky business.

Because of this, R&D intensive firms tend to use their own capital to finance their research efforts. This is not a big issue for companies already established in the market. Established firms can raise capital for new R&D out of their profits on past

R&D. But for new entrants, especially small firms, lack of financing may constitute a significant barrier to entry and a source of market imperfection.

A mechanism that addresses this problem is venture capital. Venture capital firms invest in promising R&D projects but often demand by way of compensation for their risk-taking, a significant ownership stake in the new company. Allowing the research risk to be shared, venture capital can have a positive impact on the level of R&D. However, venture capital firms rarely meet all the existing needs of R&D finance especially at the smaller end of the market where the transaction costs can be high relative to the expected returns[37]. Asymmetric information still constitutes a major problem especially of “moral hazard”: because it is difficult to monitor the true effort and the quality offered (including the future commercial possibilities) by the researchers, there is ample scope for low levels of commitment and the hiding of relevant aspects of new ideas.

9.1.8 . Conclusions

A basic flaw of the Solow model is the assumption that technology is freely available to all countries. This section has introduced the idea that something is needed to motivate the commitment of resources to R&D as an economic activity. More specifically, the section has emphasized the nature of the incentives needed to induce R&D activity and has suggested also that R&D is more likely to occur in countries that are relatively more open to international trade and where the right incentives are provided, for example, by a patent system that protect investors against imitation.

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[37] For example it is not uncommon for a firms raising .say £5 million on the London Alternative Investment Market (AIM) to need to pay out some 20% of this in commissions and fees to the investment bank that organises the issue.

9.2. World-wide knowledge

9.2.1. Overview

This section deals specifically with knowledge spill-overs. Section 9.2.2 discusses the market failure that results from the lack of appropriation of all benefits of inventions to the society. Sections 9.2.3 and 9.2.4 discuss alternative policy options available to induce an R&D level closer to the social optimum. Section 9.2.3 incorporates knowledge externalities in the growth model As we explain in Section 9.2.4, this externality implies that the economy's growth rate depends on its size. Sections 9.2.5 and 9.2.6 present alternative directions that the literature has explored on this topic to avoid this "scale effect".

9.2.2. Knowledge spillovers again

The benefits of increased knowledge do not in general fully accrue to the firm or the individual that sponsor and develop the innovation. In the case of patented inventions, for example, an obvious externality occurs when the patent expires, so that the invention becomes fully available to the society at large. Even during the life-time of the patent, the information in the patent can be used by competing firms for additional R&D. A classical example is the invention of the transistor by the telephone company AT&T. Although this firm was compensated for its R&D effort through higher margins in the telephone equipment sold, many other firms took the opportunity offered by the new invention, to develop better radios and better television sets.

Even well maintained secrets are not protected against the diffusion from technological diffusion. As an example, consider the case of Coca-Cola: even though its formula is a trade secret, the marketing concept is not. So it was not much of a surprise, following the success of Coca-Cola, that other firms, such as Pepsi Co have entered the market with close substitutes marketed in a similar way.
All in all, the existence of knowledge externalities raises a question of economic efficiency. In general the inventors themselves can appropriate only a fraction of the social benefit of their inventions. And as long as the gains to the society *exceed* the private gains, there is scope for government intervention.

9.2.3. Subsidies to private R&D

Even when excludability mechanisms provide enough *ex ante* incentives for private agents to engage in R&D, the question remains as to whether the inventors should be compensated for the positive externalities that their discoveries provide to the society at large. Because innovating firms cannot capture all the social benefits from their inventions, they will have insufficient incentive to innovate. This means in principle that there is scope for further intervention.

An obvious policy instrument to address the R&D under-investment problem is the subsidy. In principle, subsidies to R&D are more desirable, the larger are the externalities involved. But there is also an argument that subsidies are more necessary to induce innovation in competitive industries than in concentrated and less competitive industries In the latter case the opportunities to generate extra profits achieved through monopolistic positions and the resulting higher prices are much more obviously available.

Government subsidies can also be attributed either to specific innovation *projects* or more generally to particular targeted *industries* where someone judges (rightly or wrongly) that innovation is more likely to occur or to be needed. This latter possibility however raises a question about the need to provide a level-playing-field. Firms benefiting from a government subsidy are obviously handed a competitive advantage against their competitors and this is at the expense of the general taxpayer. For this reason, international agreements and some domestic competition laws (such as in the U.S.A and in the E.U.) limit the extent of narrowly focused subsidies or state-aids to particular firms. By contrast broad-based subsidisation mechanisms, such as R&D tax credits, because they do not depend on government selection of particular projects or firms, are inherently less distortionary and hence more tolerated by today's domestic competition laws and international trade agreements.

9.2.4. Government funded R&D

We argued earlier that governments have a potential role in improving the *ex ante* incentives to private R&D. By establishing and enforcing a system of property rights, governments can reduce the public-good nature of knowledge and so help to induce a faster pace of technological progress than would otherwise occur.

Not all knowledge, however, is suitable for exclusion. For example, advances in basic sciences, such as geography, economics, mathematics and physics cannot be patented. And yet, because of the very large externalities involved, advances in basic science are of the greatest importance for the progress of human kind and for economic development globally

On the other hand, even when particular types of knowledge are suitable for exclusion, it may be socially preferable to make it freely available. Remember that, because knowledge is non-rival in consumption, the use of one idea by one person does not preclude, at the technological level, the simultaneous use of that same idea by another person, or even by many people. In other words, the social cost of having more agents sharing the same idea is zero. Given the cumulative nature of knowledge – i.e. that all new discoveries build on a large existing stock of old discoveries – there is a good case to let knowledge remain freely available, even when patenting is possible.

There is particularly strenuous debate over this point at present in relation to the patenting (or not) of particular elements of the human genome project and especially those genetic elements that seem likely to lead to new path-breaking drug treatments.

Another significant contemporary example where the principle of open-access has been put into practice is the World-Wide Web invented by the British computer scientist Tim Berners-Lee in 1991. The World-Wide Web is an essential foundation of the Internet which most people now use on an almost daily basis. But Berners-Lee fought hard to keep it open, non-proprietary and free for anyone who wished to use it.[38]

As with other public goods, government may support directly the creation of knowledge. In practice, this is achieved through prizes, research grants and support

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[38] The first ever web site was the one established by Berners-Lee in 1991. Its reference is http://info.cern.ch. It explained what the Web was and how it worked . See Friedman, 2005 pp.60.

to universities and public research institutes. Academic and government scientists, for instance, and most academic researchers also do not work with the primary objective of profit-maximisation. Their main incentives will not be to patent innovations, but rather to disclose new knowledge in order to receive rewards for this. Another mechanism through which governments may promote research and development is through “procurement”. This case occurs when a public body contracts out in advance for a specific piece of research to be undertaken and thereby absorbs some or all of the risks that the private firm(s) would otherwise have to address.. This is the case of most of the large-scale research for the military and for the big space programess such as those managed by NASA in the USA.
In US and Europe, government funded R&D accounts for between one-third and one half of total R&D expenditures (Kelly and Quah, 1998).

9.2.5. Standing on shoulders

The model in Section 8.2 ignores knowledge externalities. The framework there described relies on the hypothesis that technological progress is wholly internal to the firm that makes a discovery. The reason is that the model is intended to capture individual decisions. Since each firm is assumed to be small relative to the rest of the economy, the impact of one firm´ research on the other researchers’ productivity may be considered negligible. Thus, each firm takes the arrival rate of new ideas, *b,* as given: to the firm, the pace at which new ideas arrive depend only on the number of workers employed in the research sector.

At the macro level, however, these externalities cannot be treated as negligible. When the aim of the analysis is to understand economic growth, the model should be refined so as to account for the positive impact of existing ideas from any one source on the productivity of other researchers seeking new ideas.

In terms of the model (8.1), (8.2), one may account for the externality, postulating that the arrival rate of new ideas is proportional to the stock of ideas already existent:

$$b = \bar{b}\lambda_t \qquad (8.4.1)$$

According to (8.4.1), the greater the stock of knowledge in the economy, the faster the arrival of new knowledge[39]. Combining (8.2) with (8.4.1), the pace of technological progress becomes:

$$\dot{\lambda} = \bar{b}\mu N_t \lambda_t \qquad (8.4.2)$$

where *N* now stands for the total number of workers in the economy. According to (8.4.2), the more people are employed in the production of knowledge, the faster will be the growth of the effectiveness of labour.

