The London School of Economics and Political Science

Multi-Sector Growth: The Role of Information and Communication Technologies and Other Intermediates in Recent Growth Experiences

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Declaration

I hereby declare that the work presented in this thesis is my own.

Chapter 4 was undertaken as joint work with Katrin Tinn.

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Abstract

This thesis investigates the role of Information and Communication Technologies (ICT) and other intermediate goods in multi-sector growth models that aim to account for recent growth experiences of the United Kingdom and the United States.

Chapter 2 examines how ICT drive growth in an economy with three sectors: ICT-producing, ICT-using and non-ICT-using. The benefits from ICT come from the falling prices of the ICT-using sector good, which is used for the production of intermediates. Their falling prices provide incentives for investment in sectors that use them as intermediate inputs, so the non-ICT-using sector experiences sustained growth driven by capital accumulation. Sectorial rates of growth differ, but the aggregate economy is on a constant growth path with constant labour shares across sectors. The model's predictions are consistent with evidence for the United States.

Chapter 3 is an empirical study of the patterns of intermediates use in the United States and the United Kingdom. It shows that in both countries, since 1970s there is substitution of the goods-intermediates with the services ones in the gross output of the average industry. The increasing relative prices of the services-intermediates and the complementarity between intermediates types in the production is an important driver of this trend. The estimated elasticity of substitution is used to get measures of the latent technological and/ or policy factors that affect industries' choice of intermediates.

Chapter 4 analyzes the impact of equity market information imperfections on R&D driven growth. The features of its production make R&D largely dependent on equity, which can be persistently mispriced, when the rational investors' beliefs are affected by both private and public information. Optimism in equity market raises R&D investment, resulting in technology improvement and thereby higher output, wages and consumption. Despite the capital losses, the mechanism can generate permanent gains in consumption.

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Chapter 2 of this thesis is based on my job market Chapter and benefited from discussions with participants in the European Economic Association Meeting in Budapest, ZEW Summer Workshop, CERGE-EI and Queen Mary University. An earlier version is a CEP Discussion Chapter No. 750. Anonymous referees provided with important comments and suggestions on this earlier version. Chapter 4 is a joint work with the fellow research student Katrin Tinn. The constant interaction with her gave me motivation and essential feedback at various stages of all Chapters of this thesis.

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Special thanks to special people.

To my Mother.

Chapter 1

Introduction

The recent growth episodes of the Unites States and Europe have motivated both theoretical and empirical research to shift the focus of productivity analysis to a level that can explicitly account for the multi-sector production structure. Analysis at the disaggregate level is important, because not only it pins down the industries that drive growth, but also sheds light on the way different industries are linked through their production. The interaction among industries reveals mechanisms through which growth is transmitted to the entire economy. This thesis employs multi-sector models of growth, in order to address two important features of the recent growth experiences: Information and Communication Technologies (ICT) and intermediate inputs. It investigates economic incentives generated with respect to their production and use. The purpose is to understand how these incentives can affect aggregate economic performance in the long-run, and how this impact depends on the structure of the production side and conditions in the R&D and equity markets.

The production and use of ICT received a lot of attention in relation to the "Productivity Paradox". It soon became evident that the Paradox was driven by the inability of the data to account for special features of ICT: dramatic fall in the prices of ICT output, strong depreciation of the ICT-capital and the role of ICT as an intermediate input[1]. The latter implies that in order to get correct productivity measures, the ICT intermediate inputs need also to be deflated with the use of a hedonic price index. The statistical services in the United States had a leading role in developing data at the three-digit industry level that are appropriate for gross output growth accounting[2].

The result of this effort is the resolution of the Paradox in the early 2000s with empirical studies that made use of the newly released industry-level information (Jorgenson, Ho, and Stiroh 2005b, Oliner and Sichel 2002, Stiroh 2002, OECD 2003, Albers and Vijselaar 2002, van Ark and O'Mahony 2003, van Ark, Melka, Mulder, Inklaar, and Ypma 2002). The findings of these studies regarding the role of ICT for growth may be summarized as follows. First, the ICT-producing sector experienced remarkable performance in terms of its output, labour productivity and total factor productivity (TFP) growth. Despite its small size, it is identified as the driver of productivity growth for the United States economy. Second, strong ICT-capital accumulation drives growth of the industries that use ICT intensively. These industries grow on average faster compared to the rest of the economy. Third, the difference between the United States and Europe with respect to the ICT-production and use is an important factor in their productivity gap[3].

