Measurement and analysis of capital, productivity and economic growth

Erumban, Abdul Azeez

Chapter 1

Introduction

Sustained economic growth is vital to achieving higher standards of living. Therefore, it is imperative to know what generates the process of economic growth. The creation of wealth, driven by accumulation of capital assets, is historically viewed as a key factor in this process. Capital accumulation has been a crucial mechanism in achieving technical progress, which was the driving force behind the industrial revolution (Foster, 2004; Allen, 2005). This process has helped increase the standards of living that were stagnant or only slowly increasing in the period before (see e.g. Lucas, 2003). At the same time, capital has been an important contributing factor to differences in economic growth between countries and over time (Solow, 1957; Denison, 1980). Therefore, differences in capital accumulation may be an important factor in explaining the growing disparity in the global income distribution.[1]

Despite its overriding importance in economic growth, capital is one of the least understood and widely debated concepts in economics. This is particularly true in the empirical literature, as the accurate measurement of capital input is still a matter of fierce debates. The services delivered by a single capital input are obviously an input in the production process, along side labour (Solow, 2007). But capital consists of many types of assets, and the aggregation of such capital goods and the services that flow over their lifetime is complicated. Hence there is an issue of how to aggregate these heterogeneous asset types into an aggregate capital input, which has been a longstanding debate in economics.[2] More importantly the extent of this heterogeneity has been increasing over time, as newer forms of capital such as information and communication technology (ICT) are introduced into the production process. Following initial scepticism (Solow,

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[1] Evidence suggests no significant decline in cross-country income disparity in the past decades (see Pritchett, 1997; Easterly and Levine, 2001; Clark, 2007). The latest Penn World Tables (PWT) data show that half of world's GDP is concentrated in rich countries that constitute only 15 per cent of the world's population, indicating the intensity of the disparity in income distribution Similarly, according to World Bank definition of people with an income of less than $2.15/day (in 1993 purchasing power parties), nearly 3 billion people that constitute almost half of the world population live in abject poverty (see Ravallion et al, 2007).

[2] See the literature on the well-known Cambridge controversy (for example, Harcourt, 1972 and Harcourt and Laing, 1971 and the papers therein).

1987), many studies have shown that the role of ICT-capital in boosting economic growth and labour productivity, particularly in OECD countries, is quite strong (e.g. Jorgenson and Vu, 2005; Inklaar et al., 2008). This increasing heterogeneity, however, poses a serious question: whether the standard practice of aggregating the money value of different type of assets is a good way to account for aggregate capital input in growth analysis? In addition, there is the problem of endogeneity of the capital accumulation process —capital accumulation is mainly driven by technological change, and vice versa, technology is embodied in capital goods. This issue warrants attention in the context of the increasing technological obsolescence, as firms may discard and replace their older capital by new assets, due to increasing technological change particularly in the ICT-era.

This thesis mainly concerns with the evolution and measurement of capital and the contribution of capital to economic growth and cross-country variation in economic growth. This introductory chapter further outlines the discussion about the measurement and explanation of differences in economic growth across countries and provides the background to the rest of the thesis.

1.1 The Measurement of Economic Growth

The early theoretical literature in the field of economic growth is mostly confined to the importance of physical capital accumulation and technology within the realm of neoclassical growth theory.[3] According to neoclassical growth theory, countries can attain higher growth rates by increasing savings and investment, or by improving their efficiency in using inputs, that would enable them to produce more output per unit of input. Though initially only physical capital accumulation was considered, human capital accumulation gained importance in the later literature (see for example Becker, 1964; Denison, 1964, 1967; Mankiw et al., 1992). This gained further importance with the

[3] Note that the role of capital in attaining economic growth has been discussed in the literature prior to neoclassical theory also. For instance, the physiocrat school considered capital as a productive factor in agriculture and the classical theory emphasized the accumulation of capital as the driving force of economic growth. Classical views on capital were further enriched by Ricardo's enquiry into the relationship between capital accumulation and diminishing return (Recardo, 1817). Since then there appeared a myriad of writings on capital and its role in production including the Marxian views of capital as a social mode of production.