Dividing (8.4.2) by λ, the (endogenous) rate of technological progress becomes:

$$\gamma = \frac{\dot{\lambda}}{\lambda} = \bar{b}\mu N_t \qquad (8.4.3)$$

Interpreting, (8.4.3) states that the higher the proportion of workers devoted to research and development, μ, the higher will be the growth rate of per capita income

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[39] This assumption is common to a set of models addressing R&D, such as Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992).

in the economy. This model is a cousin of the AK in that a policy change (e.g, increasing the proportion of workers engaged in R&D) affects long term growth.
This model displays a *scale effect* meaning that the growth rate of the economy depends on the size of its population. Because each researcher' discovery impacts positively on the other researchers productivity, when the number of researchers is high, the ability of each researcher to generate a new idea rises. Thus, the economy grows even when the number of researchers remains constant. With exponential population growth, the growth rate of per capita income will itself growing exponentially. This is one of the ways in which population growth has been argued to impact *positively* on a country's development. It contrasts with the more familiar Malthusian and negative ideas about population size and growth.

Box 9.2.1. Standing on shoulders in practice

We all know that James Watt invented the steam engine in 1769. However, his idea was not inspired by watching steam rise from a the spout of a tea-kettle, as the school history books like to tell us. Indeed, the idea was borne while Watt was repairing an earlier steam engine, invented by Thomas Newcomen, 57 years earlier. This engine, in turn, was an improvement of the steam engine that Thomas Savery patented in 1698, which followed the steam engine that Denis Papin designed around 1680, which in turn had precursors in the ideas of the Dutch Scientist Christiaan Huygens and so on.

We can all learn from our predecessors!

9.2.6. The scale effect

At the first sight, the scale effect suggests that larger countries should exhibit faster productivity growth. However, this prediction of the model does not square well with the 20th century empirical evidence. For example productivity in a larger country such as France does not necessarily grow faster than that in a small country such as Luxembourg. Moreover, according to the model, if population expands at any positive rate *n*, the growth rate of the economy should be growing over time. This prediction is at odds with the evidence that productivity *growth rates* (if not the development of improved productivity) are broadly stationary over time and inversely related to the growth rate of population, in cross-section samples (remember Figure 7.1.3).

The "scale effect" of endogenous growth models was criticized, among others, by Charles Jones . Jones (1995) observed that, while both the number of scientists had increased dramatically in the last part of the 20th century in advanced economies, the growth rates of per capita income did not exhibit a significant tendency to rise. Moreover, the author observed that countries with high R&D shares in total national income do not grow systematically faster than some other countries.

9.2.7. Removing the scale effect

Because scale effects do not fit too well with the stylized facts of economic growth, economic theorists have searched for alternative ways of refining the R&D model.
In this quest, two main directions have been followed:

The first assumes that innovations building on past discoveries become more difficult as time goes by. Instead of assuming that past discoveries impact on the productivity of current researchers in a linear fashion (as for example in Equation 8.3), this branch of the literature assumes that past discoveries impact on the productivity of current researchers with declining marginal returns[40]. With a constant population – i.e. with a constant research effort - this assumption implies that the growth rate of λ *decreases* over time, becoming constant in the long run. In this model population growth is *necessary* for the sustained growth of output per worker: as the population expands, the number of researchers rises proportionally. This in turn offsets the decline in the marginal productivity of researchers and so allows per capita income to also rise over time. On the other hand, when the fraction of population devoted to knowledge accumulation (μ) rises, there is an initial (negative) impact on output (remember equation 8.1), and then the rate of technological progress accelerates temporarily. Because of diminishing returns, however, the rate of technological progress falls back until reaching its previous (long run) level. The policy implication is that a subsidy to the research activity would affect the *level* of income but not its long term *growth rate*. For this reason, this model is often categorised as one of exogenous growth.

The second avenue involves adding a second dimension to the model. Specifically, R&D can increase the total number of products available for consumption (varieties) or increase productivity within any given product line[41]. The crucial feature of this class of models is that, as population expands, the number of product varieties (firms) expands as well. With such behaviour, the model can be explained in an intuitive manner s follows.

If the number of varieties and the size of the labour force vary in direct proportion, then the average firm size (and therefore the number of researchers per variety) is unchanged with the increase of the population. However, expanding the number of varieties dilutes the effect of population expansion in *each* sector, thereby eliminating the scale effect. In this alternative model, population growth is not necessary for long run growth. Countries with higher R&D spending should, however, grow faster. Thus, this model reintroduces the result that changes in policy affect the long run rate of growth (as in the general in the AK model). Because of this feature, this model has been classified as one of *endogenous growth*.

Although the scale effect is eliminated, both models display a kind of “weak” scale effect, whereby the size of the workforce affects positively the *growth rate* of per capita income. This is still a somewhat uncomfortable result, as we know from the empirical evidence that larger countries in general do *not* grow faster than smaller countries.

9.2.8. The technological frontier

An obvious way to rescue the R&D model from its inconsistency with stylized facts is to assume that this model applies not to one single closed economy but rather to the World economy as a whole. There are two reasons to do so:

The first is that knowledge spill-overs in the modern world of very fast communication and sophisticated digital technologies already well established are not confined to

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[40] Jones (1995), Kortum (1997), Segerstrom (1998). Formally, this theory may be stated assuming that $b = \bar{b}\lambda_t^{\varepsilon}$, with $\varepsilon<1$. The parameter ε captures the effect of knowledge spillovers on the arrival rate of new ideas.

[41] This direction is followed in Dinopoulos and Thompson (1998), Young (1998), Peretto (1998), Aghion and Howitt (1998), Peretto and Smulders (2002).

inside country borders. Indeed, there is no reason to assume that the people in Luxembourg only benefit from the number of researchers in Luxembourg and not also from the number of researchers in France and many other countries. National economies are embedded in a global system that generates mutual interdependence across countries. There are strong grounds for thinking that this international mutuality in R&D activity has intensified in recent years (Friedman, 2005). In this system countries rely on each other for technological transfer and they learn from each others manufacturing methods, models of organisation, marketing and product design. These features link their growth rates. If ideas flow easily across borders, technological progress as a function of the population *only* of a particular country does not make a lot of sense.

The second reason is that, because of barriers to technological diffusion, knowledge externalities (standing on shoulders) should be understood as taking place over long periods of time. International knowledge spillovers across nations drive long term growth, and not growth rates over short periods of time. In other words extending the time period under consideration increases the likelihood of global spillovers of technology.

Taking this into account, one may think the model of the earlier section as describing, not the path of a single country' technological frontier over a half century but the path of the World technological frontier over centuries. Box 9.3. provides some evidence favouring this interpretation.

Box 9.3: Scale effects: an historical experiment

To evaluate the prediction that technology improves faster when population is larger, Kremer (1993) proposed an historical experiment. He observed that before the end of the last ice age (about 10.000 B.C.) ocean levels were lower, allowing humans to migrate around the world, including across the Bering Strait, that links Asia and the Americas. Because of this, ideas could diffuse across regions. It is thus plausible that in 12.000 B.C. the known technologies were pretty similar across most human communities. Human communities were all relatively primitive with economic life based still on hunter-gatherer activities. With the end of the ice age and the disappearance of the land bridges, the continents of Eurasian/Africa, Australia and the Americas and the islands of Tasmania and Flinders became more isolated from each other. Only with the European exploration of the XVth century were those connections re-established. So there were very long periods of isolation of some communities.

If the growth model with scale effects was correct, one would expect that at the time when contacts were re-established population densities would have become higher in larger regions. Why? Because larger regions would also have built bigger populations and therefore technology would have develop quicker. For example, medieval Islam, centrally located in Eurasia, was able to acquire inventions from India, China and Greece. In contrast, the Aboriginal Tasmanians, who had little contact with other societies for the 10,000 years through to the XVth century, could not have acquired new technology other than what they invented for themselves. With a faster technological improvement, larger regions would experiment a faster population expansion and an increase in the population - land area ratio.

Kremer (1993) showed that the data confirm this prediction. By the year 1500, population densities were much higher in Eurasia-Africa (4.9/km2), the region with larger area and the closer contacts, than in the Americas (0,4/Km2), Australia (0.03/Km2), Tasmania (0,03/Km2) and the Flinder Island (0,0/Km2). The

> Old World had the highest level of technological sophistication, followed by the Americas – with the Aztec and the Mayan civilizations. Australia was in an intermediate stage, having developed some artefacts like the boomerang, but was still predominantly dependent on primitive economic activities such as hunting. Tasmania was almost unchanged and the population in Flinder Island (500 people before), had died out completely. This finding is consistent with the idea that there is a positive relationship over the very long run between initial population and subsequent population growth.

9.2.9. Conclusion

Because knowledge leaks, many of the R&D models that have been proposed and selectively discussed in this section involve some kind of scale effects. However, these scale effects are in contradiction to the cross country evidence that larger countries do not necessarily grow faster or have a larger level of income per capita than smaller countries. However, there are alternative models that can help to dilute the scale effects. At the same time there is some evidence that the very long run history of economic growth appears consistent with scale effects.