These studies also highlight the important role of intermediate inputs, ICT and

[1]Important part of the ICT-production is traded as intermediates. A primary example is semiconductors.

[2]For a thorough discussion of these data issues and how the different statistical services dealt with them in the United States, see Jorgenson, Ho, and Stiroh (2005b). Schreyer (2002) discusses differences across OECD countries in terms of computer prices data.

[3]ICT is studied also as a General Purpose Technology (Bresnahan and Trajtenberg 1996, Helpman and Trajtenberg 1998b, Helpman and Trajtenberg 1998a, David and Wright 2003, Jovanovic and Rousseau 2006), i.e. as important large-scale innovations, such as electricity, with special features with respect to their production and use. The main hypothesis is that the use of a GPT involves important externalities that increase TFP growth for the industries that use ICT intensively. This increase may happen with a lag, because investment in ICT involves important reorganisation and complementary investments. Basu, Fernald, Oulton, and Srinivasan (2003) give an overview of empirical support for this hypothesis.

non-ICT, for the output performance of the different industries in the economy. Given that intermediates are the dominant inputs for most industries, they contribute most of the gross output growth of the average industry. It is important to correctly trace the flow of intermediates across industries and over time, in order to account for every industry's output growth. The findings of the industry-level productivity analysis highlight that there is important variation across industries in terms of their intensity in producing intermediates and their growth rates of gross output, value added and intermediate inputs[4]. The results show that value-added based measures of production growth can be highly misleading if no care is taken to account for both the gross output and the intermediate goods' volume growth, i.e. a double-deflation method is used (Jorgenson, Ho, and Stiroh 2005b, Oulton 2004). They also support the aggregation of value-added growth at the industry-level, in order to account for a change in the composition of final output without imposing perfect substitution in the value added produced from different industries.

To conclude, arguably, the main finding of the industry-level productivity studies is that the ICT-producing sector drives aggregate growth. This finding is consistent with the results of the R&D-based endogenous growth theoretical literature, given that the ICT-producing sector is highly intensive in R&D and patenting activity (Carlin and Mayer 2003, Jovanovic and Rousseau 2006). Such models account for positive externalities present in the R&D-production, such as knowledge spillover (e.g. Romer 1990) and/ or negative ones like congestion (e.g. Comin and Gertler 2006). Therefore, with respect to the R&D conducted by the ICT-producing sector, the policy implications of the existent endogenous growth models would emphasize on well established property rights over the R&D output (e.g. patents) and a system of subsidies/ taxes and other incentives that achieve

[4]The latter fact is used by Oulton (2001) to explain why Baumol's unbalanced growth hypothesis can fail.

the optimal level of R&D expenditures.

In all such models, R&D expenditures are financed in perfect equity markets. The reliance of R&D intensive firms on equity finance is due to the high uncertainty, intangible capital and growth prospects of their production[5]. This is also supported by the findings of Bradley, Jarrell, and Kim (1984), Carlin and Mayer (2003) and Aghion, Bond, Klemm, and Marinescu (2004). However, the empirical support for the perfect equity market hypothesis is limited. There is important evidence that equity can diverge persistently from the underlying fundamentals (e.g Cutler, Poterba, and Summers 1991, Chan, Jegadeesh, and Lakonishok 1996, De Bondt and Thaler 1985, La Porta 1996), while market sentiment stands as an important driver of equity mispricing (e.g. Lee, Shleifer, and Thaler 1991, Swaminathan 1991). Equity mispricing driven by market sentiment can be attributed to some degree of irrationality of the equity market participants (e.g. Barberis, Shleifer, and Vishny 1998), or can be the outcome of a rational expectations equilibrium, to the extent that a public signal that captures market sentiment provides imperfect information about the underlying fundamentals (as in Allen, Morris, and Shin 2006).