emergence of endogenous growth theories (Romer, 1986; 1990; Lucas, 1988; Grossman and Helpman, 1991; Aghion and Howitt, 1992).[4]

Quantifying the Sources of Growth: The Growth Accounting Approach

A prominent approach used in the literature to quantify the effect of factor accumulation and technological change is the growth accounting approach. This approach is based on the neoclassical growth model pioneered by Robert Solow (see Barrow, 1999). It decomposes output growth into contributions of input growth (primarily labour and capital) and a measure of multifactor productivity growth (MFPG).[5] MFPG measures the outward shift in the production function. Therefore, it is the difference between the observed growth of output and the expected growth of output due to additional unit of inputs when no technological change has taken place (see section 2.4 of Chapter 2). From this logic, the growth accounting method assumes the total output growth as the sum of weighted input growth and MFPG. The MFPG is often called the Solow residual.[6]

Growth accounting is a useful and transparent tool to understand the relative roles of factor accumulation and technological change (Maddison, 1987). Growth accounting also helps one examine the time series dynamics of each country and compare it across countries, rather than using some kind of cross-country regressions under the

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[4] It may be noted that the so-called AK models that assumed a production function that is linear in capital also tried to endogenise growth, by relaxing the neo-classical diminishing returns to capital assumption (Rebelo, 1991).

[5] Note that the term multi factor productivity is used synonymously with total factor productivity (TFP) in the literature. However, since the present thesis will be dealing mostly with two primary inputs, labour and capital and their contribution to growth, throughout this thesis we call it MFP.

[6] The concept of the residual, however, may find its roots even earlier than Solow (1957). For instance, Griliches (1996) refers to Jan Tinbergen who used it as a measure of efficiency. Also there are different views on what the residual measures exactly. Abramovitz (1993) termed it as a "measure of our ignorance" and argued that it consisted of many things including the ignored part of capital such as intangibles. It could consist of improvements in allocative and technical efficiency, changes in returns to scale, and mark-ups among others, which could be broadly defined as improvements in efficiency (see Balk, 1998, p 73). Also see Lipsey (2000) for a critical note on what MFP measures and what not.

assumption of a single production function (as in Mankiw et al., 1992).[7] Solow (2001) has expressed scepticism on the fruitfulness of such cross-country growth regressions. He viewed growth theory to explain the evolution of one economy over time. And, the interpretation of parallel time-series for a group of countries, aiming to unearth the sources of differences among them would be more fruitful than cross-country regressions (Solow, 2001). We will follow this up further in chapter 2. However, growth accounting is a mechanical tool that does not provide any statistical test for the robustness of the obtained results (Easterly and Levine, 2001). It also does not say anything about the causality of the measured variables.

There is a major difference between the impacts of factor accumulation and MFPG on economic growth. These different processes are often described as inspiration versus perspiration (Krugman, 1994; Young, 1996) or assimilation versus accumulation (Collins and Bosworth, 1996; Nelson and Pack, 1998). The importance of this distinction lies in the neoclassical assumption of diminishing returns as a country accumulates capital.[8] Therefore, higher growth achieved through capital accumulation is not sustainable in the long run, while growth achieved by means of productivity gains is. By shifting to a higher production function the economy is able to produce more output with a given amount of inputs. Factor accumulation, on the other hand, means that the higher level of output is achieved through higher levels of inputs — i.e. a movement along the production function. Accumulation implies the need for more savings today, which can only be acquired at the cost of present consumption.[9] This would indicate that faster growth is achieved at the cost of present welfare; hence the positive welfare effects are lower. Thus, one could better term accumulation versus MFPG as temporary versus sustainable sources of growth or abstention versus ingenuity.[10]

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[7] Mankiw et al (1992) assumes a constant MFPG across countries. McQuinn and Whelen (2007), however, argue that though technological progress is exogenous in the Solow model, there is little reason to characterize this as implying that the rate of MFPG is the same everywhere (also see Solow, 2001). The constancy of MFPG across countries has been contested by many empirical studies in the context of large cross-section of countries (Easterly and Levine, 2001) and even across OECD countries (Inklaar et al., 2008).