9.3. Backwardness

9.3.1 Overview

How to alter the growth prospects of an economy is a policy question that confronts all modern societies. For the Least Developed Countries (LDC), the issue is not sd much one of pushing forward the world technological frontier as of benefiting as much as possible from technological diffusion from other and more advanced economies. Indeed, most research and development takes place in the rich countries, such as the U.S.A., the E.U. and Japan. In developing countries that cannot afford large investments in R&D, innovation occurs mostly through the adoption of technology developed elsewhere. This may occur by imitation, by importing machinery embodying new technology or by attracting foreign direct investment that brings some new technology as part of the package. .However, these channels do not work, however, automatically. Even if the World technological frontier is moving outward at roughly 2% per year or more as it is, many poor countries are not benefiting from this growth.

A major barrier to the adoption of new technologies is the lack of local ability to use it. Some technologies require specific capabilities (e.g, skills, complementary inputs, appropriate climate) that might simply not exist in the developing country. Even when the required capabilities exist, the process of technological catch up is often limited by weak incentives to adopt new technologies. Economic and political systems where institutions are not properly designed often see the adoption of new technologies slowed down by those vested interests who benefit in some way from the old technologies.

This section deals with this aspect of the development challenge from an individual country point of view. The main problem is how to adjust the policies and institutions of a poor country so as to better benefit from the ongoing and global technological progress. After introducing some basic ideas, such as the possible advantages of “backwardness”, and the main barriers to technology development, the section presents a model according to which there is a World technological frontier (determined according to the endogenous growth theories outlined in Section 8.4). This is then connected to the low-income country’s technology adoption effort in order to determine how close the country gets to the frontier.

9.3.2. The advantage of backwardness

As was pointed out by the classical economist David Hume (1758), instead of inventing new goods or production techniques, more backward countries can improve their living standards merely by learning from or copying the ideas and methods of more advanced countries. This includes introducing foreign production techniques, copying institutions and adopting best practices. By doing so, developing countries have the potential to skip some steps that are now obsolete and jump directly to the prevailing global technological frontier.

The opportunity to skip steps and imitate successful institutions from other countries without the need to learn form the beginning was named “the advantage of backwardness” by Alexander Gershenkron in a well-known paper published in 1952 (Gershenkron, 1952). The key proposition to bear in mind is that *imitating* is cheaper than *inventing*. Since the research effort does not have to be repeated, there is a potential advantage for those who are less developed. This theory implies that the typical follower has the potential to grow faster than the leader. This idea was very prominent in the early thinking of Jawaharlal Nehru and other leaders of newly independent nations when they asserted with confidence that the developing countries of the 1950s should progress much faster than had those older countries like Britain that had first had to develop many of the relevant technologies associated with industrialisation.

The next few paragraphs illustrate some of the theoretical reasons why the proposition of Gershenkron, Nehru and others may be overly optimistic.

9.3.3. The critical role of trade

First, technology does not spread symmetrically and automatically across geographical space. It flows instead via specific mechanisms of economic interaction. A number of studies have emphasized the role in all this of openness to the global economy. It is easy to see why. International trade, labour migration, personal and business travel, FDI, cross-border mergers and acquisitions all serve to increase the permeability of the economy to the technological progress occurring abroad (as a motivation for this point, just remember the history of the Aboriginal Tasmanians, who had no contact with other societies for 10,000 years, and hence could not acquire new technology other than that which they had invented themselves). We also saw in an earlier section that the scale of the market is an important determinant of the incentives to invest in R&D: in smaller countries, the necessary market dimension can only be achieved through exports.

In the modern global world efficient competition is increasingly the driving influence that compels firms to search for ever more efficient ways of producing goods and seek all the time for new and better technologies. By importing goods and machinery from more advanced countries, poorer countries gain more exposure to new technological developments and so become more likely to adopt the technologies to which they are exposed .

If openness promotes technology diffusion, geographical isolation deters technological progress. Countries in the periphery of the world economy or countries that are landlocked face very high transport costs and hence are less exposed to international trade. Other things such as levels of protective tariffs being equal, these countries can be expected to achieve a lower pace of technological diffusion than countries located in the centre.

9.3.4. Complementary inputs

Second, investment in new technologies often requires a set of other complementary capabilities if the new technologies are to be productive and profitable. New equipment or new ideas are said to be “complementary” to other existing capabilities when installing the former raises the rate of return of the later. In that case, investing in an innovative project not only depends on the intrinsic efficiency of the new equipment to be installed but also on the abundance/adequacy of the complementary inputs.

An obvious complementary input to new technologies is human capital. Poor countries may be unable to use the technology developed in richer countries because of a lack of human skills. For example, countries where a small fraction of the population speaks English face higher costs in implementing very specific software that is documented only in English. This means that, by promoting the

education of people, setting up universities or high technology industrial parks, governments may improve the country's permeability to technological change.
The critical role of human capital applies not only to *formal* education. It also applies to the many skills obtained from on-the-job working experience, including learning with the trading partners the managerial practices that are best suited for the technology being adopted. Thus, although a reasonable degree of openness is essential for technological diffusion, human capital in the lagging economy is also an important determinant of the absorptive capacity for technological progress in that economy.

Complementary inputs other than human capital include a large set of capabilities, such as critical bits of physical infrastructure (highways, airports, ports, telephone networks, electricity systems), business services (accountancy offices, consultancy companies) and specific legislation (adoption of new technologies often requires previous regulatory work which clarifies roles and responsibilities). The absence of an appropriate portfolio of complementary capabilities will be a serious obstacle to growth.

Some complementary inputs are difficult if not impossible to acquire in those cases where they are missing. This might be because of deep-seated factors, such as a country's geography and its culture. For example, many innovations in agriculture are developed in industrial countries, where the climate is temperate, so that they are simply not suitable for use in tropical countries. By the same token, some institutional designs that work well in industrial countries may not be adequate to developing countries, because of cultural reasons. This means that, instead of attempting to change the poorer country's deep-seated characteristics, sometimes the better policy will be to *adapt* the technology so as to make it more suitable for use in the recipient country.

9.3.5. The old blocking the new

Third, new technologies often substitute for, or even fully replace existing established technologies. In a perfect world, one would expect that countries would invest only in the frontier technology: that is, once a new type of equipment is introduced, there should be no additional gross investment in older equipments, so that the proportion of old equipments in the capital stock should gradually decrease over time. The empirical evidence on cross-country technology adoption reveals, however, that the adoption of new technologies only gains momentum after a period during which investment and the use of *non-frontier* technologies continues to dominate.

A possible explanation for this paradox is that the use of a technology requires technology-specific experience. Such experience if acquired by working with older technologies will reduce the incentive to update to new technologies, because to do so would lead to the decline of the "value" associated with this experience. The lower are the opportunities to transfer the accumulated knowledge to use with the new technology (that is, the less similar are the new and the old technologies), the larger will be the productivity loss faced by those workers being asked to move to the new technology. Consequently, both workers and firms may have significant incentives to "hang on" to older technologies and even continue to invest in them even though newer and potentially better ones are available. This theory implies that countries that are intensive users of old technologies are the countries that have the most to lose by switching to new technologies. In this case, the old technology is said to "block" the new technology and countries in this case are said to be *locked* into the old technology. This status in turn cause substantial delays before the new technology(ies) can become dominant.

A similar case occurs in the presence of so-called “network effects”. Whenever the user costs decline with the number of users, the conditions exist for a widely used and dominant technology to block a new more efficient technology. This can keep the economy *locked in* a bad equilibrium (a much cited example of how an inferior technology can block a superior technology is given in Box 9.3 below).

Locking-in effects could, in principle, help to promote income convergence. Backward countries, because they are not heavily committed to any technology, could in principle jump to the frontier by investing in structures and equipment that embody state of the art technologies. For example, many developing countries in the past decade have adopted cellular phones faster than developed countries, because most users were not already locked in to the use of more conventional phones: on the contrary in many parts of Africa for example the quality and outreach of conventional land lines was and is often extremely poor and limited. Zimbabwe under President Mugabe, for example, saw very rapid growth of cell phone usage in part because the main telephone service became so poor.

More generally, the opportunity to jump ahead of the leaders is often called “leapfrogging”. While the cell phone example has already opened up exciting new possibilities even in the poorest countries (e.g. a more secure payments system for remote families and farmers as well as greater access to quick market intelligence even for smaller farmers as with the MPESA system in Kenya), it is not yet clear whether this example has more general applicability. The evidence on balance is not very supportive of a dominant leapfrogging effect: in general, richer countries adopt new technologies earlier and faster first than do poorer countries[42].

9.3.6. Market failures

Fourth, the existence of complementary inputs suggests also that the slow adoption of new technologies may be an optimal response to resource differences between countries that lead in turn to differences in the efficiency with which these technologies can be used. It also points to the existence of possible coordination failures. Coordination failures occur when the profitability of two different investments depend on each other and there is no market mechanism to assure that both investments will take place.