Hence, market sentiment resulting in equity mispricing of R&D firms can affect aggregate economic performance and therefore equity market imperfections may provide new policy instruments for fostering growth. The analysis of such measures became important in view of the equity market rise of the late 1990s in the United States. The ICT-producing sector was a leading sector in this episode (referred also as "dot-com" boom)[6]. At the same time, there is a wide support that the productivity of this sector accelerated during the same period, driving

[5] Carlin and Mayer (2003) offer an overview of the main arguments provided by the theoretical literature in support of the equity dependence of R&D hypothesis.

[6] Jovanovic and Rousseau (2006) offer an overview of the United States equity market performance in relation to ICT.

an acceleration in the Unites States productivity growth (e.g Jorgenson, Ho, and Stiroh 2005b, Bosworth and Triplett 2004). Recent study by Jorgenson, Ho, and Stiroh (2007) shows that despite the recession that took place in parallel with the equity market downturn in 2000, the United States growth is projected to be only moderately below its late-1990s rate.

In order to account for growth of the United States economy in the ICT era, Chapter 2 develops a multi-sector endogenous growth model. The theoretical framework is built on three main sectors: ICT-producing, ICT-using and non-ICT-using. The knowledge externalities present in the production of the ICT-producing sector (in the spirit of Romer 1990) drive long-run growth. The ICT-using sector uses ICT-capital that embodies the advances in ICT, while the non-ICT-using sector uses non-ICT-capital, which embodies a stagnant technology. The analysis highlights the role of the ICT-using sector, as a transmitter of growth from the ICT-producing sector to the rest of the economy through its production of intermediates. The high productivity of the ICT-using sector results in falling intermediate goods prices. As a result, the non-ICT-using sector benefits from ICT in terms of the expanding investment opportunities. At the same time, the production of intermediates by the low productivity non-ICT-using sector implies that the prices of intermediates and capital do not fall as fast as prices of the ICT-using good. Consequently, growth of the ICT-using sector is lower than growth in the ICT-producing sector.

In the long-run equilibrium, there is constant but different output growth across sectors. The ICT-producing sector experiences the fastest growth, followed by the ICT-using and then the rest of the economy. Under a condition on preference, aggregate economy evolves along a constant growth path that is consistent with the Kaldor stylized facts. Along this path, there is no reallocation of labour resources across the three sectors. Chapter 2 also presents evidence from the United States economy in support of the model's theoretical predictions. A calibration exercise shows that the model's predicted steady-state labour allocation is consistent with the data. The transition dynamics are derived for the economy, where prices fully internalize the knowledge externalities, output markets are perfectly competitive and all intermediates are produced by the ICT-using sector. They are calibrated to match the acceleration of the ICT-producing sector productivity in 1995, in order to provide intuition on the effect of market distortions.

Chapter 3 is an empirical investigation of the patterns of intermediate inputs' use in the United States and the United Kingdom economy. Empirical studies with a focus on the role of intermediates extensively analyze the patterns revealed in the use of ICT and non-ICT intermediates (Jorgenson, Ho, and Stiroh 2005b). Chapter 3 diverges from these studies and considers the patterns regarding the use of goods-intermediates (i.e. energy and materials) and services-intermediates. It shows that there is a substitution of the goods-intermediates with the services ones in the aggregate gross output of both economies. This pattern is driven not only by the change in the relative size of the goods and services sectors in terms of final output[7], but also because the average goods or services producing industry decreases its expenditure on goods-intermediates. In order to account for the intermediate inputs choice of different industries, Chapter 3 employs a partial equilibrium model under the competitive input markets assumption. An industry chooses the composition of its intermediate inputs given their relative prices, the degree of substitutability of the two types of intermediates in the production and technology or policy factors that affect its productivity in using each type of intermediates. The econometric analysis delivers broadly similar results for the

[7]See Kuznets (1957) for a first account on the sector-level structural change.

two economies. First, there is a low degree of substitutability between the goods and services-intermediates. This explains in a coherent way the observation of decreasing expenditure share of goods-intermediates in the face of their decreasing relative prices. Second, technology or policy related factors are important drivers of the industries' choices over intermediates.