[8] After reviewing empirical works on growth analyses Temple (1997) has observed that the diminishing returns assumption holds. In contrast, the new growth literature bypasses this assumption by allowing non-decreasing returns to physical and human capital.

[9] Provided there is no foreign investment.

[10] Abstention implies abstaining from current consumption to invest for future, and ingenuity implies creativity that could lead to technological change. This distinction was used by McCloskey (1981), while explaining the Industrial Revolution.

There have been a number of cross-country studies, within the realm of the neo-classical theory, that examine the sources of growth and development in terms of the relative importance of accumulation vs. assimilation. The dominant conclusion is that the persistence of output and labour productivity differences across countries is driven by MFP differences rather than differences in physical or human capital accumulation (Hall and Jones, 1999; Easterly and Levine, 2001; Caselli, 2004; Jones and Olken, 2008). However, many other studies in the context of the 'East Asian miracle' (Young 1994), Middle East and North African growth (Abu-Qarna and Abu-Badera, 2008) and world economic growth (Jorgenson and Vu, 2005) seem to stress the importance of capital deepening over the MFP gain. In what follows we discuss some studies of economic growth in East Asia, India and China, as well as the ICT-led growth in the OECD countries. This is aimed to highlight some important issues in the measurement of capital and thus situate the relevance of the present thesis.

Asian Economic Growth

The Asian continent has become the most dynamic region in terms of economic growth in recent decades. Economic growth in Asia in the context of the so-called East Asian miracle in the 1970s and 1980s has been widely discussed in the literature. And the more recent emergence of India and China as two of the fastest growing economies in the world has gained increased attention. In East Asia, South Korea, Taiwan, Singapore and Hong Kong have registered an annual average growth rate of more than 5.5 per cent during 1960-85 (see Young, 1994, Table 1) which was historically an unprecedented growth rate for such a long period (see Nelson and Pack, 1998). This impressive growth has also helped these countries raise their standard of living more than four-fold during this period, making some observers conclude their performance as 'miraculous' (World Bank, 1993). Initially this rapid growth was thought to be a result of high MFPG, thus explaining their growth in terms of technology catch-up. Later studies, spurred by Young (1994), however, dismissed the miracle hypothesis, by stressing that the growth is mostly the result of high rates of factor accumulation; productivity gains were moderate (Young, 1994, 1995**;** Krugman, 1994; Collins and Bosworth, 1996). The East Asian countries showed very high saving rates, encouraged by government policies that helped them boost capital deepening (Krugman, 1994; Nelson and Pack, 1998). Such investment-driven growth may, however, have led to diminishing returns, posing questions on how sustainable this growth is. Hence Krugman (1994) predicted a slowdown in growth in these countries, as happened in the former Soviet Union. These results were, however,

contested by later studies that supported the productivity hypothesis (Klenow and Rodriguez-Clare, 1997; Hsieh, 2002). For instance Hsieh (2002) argued that Young (1995)'s findings are not correct, once adjustments are made for the overstatement of the capital growth rates in these countries. This debate is of great importance as it has implications for assessing the long-run sustainability of economic growth.

Economists now pay much attention to the recent awakening of Asia's two long-dormant giants, India and China, particularly in the 1990s. The recent swell in the growth performance in these countries raises similar issues as in the East Asian case on the sources of growth. As in the case of East Asian countries, the saving rates particularly in China have become very high leading to rapid capital accumulation, again raising the question of sustainability (see e.g. Herd and Dougherty, 2007). For instance Jorgenson and Vu (2005) show an increase in the contribution of capital in the post 1995 period in both these countries, but no evidence of productivity gain is seen in India and a sharp decline in MFP contribution is observed in China. Herd and Dougherty (2007) also observe a decline in MFP in India and China in the later part of the 1990s, along with an increase in capital deepening. Bosworth and Collins (2008) however show that both capital and MFP contributions are equally important in these countries in during 1993-03 period (see Table 1, Bosworth and Collins, 2008; also see Bosworth et al., 2007). Many studies on India's manufacturing sector have also observed stagnant MFPG in the 1990s (Goldar and Kumari, 2003; Balakrishnan et al., 2006). Similarly, Young (2003) argues that the MFPG in Chinese non-farm economy has not been very high during the reform period and expresses scepticism concerning the potential for future MFPG.