A similar story holds in the presence of network effects, whereby the adoption costs of a given technology decline with the number of users of the same technology. For example, the switch to automobiles running on bio-diesel fuels is only possible if existing gasoline suppliers across the country install bio-diesel services. This, in turn, only pays off if the number of users of bio-diesel reaches some critical point. But it is easily seen that this can lead to a vicious-cycle: users do not switch to bio-diesel because there is not enough supply and supply does not respond because demand is insufficient.

Another factor slowing down the adoption of new technologies are information spill-overs. The process of finding out which of the many potential innovations in a given period best fits a country’s circumstances is often a problem of self-discovery. The

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[42] Comin and Hojbin (2004).

firm that first implements a new technology runs a risk of failure. If it succeeds, other firms will imitate it. But if the lead time achieved by moving first is not long enough to compensate for the extra cost of developing the technology, the firm will optimally prefer to postpone the adoption of the new technology. Because the firm that first implements any new technology provides valuable information to other potential entrepreneurs without being compensated for this, an information externality arises.
Spillovers also occur when the innovating firm has to train its own workers. If dealing with the new technology requires a minimum level of specific training, in order to implement the new technology, the innovating firm has to invest in additional training for its workers. But once it does this the risk exists of technology-followers free-riding on workers mobility. Again, the private returns for the innovating firm are lower than the social benefits.

By inducing a harmonious development of complementary inputs and by properly subsidising the innovation efforts, governments may (at least in theory) alleviate the market failures described above – all of which reduce the alleged benefits of backwardness - and so improve the growth prospects of a country that can flow from the adoption of new technologies.

9.3.7. Disadvantages of backwardness

Bringing some of these points together we note that a critical problem with government intervention is that many of the required conditions for effective technological change cannot be created at once. Instead, they are likely to evolve slowly, according to the accumulated experiences (learning by doing) in producing with older technologies. The degree of similarity of the new technology to the old technology determines just how transferable the accumulated knowledge is. In much the same way that new ideas develop on the back of old ideas, a country’s ability to implement new technologies depends on the extent to which these technologies can use the capabilities bequeathed by previously existing activities.

This means that there are also disadvantages to backwardness. Countries that are too backward may lack many of the complementary inputs to enable the new technologies to be both productive and profitable. This sets up a potentially *virtuous* cycle: economies that have previously accumulated infrastructures, human capital and developed business support activities are likely to be more attractive for further accumulation.

India’s example of reverse migration in receny years again provides an interesting example of this. One of the things that India did well in its bad years of intensive controls and very slow growth was to maintain the seven high quality Institutes of Technology established under Jawaharlal Nehru soon after Independence and six good quality Institutes of Management. These Institutes trained hundreds of thousands of Indians to a high standard in very competitive environments. In the years of tight economic controls and slow growth through 1990 many of these well trained Indians migrated to seek appropriate work in the USA and in Western Europe. But with the reforms of the 1990s, and the beginnings of the IT revolution that followed, many tens of thousands have been voluntarily returning. They thereby provide one of the absolutely critical complementary resources to support India’s remarkable assimilation of modern international digital and IT technologies in a wide range of sector applications. (Friedman, 2005 pp. 127)

Box 9.3: We are all Locked in to QWERTY

The QWERTY keyword that can be found on almost any computer was designed in 1873, with a series of tricks designed to slow down typists. For example, the commonest letters are scattered over all rows and concentrated on the left side of the keyboard, so that right handed people have to use their weaker hand to reach them. Why was this keyboard designed with such unhelpful and unproductive features? The answer is that mechanical typewriters in 1873 jammed easily if two keys were struck in very quick succession. The QWERTY key layout emerged to slow typing speeds and so reduce the frequency of jams. It was therefore a purposeful inefficiency created to avoid problems of jamming.

What makes this case interesting is that when improvements in typewriting eliminated the problem of jamming, the QWERTY keyboard was already installed in most of the world's machines and the secretarial profession was trained to use it. Alternative keyboards, allowing for faster writing and lower effort were tried, but they did not succeed because people were already locked into the less efficient technology and refused to change. (David, 1985).

9.3.8. Barriers to creative destruction

So it is clear that taking opportunity of the advantage of backwardness is not something that happens automatically. Innovation occurs when firms have some real incentive to adopt new technologies and so are willing to sacrifice current consumption while they are installing new technology in order to achieve a future payoff.

These incentives, in turn, differ from country to country, depending on the various *barriers* placed in the path of entrepreneurs. These barriers take different forms, such as regulatory and legal constraints, bribes that must be paid, violence or threat of violence, outright sabotage and worker strikes. These barriers in turn reflect the various ways in which governments and groups of individuals increase the amount of investment a firm must make in order to adopt a more advanced technology.
A typical barrier is one of vested interests that are wedded to the old technologies. Because creative destruction creates some winners and some losers, those whose economic, political and social interests are threatened by the adoption of new technologies are likely to put effort into the prevention of their diffusion or alternatively will try to capture the rents that these technologies yield. This often translates in practice into protection against competing imports embodying more efficient technology.

In general, any low-income economy's permeability to the technological progress occurring inexorably abroad depends on the quality of the local economic and legal institutions and on the political environment. A favourable business climate, the rule of law and the protection of property are essential for growth from creative destruction. Other aspects include a predictable legal and political environment, a fair tax system and the commitment of policymakers to accept the underlying changes that the new technology is likely to bring. Sometimes, technology exists but societies seem hopelessly conservative, inward looking and hostile to change, so that some of the key incentives to adopt the new technologies are missing.

Whatever their form, these barriers have the effect of increasing the cost of technology adoption. Barriers to technology adoption are certainly an important deterrent to the adoption of new technologies even when these are being produced globally in ever greater abundance.

9.3.9. A simple model of technology adoption

The discussion above all points to the conclusion that taking full opportunity of the world technological diffusion requires deliberate efforts by the local economy and its various players. These efforts include setting up a minimum level of skills, basic infrastructures, and providing the appropriate incentives for private agents to invest in new technologies. In some cases, specific measures to adapt the technology to the existing circumstances are also called for.

This section presents a simple model of convergence through technological transfer. In this model, country characteristics and the level of the country's innovation "effort" determines its productivity level relative to the world technological frontier, while its long run growth is linked to the expansion of that world technological frontier[43].
Because this country is assumed to be small relative to the total world economy, the expansion of the world technological frontier is assumed exogenous (you may regard the expansion of the World technological frontier as driven by the research effort of all countries, according to the theories presented in Section 8.4)

In this model, two kinds of policies to improve the country's permeability to the world-wide technological innovation are distinguished:

(i) *Innovation effort*, which is meant to capture both R&D and the policy and other efforts to support technology adoption;

(ii) The removal of the any existing barriers to creative destruction. This *reform effort* and the measures associated with it can include greater openness to trade, improving the rule of law, changing specific legislation which may deter some forms of technology, enforcing property rights.

Output in this country is produced according to a Cobb-Douglas production function of the form:

$$Y = AK^{\beta}(\lambda N)^{1-\beta} \qquad (8.5.1)$$

Where K includes both Human and Physical capital (meaning that β is around 0.6-0.7) and λ is the Harrod neutral technological level in the country. Output can be used for consumption (C), Investment (I=sY) or in the innovation effort (R). In the interests of simplicity, we assume that a constant fraction of GDP is devoted to the innovation effort:

$$R = s_R Y \qquad (8.5.2)$$

The capital stock evolves as stated in the basic Solow model, with exogenous saving (see equations 6.3.4 and 6.3.5). The level of technology is assumed to evolve according to:

$$\dot{\lambda} = \left(\pi \frac{R}{N}\right)\left(\frac{\bar{\lambda}}{\lambda}\right)^{\frac{1}{\sigma}} \quad \text{, with } \sigma>1 \qquad (8.5.3)$$

where π is positive a parameter determining the productivity of the innovation effort and $\bar{\lambda}$ represents the world technological frontier.

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[43] This model draws on Klenow and Rodriguez-Clare (2004).

In (8.5.3) the country' productivity effort is scaled by population, N, implying that the change in technology will be proportional to research intensity (this avoids scale effects). The parameter π determines the productivity of the innovation effort. For a given innovation effort, the change in the country's technological level will depend on the society's success in reform in the sense of removing the existing barriers to technological development. A small value of π may be generated by high import tariffs or trade quotas, legal restrictions against the establishment of foreign firms, lower enforcement of property rights. The provision of a reformed and so sounder economic framework, in turn, is expected to improve the country's permeability to foreign technology. This in turn can raise the value of π.

According to equation (8.5.3), the change in the country' technological level depends positively on the gap between the country's technological level and the world technological frontier, $\bar{\lambda}/\lambda$. This term captures the existence of potential "benefits to backwardness". The parameter σ imposes diminishing returns on these benefits. That is: the "advantage of backwardness" is larger, the further away a country is from the technological frontier. The rationale for this assumption is that, as the country approaches the frontier, less ideas will be available for copying and the effective cost of copying will rise (Parente and Prescott, 1994, Barro and Sala-i-Martin, 1997).