As part of the discussion of results, Chapter 3 uses the estimated elasticity along with the data to derive measures of the latent technology or policy related factors. It uncovers important differences across the two economies and over time in terms of their efficiency in using the different types of intermediates and identifies the industries that drive these patterns. Moreover, using data at a higher level of aggregation and a value-added based measure of productivity, it finds a negligible impact of the substitution between the two types of intermediates on the aggregate economy. It also shows that the ICT-producing sector's choice of intermediates departs significantly from the average industry.

Chapter 4 presents a theoretical framework motivated by the output growth and equity market performance of the United States economy during the 1990s. The analytical framework focuses on the importance of equity market information imperfections for the production of R&D and thereby long-run economic performance. The mechanism through which equity market performance feedbacks on growth, relies on two features. First, R&D firms are equity-dependent, with respect to their investment funding. Second, equity can be subject to persistent rational mispricing, when both imperfect public and private information are available. As a result, in the presence of optimism in the market there are two opposing effects on aggregate consumption. On the one hand, the rise of equity prices above the fundamentals generates additional funds for R&D investment that results in technology improvement. This expands output and raises wages, having a lasting positive effect on aggregate consumption. On the other hand, the equity market losses realized in the equity market reduce consumption. The positive effect is more likely to dominate the stronger are the knowledge externalities and the lower is the congestion in the R&D-production.

Equity mispricing due to optimism results in welfare gains compared to the case with perfect information in the equity market. This is because even the perfect equity market fails to deliver equity prices that fully internalize the externalities caused by the R&D expenditures of particular firm. The impact of a noise trading shock is qualitatively similar to that of a public signal, but its persistence is very small. Following a true productivity shock, the economy with perfect information in the equity market has higher welfare gains compared to the one with imperfect information, because equity prices fully account for the future productivity gains. Chapter 4 concludes with a discussion on the scope for policy that fosters productivity within the context of an imperfectly informed equity market.

This thesis is organized as follows. Chapter 2 introduces a multi-sector model, where growth is driven endogenously by ICT and the interaction of the ICT-using and non-ICT-using sector through intermediates production delivers the aggregate economy path. Chapter 3 is an empirical investigation of the patterns in the use of goods-intermediates and services-intermediates in the United States and the United Kingdom, accounting for the degree of substitution between the two types of intermediates. Chapter 4 presents an R&D-based endogenous growth model, where R&D investment is based on equity that is subject to mispricing due to information imperfections. Chapter 5 summarizes the conclusions of the different Chapters of the thesis, discusses their policy implications and considers directions for future research suggested by the theoretical and empirical analysis of the thesis.

Chapter 2

Information and Communication Technologies in a Multi-Sector Endogenous Growth Model

2.1 Introduction

Current research on economic growth puts emphasis on examining the sources of growth at the industry level. The advantage of this approach is that it allows the identification of both the growth-generating industries and the mechanism through which their growth is spread to the rest of the economy. This Chapter is in this spirit. It studies a multi-sector economy. The first sector produces Information and Communication Technologies (ICT). The second sector uses ICT to produce intermediate goods for itself, and for the third sector, which does not use ICT. It shows that innovations in the ICT-producing sector lead to a growth equilibrium characterized by falling intermediate good prices. This provides incentives for capital deepening in the entire economy. The falling intermediate good price mechanism is still present, yet weaker, when the non-ICT-using sector contributes also to the production of intermediates. The model derives the conditions for the existence of a constant growth steady-state path for the aggregate economy. On this path there is no labour reallocation across sectors, but sectorial output growth rates differ, with the ICT-producing sector exhibiting the fastest growth, followed by the ICT-using one and then the rest of the economy.