The above discussion shows that the relative roles of capital accumulation and MFPG have been widely debated in the context of Asian economic growth.[11] The estimated relative contributions of MFPG and capital accumulation to growth critically depend on how accurately inputs and output are measured. While in the context of China, for instance, the very estimate of output growth itself is questioned by many studies (Krugman, 1994; Wang and Meng, 2001; Maddison, 2006; Holz, 2006), a common problem applicable to most countries is the accurate measurement of capital input. If, for instance, capital stock is over-estimated, which is often argued to be the case for developing countries (Pritchett, 1997), the contribution of MFPG — which is

[11] Studies have also highlighted the roles of political institutions and policies that helped stimulate investment in East Asian countries (World Bank, 1993; Barro and Sala-i-Martin, 1995; Stiglitz, 1996; Barro, 1997) and in India (Rodrick and Subramanian, 2004; Subramanian, 2007).

obtained as a residual in the growth accounts framework — will be underestimated (see e.g. Hsieh, 2002), and vice versa. Similarly, if the differences in the asset composition of capital stock are not taken into account, the resulting estimates of MFPG will be biased, as will be shown in chapters 2 and 3.

ICT-led Growth in the EU and the US

While the discussion in the context of the East Asian Miracle and India and China revolved largely around the sustainability of the growth dynamics, the growth debate in the United States (US) and the European Union (EU) has been around the importance of ICT-capital deepening. Many studies examined the question why most European countries have lagged behind the US in terms of GDP and labour productivity growth since the mid-1990s, and have highlighted the importance of ICT use (see e.g. Jorgenson et al., 2005; Timmer and van Ark, 2005; van Ark et al., 2008; Inklaar et al., 2008). The observed divergence in labour productivity growth between the US and the EU has been notably attributed to larger ICT investment in the US (van Ark et al., 2008). However, differences in MFPG still seem to be the major driver of cross-country difference in labour productivity growth between EU countries (Inklaar et al., 2008).

One major issue that emerges from these discussions is again related to the measurement of capital, particularly that of ICT capital. The rapid advances in technology in ICT-related equipment, such as memory chips and semi-conductors have brought new hardware and telecommunication products to the market that are characterised by higher quality, and showing better performance than their predecessors. This may result in rapid replacement of older machines as they become quickly technologically obsolete. The rapid technical progress in semi-conductors has also led to huge declines in ICT prices providing investors an incentive to substitute other forms of capital with ICT (Jorgenson, 2001). To measure capital input for growth accounting purpose, it is essential to know the rate at which the efficiency of a new capital equipment improves and also the rate at which the old vintage machines are replaced by the new generation ones. One way to account for the improvement in the efficiency of capital input is to use appropriate price deflators such as hedonic price indexes, which take into account quality changes (Griliches, 1961, 1994; Gordon, 2000; Triplett, 2004). However, such price indices are still not available for many countries, especially not for low-income countries. The issue of replacement poses the question of what is the life time of capital assets and what determines their replacement rate. This is further explained in chapters 4 and 5.