The World technological frontier is assumed to expand at the exogenous annual rate $\bar{\gamma}$:

$$\bar{\lambda} = e^{\bar{\gamma}t} \qquad (8.5.4)$$

9.3.10 The Steady state

In the long run, the country will evolve along a path that is parallel to that of the world economy. This means that its productivity level will grow at the same rate as the world technological frontier. Substituting (8.5.2) in (8.5.3), dividing both terms by λ, setting $\dot{\lambda}/\lambda = \bar{\gamma}$ and solving for the technological gap, one obtains:

$$\frac{\bar{\lambda}}{\lambda} = \left(\frac{\bar{\gamma}}{\pi s_R \tilde{y}}\right)^{\sigma} \qquad (8.5.5)$$

where $\tilde{y} = Y/\lambda N = A^{1/1-\beta}(K/Y)^{\beta/1-\beta}$. Equation (8.5.5) states that a country's effort on technological adoption affects its relative income gap vis-à-vis the most developed country. Solving for the country technological level, one obtains:

$$\lambda = \left(\frac{\pi s_R \tilde{y}}{\bar{\gamma}}\right)^{\sigma} e^{\bar{\gamma}t} \qquad (8.5.6)$$

It is noteworthy that the size of the technology adoption effort, s_R, affects the country technological level conditional on per capita output per unit of efficiency labour, $\tilde{y}$. This property captures the idea of interactions between the innovation effort, input availability and the economy's efficiency level, as described in the earlier sections. The model therefore establishes a causal relationship from efficiency and capital intensity on the one hand to the *level* of TFP on the other. The implication is that some differences in TFP across countries may be due to differences in factor accumulation.

The steady state level of per capita output in this model can be obtained by referring to equation (6.4.13) in the Solow model, which is repeated here:

$$y_t^* = A^{\frac{1}{1-\beta}} \left(\frac{s}{n+\delta+\gamma} \right)^{\frac{\beta}{1-\beta}} \lambda_t . \qquad (8.5.7)$$

Using $\tilde{y} = y/\lambda$ $\tilde{y} = y/\lambda$ in (8.5.5), solving again for λ and substituting in (8.5.6), one obtains the steady state level of per capita income in this extended model:

$$y_t^* = A^{\frac{1+\sigma}{1-\beta}} \left(\frac{s}{n+\delta+\bar{\gamma}} \right)^{\frac{\beta(1+\sigma)}{1-\beta}} \left(\frac{\pi s_R}{\bar{\gamma}} \right)^{\sigma} e^{\bar{\gamma} t} \qquad (8.5.8)$$

As in the Solow model, the country characteristics determine *levels* of income per capita etc.,but not the steady state growth rate. The main difference with the earlier Solow model is in respect to the set of exogenous parameters that determine the steady state. In particular, the country's ability to approach the world technological frontier depends on its efficiency level, on the propensity to invest in physical (human) capital and on the proportion of resources spent on the adoption of new technologies. However, the long run growth rate is exogenously driven by the world technological parameter $\bar{\lambda}$ [44].

9.3.11. Transition dynamics

As in the basic Solow model, the principle of transition dynamics applies to changes in the exogenous parameters of this model too. A change in a parameters will produce a *level effect* and a transitory period during which the country will approach the World technological frontier. During this period, the country can exhibit faster growth rates than the world average, but this is only a temporary phenomenon. In the long run, the country's growth rate will be that dictated by the growth rate of the World technological frontier.

To see how the model works in the short run, Figure 9.3.1 depicts the growth rate of the country technological level, γ, as a function of the country technological gap, $\bar{\lambda}/\lambda$. According to equation (8.5.3), this relationship is positive. This captures the advantages of backwardness idea. The figure also depicts the annual growth rate of the World technological frontier, $\bar{\gamma}$, which is independent of the country technological gap.

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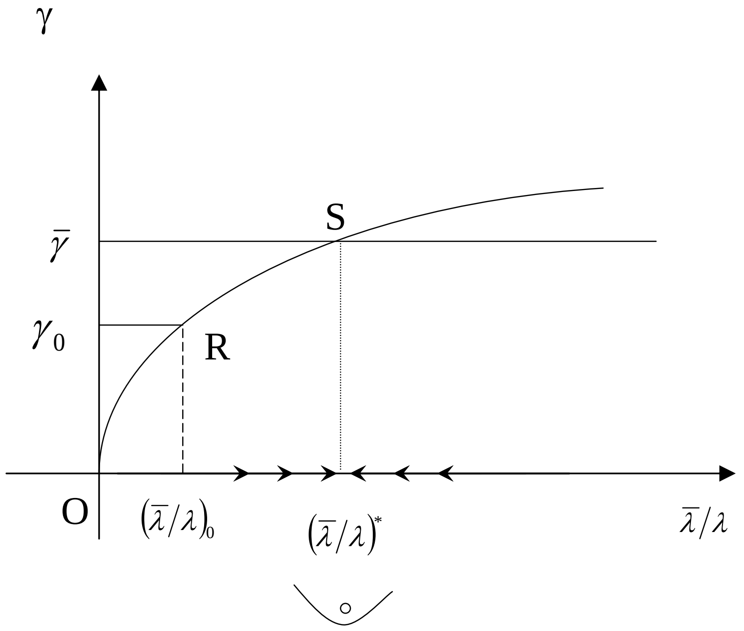
[44] This model feature - that differences in policies or other country parameters generate differences in levels, rather than in growth rates is common to a set of models with technological diffusion (Howitt, 2000, Parente and Prescott, 1994, Eaton and Kortun, 1996, Barro and Sala-i-Martin, 1995, chapter 8). Klenow and Rodriguez-Clare (2004) and Howitt (2000) extend the model so as to allow the expansion of the world technological frontier to be driven by the research efforts of all countries, but the student will thank us for skipping this complication

Now assume that the initial position of the country is point R, with a technological gap equal to $(\bar{\lambda}/\lambda)_0$ With such a gap, the rate of technological expansion in the economy is smaller than the world rate, that is $\gamma_0 < \bar{\gamma}$. This means that the country will be diverging from the world tendencies: its technological gap will increase. In the figure, the country will move rightwards, from R to S. As the technological gap increases, the advantage of backwardness shows up more strongly (there are lower imitation costs) meaning that the country will obtain a faster rate of technological progress, *for a given innovation effort*. Thus, as the country moves rightwards, its growth rate increases. However, when point S is reached, the country growth rate is exactly equal to the world growth rate, so that its income gap stabilizes. By the same token, if the country starts on the right hand side of S, it will converge to S.

Figure 9.3.1: transition dynamics and the steady state in the technology adoption model



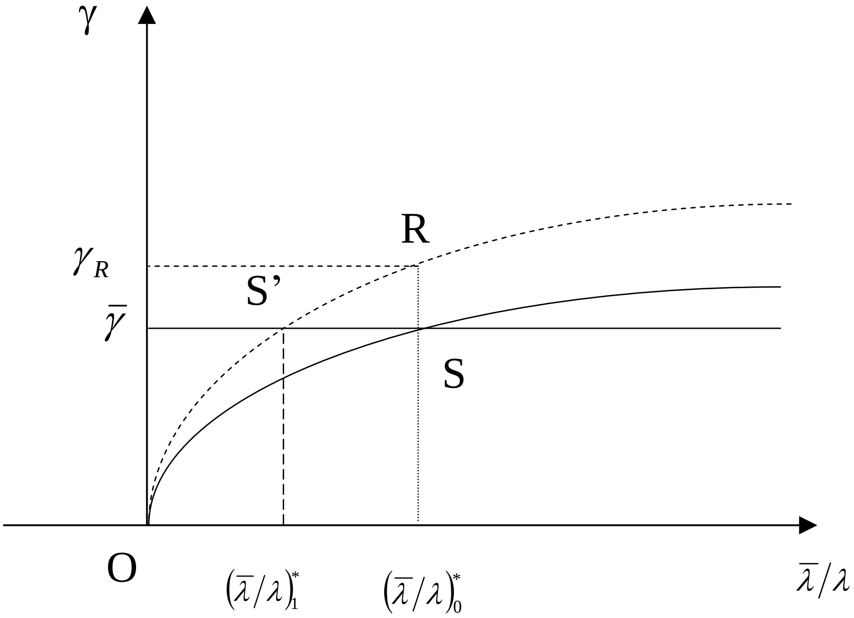
9.3.12. The effect of policy changes

Figure 9.3.2 describes the effect of a rise in the innovation effort (s_R) . Contrary to what happened in the first case above, now the steady state moves to a different point as the locus describing equation (8.5.3) shifts up.