The motivation for this Chapter comes from the empirical literature that studies the United States economy over the past thirty years (Jorgenson, Ho, and Stiroh 2005b, Oliner and Sichel 2002, Stiroh 2002). These studies use data at the three-digit ISIC level and perform a detailed growth accounting exercise that identifies the ICT-producing sector as the source of growth, in spite of its small value added and employment share. Complementary growth accounting exercises (Albers and Vijselaar 2002, van Ark and O'Mahony 2003, van Ark, Melka, Mulder, Inklaar, and Ypma 2002) investigate the sources of United States and European Union growth by looking at three sectors with the same broad structure as in this Chapter. These studies confirm the high productivity growth in the ICT-producing sector and find important gains in productivity that stem from it for all sectors. The benefits are mainly for the ICT-using industries.

Table 2.1 presents the real value added growth for the total economy and the ICT-producing, ICT-using and non-ICT-using sectors and its sources (capital, labor and TFP growth)[1,2]. The data show that the ICT-producing sector experiences the highest value added growth across the three sectors, which is driven

[1]The classification of industries into the three sectors follows that of Jorgenson, Ho, and Stiroh (2005b). The "ICT-producing" industries produce computer hardware, electronic components, telecommunication equipment and computer services (includes software production). Industries are classified as "ICT-using" or "non-ICT-using" according to their ICT-capital intensity in 1995. See Appendix A.7.4 for details regarding the industries in each major sector.

[2]Calculations are by the author. Any differences to Tables 8.1 and 8.2 of Jorgenson, Ho, and Stiroh (2005b) are due to rounding and limitations in the available data. Details on the data and the aggregation method used are in Appendix A.7.

mostly by TFP growth. This sector contributes all of the economy's TFP. The value added growth for both the ICT-using and the non-ICT-using sector is driven by capital accumulation, while the ICT-using grows faster than the non-ICT-using. In their empirical investigation, Jorgenson, Ho, and Stiroh (2005b) conclude that the most important source of United States growth has been the accumulation of ICT and non-ICT-capital, especially during the 1990s.

Table 2.1: United States aggregate and sector-level value added sources of growth

		Sources:		
	Value added growth	Capital	Labor	TFP
Total Economy	3.18	1.74	1.17	0.28
ICT-producing	20.42	4.06	3.40	12.97
ICT-using	4.04	2.33	1.68	0.03
non-ICT-using	2.38	1.46	0.92	0.00

Notes: 1977-2000 average growth rate (%)
Source: Jorgenson et. al. (2005)

The incentives for ICT-capital accumulation come from the dramatic price declines of ICT goods[3]. This fall has generated incentives to invest in these goods, by driving down the production cost for ICT-using industries. The resulting falling prices of the goods produced by the ICT-using industries give rise to investment opportunities for the industries that use the ICT-using sector's goods. Through this mechanism, the gains from the fall in costs are transmitted to the entire economy. In order to develop intuition for the impact of price declines of ICT goods on aggregate productivity, one may consider the following example: An ICT-producing industry develops a new microprocessor. This chip is embodied in computers, which are used in the production of general-purpose machinery that is of higher quality and can be made available at a lower price. The air-conditioners

[3]For an overview of the dramatic fall in the prices of the ICT goods, see Chapter 1 of Jorgenson, Ho, and Stiroh (2005b). The United States Bureau of Economic Analysis (BEA) was a pioneer statistical service in using hedonic techniques for the construction of the prices of these goods.

that are part of this production is used by financial institutions, as well as by hairdressers. Therefore, despite the fact that the hairdressers do not use directly ICT, they benefit from its advances because it lowers their costs.

The theoretical framework presented in this Chapter can account for the findings of the growth accounting exercises, as summarized in Table 2.1. In the model, the ICT-producing sector is the technology producing sector; by construction, it is the engine of growth[4]. The sector that directly benefits from the advances in ICT-production is the one using ICT-capital; the ICT-using sector. As long as this sector produces goods that are used throughout the economy, by both the ICT-using and the non-ICT-using sectors, the ICT-production growth is transmitted to the entire economy. This is because the falling costs for the ICT-using sector allow for falling prices of its output and therefore falling capital prices. Thus, growth is driven by the accumulation of both ICT and non-ICT-capital goods.