Proximate versus Ultimate Sources of Growth

In the previous section, we explored the quantification of the contribution of factor accumulation and MFPG to economic growth. However, factor accumulation and technological change, whether embodied or disembodied in capital, cannot explain the deeper causes of economic growth and cross-country differences. They are only *proximate* causes of economic growth (Maddison, 1987, 1991; Rodrik, 2003), as the conditions underlying accumulation and assimilation may vary from country to country and from time to time. Consequently, there have been attempts to understand some *ultimate* causes of economic growth (North, 1990; Maddison, 1991; Hall and Jones, 1999; Acemoglu et al., 2001; Sachs 2001; Rodrik et al., 2004). According to Maddison (1991), the *ultimate* causes of income differences include institutions, ideologies, interest groups, historical incidents and economic policies, among others.[12] Rodrik (2003) summarizes three major strands of literature that go deeper into the question of the *ultimate* sources of growth, namely, the geography approach, the integration approach and the institution approach. The geography approach highlights the importance of climate, natural resources, disease burden, transport costs and diffusion of technology (see Diamond 1997; Gallup et al., 1998, and Sachs 2001, 2005). The integration approach emphasizes the role of international trade as an engine of economic growth, through market integration (Sachs and Warner 1995; Frankel and Romer, 1999). The institution approach attributes a pivotal role to institutions, in particular property rights, legal systems, trust among citizens, type of governments, and the rule of law (North, 1990; Hall and Jones, 1999; Acemoglu et al., 2001, Easterly and Levine, 2001).

There have been two prominent empirical approaches developed in the literature to understand the ultimate causes of economic growth. The first is a direct approach, linking ultimate causes to economic growth directly using cross-country regressions. The second is a two-step approach, where one first examines the proximate causes by means of the growth accounting approach and then explains the observed results in terms of the ultimate causes. While the former approach is used in a cross-country context, the latter is mostly used to identify the sources of growth in country-specific studies. In what follows we discuss the empirical literature that tried to look into the ultimate causes separately and also along with proximate causes.

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[12] Also see Szirmai, van Ark and Pilat (1993), for a detailed discussion on Maddison's views on proximate and ultimate sources of growth.

The empirical literature on cross-country regressions has predominantly come to the conclusion that institutional factors are the main drivers of economic growth (Acemoglu et al., 2001; Easterly and Levine, 2003; Acemoglu et al., 2003; Rodrik et al., 2004). Countries with better institutions in terms of secure property rights and stable policies tend to perform better (Hall and Jones, 1999; Rodrik, 1999). Even the role of geography is often viewed to play only through its effect on institutions (Acemoglu et al., 2001; Easterly and Levine, 2003).[13] The effect of international trade is also seen to have a significant relation with institutions. Better institutions promote trade and also larger trade helps to improve the quality of institutions (Rodrik et al., 1999; Wei, 2000). Similarly the role of economic policy in influencing economic growth (see e.g. Sala-i-Martin, 2000) is found to be minimal once controlled for the role of institutions (Easterly, 2005; Rodrik, 2005).

However, the cross-country regression approach has been heavily criticized in the literature. It may be noted that the cross-country regressions assume a single model for all countries, thus ignoring country specificities.[14] More importantly it does not help us understand the channels by which these ultimate factors affect economic growth. In this regard, a number of studies have highlighted the possible relationship between proximate and ultimate sources of economic growth-the former can be seen as the facilitator of the latter (Maddison, 1987, 1991; Hofman, 2001; Rodrik, 2003). Rodrik (2003) depicts the mechanism by which the ultimate causes influence the proximate factors and thereby economic growth (Figure 1.3, Rodrik, 2003). For instance, better institutions may help countries stimulate investment in physical and human capital, and also use these factors efficiently in production, helping them to attain faster growth (North, 1981; Pilat, 1993; Durlauf et al., 2008). Such effects may not be captured if economic growth is directly related to institutions. For instance, democracies are often argued to perform better than authoritarian regimes as politicians in democracies are accountable through elections thus providing an incentive system that increases the quality of bureaucracy (Sen, 2000). However, empirical evidence shows no direct relationship between democracy and

[13] Sachs (2003), however, disagreed by showing that the malaria risk, a variable associated with geography, shows a direct effect on growth.