If the country is originally in the steady state S, then, at the point of impact, the growth rate of technology increases from $\bar{\gamma}$ to γ_R. Since the country's technology level is now growing *faster* than is the World frontier, the technological gap starts decreasing, meaning that the country moves leftwards, in the direction of S'. As the technological gap decreases, the benefits of backwardness decrease as well, implying a decline in the country' growth rate until the new steady state is reached.

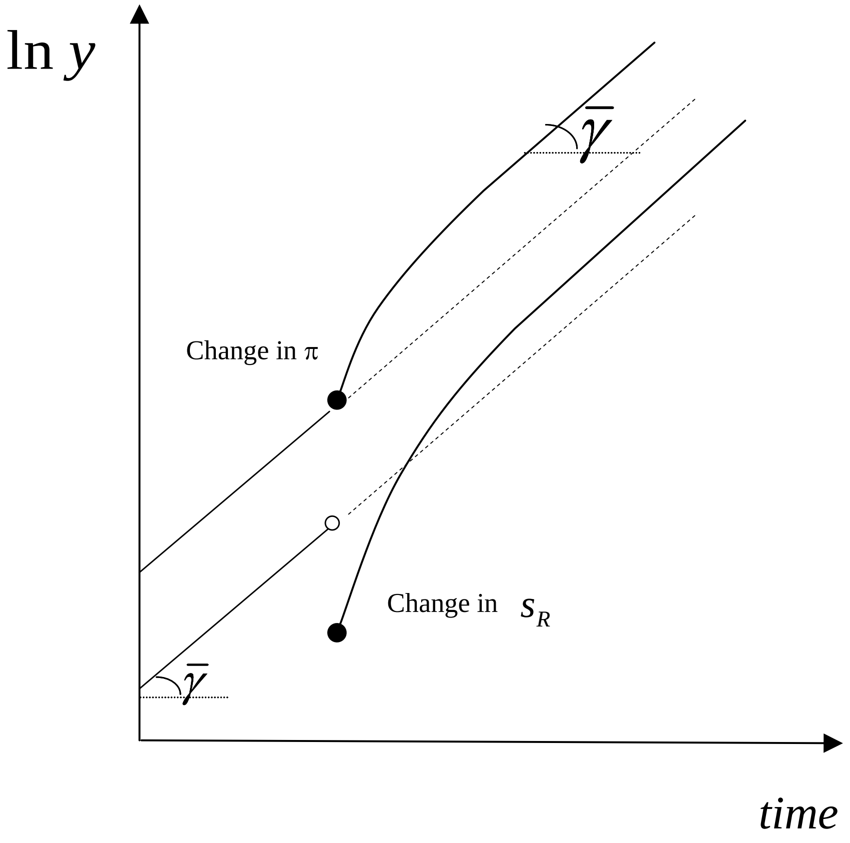
A similar adjustment will happen if, as an alternative we examine the removal of a barrier to technological adoption: suppose, for example, that a major anti-corruption reform takes place, enhancing the ability of the economy to adopt new technologies, for a given explicit innovation effort. In our model, this will be captured by a rise in parameter π, shifting up the locus describing equation (8.5.3).

Figure 9.3.2: The effect of an increase in innovation effort or innovation productivity



Although changes in s_R and π have similar effects in terms of Figure 9.3.2, the path of per capita consumption differs in the two cases. Figure 9.3.3 describes that difference. In the case of an increase in the innovation effort, a greater proportion of resources is spent on the innovation activity, implying an initial *fall* in per capita consumption. The subsequent narrowing of the technological gap may be or may not be enough to compensate for that initial fall. In the figure, it is assumed that it is, but this is not necessarily true. As in the Solow model there is a golden rule for the optimal spending – in this case spending on innovation. By contrast in the case of a removal of barriers to technological adoption, the faster technological progress occurs without any initial decline in per capita consumption. Note that you can refer to this figure to interpret the path of Japan after WWII, as described in Figure 7.3.2. above

Figure 9.3.3: the path of consumption following a change in s_R and a change in π.



Equipped with this new model we can readily see that observed country divergence episodes can reflect widening barriers to technological development, in addition to the differences in investment rates in human or physical capital, as suggested by the earlier neo-classical model.

The new model thus offers a possible interpretation for the widening of the World income gap that occurred after the industrial revolution in the 18th century. As noted by Parente and Precostt (2004), the opening up of large income differences in the World economy as shown clearly in the Figures in Chapter 3, coincided with the onset of modern economic growth. The divergence could thus reflect the interaction between country-specific barriers to technology adoption on the one hand with the emergence of modern technology-driven growth on the other. The authors note that the time it takes for a typical country to go from a level of per capita income of $2,000 to one of $4,000 has fallen since the late 19th century, suggesting a potential for those low-income countries willing to seize it, to grow rapidly by removing barriers to adopting technology that has already been adopted somewhere. The modern 20th and 21st century examples of South Korea and China are wholly consistent with this important proposition.

Box 9.4. The TFP controversy in East Asia

There are many examples in the literature of practical applications of growth accounting. One particularly famous and also controversial application was by Young (1995) for the so-called Asian Tigers (Hong Kong, Singapore, South Korea and Taiwan). Economists have for many years turned to these successful countries for clues that can explain the successes of development and so provide examples of effective development to guide the rest of the world. The World Bank in particular had come down strongly and controversially in favour of the idea that the East Asian economies by operating sounder domestic policies than other developing countries had used their accumulating factors far more efficiently. This in turn was argued to be a major reason for their exceptionally high growth rates compared with, say African and Latin American economies.

So in its 1991 *World Development Report*, the Bank used a sample of 68 countries from 5 main regions of the developing world to decompose growth rates of GDP over the period 1960-1987. The results are as shown in Table 9.3.1 below.

Table 9.3.1 GDP Growth and TFP 1960-1980 in selected Developing Countries

	GDP Growth-Rates 1960-1973	GDP Growth-Rates 1973-1980	TFP 1960-1973	TFP 1973-1980
Africa	4.0	2.6	0.7	-0.7
East Asia	7.5	6.5	2.6	1.3
Europe, Middle-East and North Africa	5.8	4.2	2.2	0.6
Latin America	5.1	2.3	1.3	-1.1
South Asia	3.8	5.0	0	1.2
Sixty-Eight Developing Countries	5.1	3.5	1.3	-0.2

Source: World Bank, 1991, pg 43

It can be seen there that not only did East Asia enjoy the fastest growth of any of the five regions in each of the two periods, but it also depended on TFP growth for a higher absolute amount of total growth than did the other regions – almost 2 percentage points of its overall growth of almost 7 percent per annum. By contrast, TFP growth rates in both Africa and Latin America were almost zero on average in that same period. The Bank study linked these differences to a variety of factors but most importantly to sounder economic policies and to a lower incidence of distortions in East Asia. The Bank's conclusion was also consistent with a prevalent view of that time and the model just described that technological catch-up supported by sound policies was the main issue explaining East Asia's exceptional performance.

In an influential article, Young (1995) dissented from this view and found instead that the bulk of the impressive growth achieved in the four East Asia miracle countries in the period 1966-1990 could be attributed much more narrowly to their fast rates of factor accumulation, and not to their exceptional levels of productivity growth (TFP). These countries, he concluded have achieved their very high growth rates because of their ability to achieve much higher rates of savings and investment and a drastic increase in the fraction of population at work (largely via the increased labour force participation of women). At the same time large population shifts from agriculture into manufacturing and greater attention to education, has resulted in levels of educational attainment close to those of the leading industrialised nations.

Columns (1), (2) and (3) of Table 9.3.2 present a summary of the Young (1995) estimates. These are obtained using a decomposition similar to (6.3.1a), with the difference that they aggregated raw labour and human capital into a single measure of labour. The data in column (3) indicate that indeed TFP growth accounts for only a relatively small proportion of GDP growth in some of these countries. Singapore for example was a particularly bad performer in this respect, with TFP growing at a rate close to zero.

Table 9.3.2. - Productivity growth in East Asia

	Young (1995)				Klenow and Rodríguez-Clare (1997)			Hsieh (1999)		
	Y (1)	Y/N (2)	TFP (3)	Harrod Neutral (4)	Y/N (5)	Harrod Neutral (6)	Rank (98 countries) (7)	R (8)	w (9)	Dual TFP (10)
Hong Kong	7.3	4.7	2.3	3.7	5.5	4.4	4	0.3	4.0	2.7
Korea	10.3	4.9	1.7	2.5	5.4	2.5	17	-4.8	4.4	1.6
Singapore	8.7	4.2	0.2	0.3	5.1	3.3	6	1.2	2.7	2.0
Taiwan	9.4	4.8	2.6	3.5	5.3	3.0	7	-1.7	5.3	3.5

Source: Columns (1) - (3) are from Young (1995) and display average growth rates for the period 1966-1990 (1966-1991 in Singapore). Columns (4)-(6) are from Klenow and Rodriguez Clare (1997) and refer to the period 1960-85. Column (7) displays the rank order of estimates in Column (6) in a sample of 98 countries. Columns (8)-(10) are from Hsieh (1999). The user cost of capital in column (8) is based on the "average lending rate", for Singapore (1968-1990), the "secured loan rate", for Taiwan (1966-1990), the "best lending rate", for Hong Kong (1966-1991) and the "curb market loan rate", for Korea (1966-1990).