[14] See Temple (2000) for a discussion on econometric problems of cross-country growth regressions, focusing on three major issues: parameter heterogeneity, outliers and model uncertainty. Also see Rodrik (2005) who discusses the misuse of cross-country growth regressions and Durlauf et al (2008) who show the inability of cross-country growth regressions in judging alternative growth theories.

economic growth (Temple, 1997; Rodrik, 1997). Rather, democracy is found to have significant role in stimulating investment in human capital and in creating political stability (Barro, 1996; Hristos and Mehmet Ali, 2008). Similarly Durlauf et al (2008) suggests that the direct effect of institutions on growth is fragile, while they have a clear impact on physical capital accumulation.

Therefore, cross-country regression can be more insightful in explaining the differences in proximate factors that drive economic growth, rather than economic growth per se (Temple, 1999; Easterly and Levine, 2001; Solow, 2001). This is the main motivation for the two-step approach. In the first stage, one identifies the proximate factors that need further explanation. In the second stage one focuses on the interpretation or explanation of differences in the proximate causes in terms of some ultimate causes (see Hall and Jones, 1999). Many studies have tried to examine the ultimate causes using the two-stage approach. These studies have highlighted a number of factors that cause the divergence in productivity across countries including social infrastructure (Hall and Jones, 1999), labour relocation (Temple and Wößmann, 2004), production externalities (Durlauf et al., 2008) and economic policies (Bergoeing et al., 2002). Similarly, several studies in the context of OECD countries have tried to relate MFP differentials to differences in product market regulations, privatization and regulatory policies and competition (Gust and Marquez, 2002; Nicoletti and Scarpetta, 2003; Inklaar et al., 2008). The need for explaining proximate causes in terms of ultimate causes reinforces the importance of growth accounting and thereby the measurement of capital input, which is the central issue dealt with in this thesis.

1.2 Aim and Outline of the Thesis

The above discussions make clear that accurate measurement of aggregate capital is essential for quantifying proximate sources of economic growth and cross-country growth differences. This thesis focuses mainly on the measurement of aggregate capital input for growth accounting purposes. The results of growth accounting are very sensitive to the way capital is measured. Therefore, the reliability of results largely depends upon the quality of measured capital input (see Aghion and Howitt, 1992, 2007). Capital input has been measured in alternative ways in the literature. These differences in the measurement have led to important differences in results as well, suggesting how imperative it is to measure capital properly.

A country's capital stock is characterized by the co-existence of various assets and vintages at the same time. These assets and vintages vary in terms of their marginal

productivities. In order to implement growth accounting, it is essential to aggregate these various assets of different vintages and efficiency accurately. For example, suppose a firm has two heterogeneous asset types, say computers and trucks, and two different vintages of each, 1990 and 2000. It is not appropriate to sum the stocks of trucks and computers. It is also not appropriate to sum the stocks of each individual asset for the vintages 1990 and 2000. The marginal productivity of computer differs from that of truck and the marginal productivity of a computer of vintage 1990 differs from that of vintage 2000. Further, as these assets are not immediately and fully directly consumed in the production process, we need to measure the services delivered by these various assets and vintages that constitute the actual inputs in the production process. Therefore, the correct measure of capital input in productivity analysis for the firm should be the sum of the services delivered by the computer of vintage 1990, the service delivered by the computer of vintage 2000, the service delivered by the truck of vintage 1990 and the service delivered by the truck of vintage 2000. This aggregation, however, is not straightforward, as the service delivered by different capital assets is not directly observable. We therefore have to rely on economic theory to derive appropriate measures of capital. The present thesis sticks to the neo-classical view that different assets and vintages can be aggregated under some assumptions regarding their age-efficiency and age-price distributions. We examine various ways of aggregating capital input that could be used in improving our understanding of the proximate sources of growth.[15]

The remainder of this thesis is presented in six chapters. The next two chapters focus on the sensitivity of capital and productivity measures to alternative ways of capital aggregation. Chapter 2 takes a look at the capital measures presently used in the Penn World Tables (PWT), which is the most widely used measure of capital stock in the empirical literature, and provides an improved series of estimates. Currently the PWT provides estimates of capital stock that implicitly assume that the contributions of different types of assets to production are the same. The new measure takes into account the differences in the marginal productivities of different assets while measuring an