Based on this evidence, some authors disputed the view of the World Bank and concluded that the East Asian episodes illustrate the importance of neo-classical transition dynamics (that is, the old-fashioned hard work and effort!) rather than technological progress or efficiency. Paul Krugman who helped to popularise the results of Young (1995) summarised by arguing that the key issue was "transpiration" rather than "inspiration".

The implication of this finding for development economics is straightforward but potentially extremely important: if technological catch up played only a minor role in East Asia's growth, this means that belt-tightening and policies that address the issues of low initial savings and investment and poor education are the more critical ones to promote faster growth. Thus, the quest for policies that encourage the greater aggregate efficiency that many authorities have emphasised in the East Asian context appeared to be relatively less important.

Because this was a controversial conclusion, the subject of the magnitudes of TFP growth in East Asia quickly became a very topical issue in the research arena. Among others, the following issues have been under discussion:

First, the decomposition used by Young (1995) does not attempt to control for factor accumulation that is *induced* by TFP change. Stressing this point, Klenow and Rodriguez Clare (1997) computed the Harrod neutral rates of technological progress implied by the Young (1995) estimates of Total Factor Productivity. Their results are reproduced in column (4) of Table 9.3.1. Clearly, the adjusted measure of technological change are higher than those in Column (3).

A second problem is related to data measurement. In general, growth accounting exercises are sensitive to crucial assumptions, namely the weights assumed in the production function, the data sources and the treatment of human capital. Differences in data definitions across countries also create problems in international comparisons. To illustrate how sensitive the estimates are to changes in methodology, we display in columns (5) and (6) of Table 9.3.2 the estimates of Klenow and Rodriguez Clare (1997) for output per capita and (Harrod neutral) productivity growth. Although the estimates for South Korea and Taiwan roughly match those of Young, estimates for Singapore and Hong King are much higher. In the case of Singapore, the difference is qualitatively important.

The third caveat to the Young results is that the contribution of TFP growth should be evaluated *per se* and not as a proportion of output growth. In general, estimates of TFP growth using comparable data for a large set of countries reveal that East Asian productivity growth is relatively high when compared to other regions. Column (7) displays the rank order of the Harrod neutral rate of technological progress estimated by Klenow and Rodrigues (1997) in their 98 countries sample. Clearly, the TFP growth rates in the four East Asian economies are high relative to those of most other countries..

More recently, Hsieh (1999) observed that, if East Asian grown was mostly driven by transition dynamics, with little technological progress, then the return to capital should have fallen dramatically, because of decreasing marginal returns. However, in Singapore the rates of return did not behave in that way. Manipulating the condition that output equals factor incomes, the author proposed a new (dual) estimate of TFP growth, based on factor prices:

$$\frac{\dot{A}}{A} = \beta \frac{\dot{R}}{R} + (1-\beta)\frac{\dot{w}}{w} ,$$

where R is the rental price of capital (the real interest rate plus the depreciation rate multiplied by the relative price of capital) and *w* are real wages (obtained as a weighted average of workers of different qualities). The dual estimate of TFP growth has the advantage of being based on market prices (namely wages and interest rates), rather than on national accounts, which are provided by official statisticians. Some of the Hsieh (1999) results are depicted in columns (8)-(10) of Table 9.3.2. As the table reports, in the case of Singapore there is a significant difference between the Young (1995) primal estimates of TFP and the Hsieh (1999) dual estimates of TFP. The author suggested that national accounts data in Singapore are probably wrong.

In sum, the recent developments in this discussion point to the case that technology and aggregate efficiency may have played a much larger role in the economic transformation of Singapore than the original Young estimates suggest. This in turn supports the proposition about the influence of technological adoption discussed in this section.

9.3.13. Summing up

The models of technological development and growth presented in Section 8.4 lead to different predictions concerning the relationship between R&D intensity and growth, but they all have some form of scale effect. We argued that these models should be understood to apply to *global* technological progress, rather than to the *country* level. The model presented above is intended to apply to individual countries.

The two main features of this model are:

- In the steady state all countries grow at the same rate thanks to international knowledge spill - overs;

- Differences in policies or in other country parameters generate differences in TFP levels rather than in growth rates. Although in the long run countries evolve in parallel, policy changes give rise to transitory adjustment paths during which the country converges or diverges from the World technological frontier.

CHAPTER 10: KEY MESSAGES TO CARRY FORWARD

At the beginning of this second Part of the book it was emphasised that growth theory is an important, even the core element, of the study of development economics. At the same time it was noted that such theory cannot yet provide a unified and integrated set of propositions to guide the search for practical development solutions in the poorer countries. It was also pointed out that growth models utilise a set of techniques that for the most part involve highly aggregative approaches to development. In doing so, they abstract necessarily from much of the sectoral and other detail that is so important to understanding the situation in the poorer economies of today's world.

Both these propositions need to be borne in mind as we review the important insights that we can indeed derive from the three substantive chapters and the wide range of growth models that we have reviewed above. These can be thought of as adding to the insights that we derived earlier from the bare-bones model of Chapter 1.

The conclusions of growth theory need to be interpreted on their own terms. If we do that then both the policy practitioners as well as the more academically-inclined reader will find many important insights to carry with them as they read further into this book. In this final chapter of Part II we focus on just five of the more critical insights.

1. Single Factors of Production Cannot Explain Growth

Four factors of production were identified in our introduction to growth models (see Figure 6.1). But significantly the analysis has shown that none of these four factors on their own can be regarded as critical in explaining development or the failure of countries to develop. Indeed it is the complementary team work between the four factors and various combined effects from these that figure in most of the more advanced models and indeed in all real world growth

This conclusion is not one that has always been shared by growth theorists. In the earlier classical models, it was common for the availability of *land* to be categorised as the critical limit on growth and development. But 200 years of experience across many countries – rich and poor - has shown that the constraining influence of land-availability has routinely been side-stepped by the accumulation of other factors of production, and especially technology.

The early tendency after World War II was to present *physical capital* accumulation as the key to more rapid growth in the low-income countries. This tendency persists even today in the policy recommendations that lie behind the targets of the Millennium Development Goals and the Make Poverty History campaigns. However, the hard logic of our aggregative growth models shows clearly enough that the mere process of capital accumulation cannot support sustained growth over time without the intercession of other critical factors of production. This is an extremely important message not least for practitioners in the aid community.

The simple Solow neo-classical model, for example needs to invoke the unsatisfactory *deus ex machina* of exogenous technical progress to achieve consistency with the real world facts of rising incomes over time. This is true also in the more sophisticated model of Mankiw, Romer and Weil even though this model does account explicitly for the role of the additional factor of human capital. Many growth accounting models including the original Solow contribution of 1956, reveal an alarmingly high residual of unexplained growth even when identified factors of production including capital are taken full account of. There are mysteries still to be explained!

2. Transitions v Equilibrium States: the Complexity of Interpreting Data

In several of the models discussed above we have illustrated one of the preferred methodologies of theoretical growth modelling. This methodology involves studying the impact of exogenous events such as an increase in the savings rate or the acquisition of new technology by treating these events as disturbances to an already established long-run equilibrium, or “steady state”. Among other things this approach gives us one way of simulating the growth effects of various possible policy changes. This technique has been illustrated at several different points in the past three chapters.

However, little has been said, either here or in most growth models about either the length of time needed for the transitional adjustment to occur or about the shape of the transition when multiple rather than single disturbances occur. It is now pretty much accepted that this transition process may be quite long-lived (in some of the Mankiw et al formulations, for instance, half of the transition dynamic may take as long as 35 years). With adjustment lags as long as this, it is extremely difficult in practice to disentangle empirically whether the time series data we observe for any one country are describing that country’s steady state or the transitional adjustment from one steady-state to the next. Furthermore, since the *steady state* (or equilibrium) predictions of some models (e.g. Harrod-Domar) look very similar to the *transitional* predictions of other models (e.g. Solow) this make it difficult in practice to assess empirically the relative merits of different competing models.

More generally this second point is a warning about any over-casual use of time series data to draw conclusions about the causes of growth. The structural frameworks that growth models provide are certainly very useful. However, they are often less than conclusive in helping either to empirically design empirical research experiments or in distinguishing one model specification from another.

3. Growth explanations need to dispense with Diminishing Returns

It is second-nature for economists with any degree of technical training to rely on diminishing returns in much the same way that a doctor relies on his stethoscope or a chef on his knives. The simpler neo-classical models that dominated the literature for some 30 years after 1956 made central use of this crucial proposition in formulating their ideas and predictions. However, as the inconsistencies between these predictions and certain real world magnitudes and effects have progressively been uncovered (see especially Section 7.3 above), the underlying idea of diminishing returns has itself been questioned.

Our analysis has shown that the more recent models of the past twenty years in particular, have made increasing use of mechanisms involving *externalities* of various kinds. They have also had the effect of rejecting diminishing returns at least at the level of the aggregate economy if not at the level of the individual firm. Today the more plausible growth models in the literature involve varying degrees of “team-playing”, complementarities and interaction between different factors that the earlier models treated as relatively independent of each other. The examples illustrated in earlier chapters include complementarities between workers and machines resulting in “learning by doing”; complementarities between the activities of different firms or different workers within the same economy; and complementarities between public/social investments and private investments. In all these and other cases it is readily shown that the combined growth effects of the interactive efforts of different players can be greater than the sum of the individual component parts.

There are several points to stress about this relatively recent and important shift of emphasis in the mainstream literature as charted in our three substantive chapters. First, it is a shift that brings back into play and into some degree of mainstream respectability, those important early contributions of Krugman's "high development theorists." Second, once the complementary relationships between various different elements are accepted as important, the task of specifying a credible and robust *quantitative* model of growth for any given economy becomes inherently much more difficult even than it was before. This is because it is very much easier to write down and implement models of growth in which the component elements (e.g. factors of production) are largely independent of each other. Once the models start to incorporate complex interactions and mutual dependencies across different players in the economy (e.g. the public and the private sectors) it becomes inherently more difficult to measure and calibrate the various effects. This is why, for example the simpler earlier models of growth such as Harrod-Domar have survived in the mainstream practical work of organisations such as the World Bank even though the relevance of such models has been broadly and authoritatively questioned. Third, and most important, and as also illustrated in the earlier chapters the new approaches provide a wide array of reasons for rejecting the more simplistic neoclassical notions that growth will take care of itself and without the intercession of practical policy interventions from wise governments. The more complex recent models have given us more reasons for expecting policy interventions to have significant development effects.

4. Backwardness and Global Interdependencies

It was a common assumption of Jawaharlal Nehru and the other architects of early post-independence economic policies that the poorer countries of that period would benefit from the already accumulated global pool of technical know-how that was then available. As a result these pioneers confidently expected that the poor countries of the early 1950s such as India would grow much more rapidly than had the predecessor industrial countries such as Britain, France and Germany in earlier eras. This prediction has proven to be generally sound as is illustrated comprehensively in our 50 year reviews by region in Chapter 4 of Part 1: albeit with a significant number of countries failing to share fully in the benefits.

The discussion especially in Chapter 9 above provides the rigorous theoretical basis that supports this line of reasoning and builds on the original idea from Alexander Gershenkron that *imitating* is invariably cheaper than *inventing*. However, that analysis also identifies at least four substantive reasons why the intuition of Nehru and his contemporaries did not and still does not have broad relevance across all the countries of the developing world. In particular there are many side conditions including the availability of the right complementary inputs, the adoption of the right supportive policies, and the degree of openness to the practical transmission mechanisms of new technologies (i.e. trade, FDI, migration etc.) that determine whether the benefits of today's inexorable but global technological progress will or will not impact positively on the growth of any particular poor country.

The models in Chapter 9 are important not because they lay down detailed blue-prints about how any individual developing country can benefit more fully from the global technological revolutions that are occurring. Rather, these models lay out the broad elements of the processes that are involved in transmitting the global technological frontier (which is moving outwards inexorably) across international boundaries. For any individual developing country that broad framework can be seen as defining the main areas in which that country needs to examine its own policies in order to achieve greater benefits from technological globalisation. And again the insight is that this is a multifaceted and broad-based problem: solutions do not lie in just a bit more R and D spending, or a slightly more liberal trade regime.

5. Policy Directions – merely a Sketch of Possibilities

As was noted in Chapter 6, most policy-makers in developing countries and in the international donor agencies have not traditionally regarded formal growth theory, as having much to say to them and have certainly not regarded it as the essential analytical core of their ideas. However, as we have attempted to illustrate through some of the models in Chapters 8 and 9, the newer growth models of the past twenty years do now provide a series of entry points into the practical policy debates about developing countries that was largely absent in the earlier literature.

It was partly for this reason that the AK model was used as the starting point in Chapter 8. For as was subsequently shown, this simple structure can absorb a significant number of other more complex ideas many of which point to the policy directions that are needed to enhance growth rates. That model can also be generalised to help analyse a large number of important policy issues – beyond those discussed in detail in these chapters - and their relationships with the insights from formal models of growth.

A useful entry point for this is the observation from the original Romer, 1986 model that there can be a divergence between private and social rates of return once a model with capital externalities is considered. Similar the Lucas,1988 model involving complementarities between physical and human capital shows how similar gaps affecting the levels of private investments in skills may arise. The Romer gap in principle can be closed by the use of an investment tax credit or, in more dramatic ways involving direct government investment in some productive activities (see 8.4.6 above). The Lucas gap can be addressed via education subsidies or direct government investment in education and training. However, having noted these benign results of policy interventions we stress immediately that the models do not of themselves tell us much about the likely effectiveness of specific government interventions of these types in particular countries. One of the tasks in Part III of the book will be to become more explicit about the role of good (and less-good) governance and public administration in explaining successful and less successful cases of development. The growth models discussed here merely confirm that the *necessary* conditions for policy engagement are present.

The analysis of possibly useful policy interventions was continued in Section 8.5 with a discussion of the development role of governments in providing various types of infrastructure and other “public goods”. This analysis was based on a model of Robert Barro (1990). The simplest form of this model readily reveals that public investment (e.g. in roads and bridges) can certainly increase the rate of return on any private investments that use these facilities. However, once the taxes needed to finance the public investment and also the possibly wasteful use of some of those tax revenues are both factored in, then the same models can readily generate effects working in the opposing direction: i.e. government involvement can possibly have growth-reducing effects. This conclusion then leads us readily to the additional important insight that the reform of government (in this example through a more efficient system of tax administration) can actually increase the return to private investment and so boost the growth rate of the economy. Technically the reform can be shown to be equivalent to a rise in the private rate of savings.

Next the flexibility of this style of model based around the general AK structure is demonstrated in Section 8.6 by analysing a small sample of the other policy areas where reforms might also provide the *necessary* conditions for faster growth. The reader who has conscientiously addressed the earlier materials should be mightily encouraged to learn that these other areas of policy include a wide range of the practical policy dilemmas with which developing countries routinely grapple. They include monetary policy (vital to ensure a modest level of general inflation); financial sector reform (essential to the building of sound institutions to mobilize savings and intermediate these savings efficiently); trade reform (equally essential to help position a country soundly vis a vis the global economy); and the building of new institutions more generally such as legally enforceable property rights that can enhance the rates of return on private investments. In short, the effective absorption of the earlier models should also enable the reader to interpret many other policy areas in terms of the formal structure of growth models.

Further the policy areas listed in the previous paragraph all relate to topics where the detail about what we mean by “reform” and the specifics of the reform experiences in particular countries will be addressed more fully in Part IV of the book. For the moment we merely note the potential impacts on growth that can follow such reforms if they are carried out successfully.

Finally, in Chapter 9 the AK structure is further developed to look at the particular issues associated with the accumulation of technology and above all its transmission internationally and especially to poorer economies. This Chapter starts with the common-sense point (ignored by many earlier models) that there is no *free lunch* as regards the accumulation of new technological knowledge: someone has to commit time and other resources to its identification and development. But since knowledge can normally “spill-over” to benefit companies and individuals other than those who make that research commitment, then there is likely to be market-failure that results in sub-optimal levels of R and D activity. This is routinely addressed in all countries by various public sector interventions (e.g. patents) that are designed to slow the pace of spill-overs. These arrangements are likely to undermine somewhat the confidence that people such as Nehru had, and many other still have about the benefits that poorer economies can extract from modern technological advances.

In order to analyse this issue of technological “backwardness” and its potential benefits more fully, Section 9.3 has presented another version of the model in which the ever-improving technological frontier defined at the level of the *global* economy is combined with a parameter defining a wide range of the policy interventions that help or hinder any given country from making the fullest use of the improving global technologies. The policy implications from this last model have already been summarised in paragraph 4 above. In particular, it suggests that the developing countries really can have some independent policy influence over the pace at which new global technologies impact their economies and so their growth rates. This is not to say that growth benefits would not also accrue by complementary actions by rich countries to remove or moderate some of the restrictions on technological diffusion that they maintain for their own purposes (e.g. patent protection of important medicines). The important message is that there are significant policy choices for the developing economies even though, like Nehru in the late 1940s they might expect to receive some automatic gains from the processes of technological diffusion associated with their relative backwardness.

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