[15] The issue of aggregation of capital assets is widely debated in the literature (see for instance the famous Cambridge Capital Controversy). The Cambridge UK approach dismissed the very existence of a neoclassical aggregate capital input and production function, arguing that it is not adequate to add up heterogeneous capital assets. Hicks (1974) presents an overview of some aspects of the capital controversy, both among earlier and contemporary economists. See Cohen and Harcourt (2003) for a post-mortem on the Cambridge controversy. Also see Burmeister (2000) and Harcourt and Laing (1971).

aggregate capital input. Based on this new measure, the chapter examines proximate causes of economic growth for a set of about 150 countries over the period 1971-2003, subdivided into 1971-80, 1981-90 and 1991-03. We find that the standard capital stock measures produce a bias in the measured contribution of MFPG and capital accumulation to output growth. Our results indicate that many of the differences in world income growth during the period are explained by differences in MFP. This is true in the 1990s as well, which is striking given the growing globalization and the associated removal of trade barriers that are supposed to stimulate trade and foreign direct investment (FDI) across the world. The increase in trade and FDI are assumed to increase technology spillovers. However, these major changes in the global economy have not translated into a more equal welfare distribution between countries.

The third chapter examines another important aspect of capital input measurement, which is the measurement of capital service prices. The chapter examines the sensitivity of growth accounting results to alternative approaches to measured capital service prices. This includes an assessment of the role of capital gain, internal versus external rate of return and the impact of corporate taxes on the measurement of capital service prices. We observe that the incorporation of corporate tax has only little impact on measured MFPG in OECD countries. In contrast, the choice between internal versus external rates of return in the measurement of rental prices matters much more, especially in service industries.

The second part of the thesis examines the determinants of capital taking into account the possible endogeneity of investment decisions. The retirement of capital assets may not be a mere technical necessity; rather it could be an endogenous decision by firms due to rapid improvements in technology in capital producing sectors. The growing importance of ICT capital, which has led to an increase in technological obsolescence, also signifies the importance of the endogeneity of capital retirement. The premise here is that advances in (production) technology can make existing capital technologically obsolete. As a consequence, firms will choose to scrap their capital much before the end of physical lifetime. This would suggest the importance of a better understanding of asset lifetimes and their determinants (Blades, 1993; van Ark and Timmer, 2000). Chapter 4 provides a new approach to measure the lifetime of capital asset using actual data on scrapping of capital assets in Dutch manufacturing firms. The lifetime of capital is often assumed to be constant across countries when measuring capital input in international comparisons of economic growth. However, it is likely that there are temporal and cross-country variations in the lifetimes of capital. A comparison

of the new results for the Netherlands with available evidence for other countries shows differences in asset lifetimes across countries. Furthermore, the lifetime is seen to vary notably across industries.

Chapter 5 aims to explain the determinants of capital retirement, which is one of the most important aspects of the lifetime of capital assets. Extending on our empirical work for the Netherlands in chapter 4, this chapter assumes that the retirement of capital is an endogenous decision taken by firms based on a number of factors. We focus, in particular, on the role of technology, in stimulating the discarding of assets. Our results indicate a significant effect of innovation on discard behaviour.

Taking a broader perspective on economic growth in chapter 6, we examine some ultimate causes of cross-country differences in economic growth. In contrast to the standard cross-country regressions, in which economic growth is directly related to selected ultimate causes, we aim to explain why some countries are faster in adopting technologies than others. In doing this we consider an unconventional variable, i.e. cultural differences, in explaining cross-country differences in ICT adoption. We find significant cultural effects on technology adoption, in particular cultural traits such as power-distance, uncertainty-avoidance and individualism act as impediments to technology adoption.

Chapter 7 provides an overview of the major findings of the thesis, and concludes the thesis.