In equilibrium, there is unbalanced growth across sectors. The sector that exhibits the fastest growth is the ICT-producing. Its source of growth is TFP growth, where the latter is defined as the part of production growth that is not due to capital or labour accumulation. The ICT-using sector grows faster compared to the non-ICT-using sector. Its source of growth is the accumulation of ICT-capital, which embodies the advances in the ICT-production. The slowest growing sector in the economy is the non-ICT-using sector. Its source of growth is the accumulation of non-ICT-capital, which has lower productivity growth than the ICT-capital, since it does not embody any technological advances. Under some restrictions on preferences the aggregate economy is on a constant growth path with constant employment shares. On this path, while aggregate growth is driven endogenously

[4]In further support of this assumption, USPTO data show that the 1985-2004 average growth in the number of patents for the ICT-producing sector was significantly higher compared to the rest of the economy (13% as opposed to 8%).

by the progress in the ICT-production, the economy's output growth rate is bound to be lower than that of the ICT-producing sector. This is due to the fact that to the extent that the non-ICT-using output is also used for the production of capital goods, the growth potential of the aggregate economy is reduced.

The theoretical framework developed in this Chapter is closely related to the endogenous growth literature that focuses on R&D (Romer 1990, Grossman and Helpman 1991b, Jones 1995). Its contribution to this literature is that it highlights how inter-industry transactions serve as a mechanism through which growth is transmitted across sectors of potentially different output potential. For this purpose, the assumption regarding the production of ICT is only at the backstage and is used in order to generalize the results of the model. The merit of the adopted framework is that while being simple enough to handle analytically, it still allows for an incentive-based technology production and market distortions that drive the allocation of resources away from the first-best.

This Chapter introduces into a Romer (1990)-type model the non-ICT-using sector that uses only capital goods that come from an old technology. The old technology is assumed to have achieved its innovation potential. This assumption drives the equilibrium result that the non-ICT-using sector has a lower output growth. The assumption that a new type of capital (ICT-capital) embodies higher productivity compared to the old one (non-ICT-capital) is in-line with the vintage capital literature (e.g. Aghion and Howitt 1992)[5]. The "Schumpeterian effect" that is central in this literature, is absent here. The maintained assumption is meant to account for the fact that for a long period after the introduction of new large scale technologies, some productive industries do not make use of them, nor they can readily readjust all their existent capital stock.

[5] The assumption that capital embodies technical progress goes back to the original contribution by Solow (1960).

Methodologically, the model of this Chapter is also related to the literature on multi-sector growth analysis. This literature has been mainly motivated by the Kuznets (1957) facts regarding the imbalances at the sector level that the Kaldor stylized facts disguise. Most of the literature in this area develops a consumption side based explanation to account for the sectorial growth differences (for a survey see Matsuyama 2005). Even though the model's equilibrium conditions put restrictions on preferences, the source of growth differentials across sectors is driven entirely from the production side characteristics. To that extent, this Chapter rather relates to the multi-sector growth analysis of Ngai and Pissarides (2007) and Acemoglu and Guerrieri (2006). In the former, sectorial growth differences are driven by differences in exogenous TFP growth. In the latter, the differences are driven by the interplay of differences in the capital share and capital deepening, while their analysis extends to allow for endogenous growth. While this Chapter also highlights the importance of capital accumulation, its emphasis is put on the intensity of use of particular types of capital. Furthermore, this Chapter contrasts with these studies in terms of the restrictions adopted to account for the observed reallocation dynamics across the sectors. This is because the patterns of resources' allocation are not the same when different criteria are used to disaggregate the economy into sectors.

Another strand of literature related to this Chapter is the recent theoretical literature that deals with the impact of ICT upon growth. Following the "paradox" of the low productivity growth of the 1970s and 1980s (Quah 2002), the recovery of productivity growth in the United States economy in the 1990s has been explained in the context of General Purpose Technologies (GPT) (Helpman and Trajtenberg 1998b, Helpman and Trajtenberg 1998a, Jovanovic and Rousseau 2006)[6]. Several

[6]Economic historians were the first to draw the analogy between ICT and great inventions of the past, such as the combustion engine, electricity and railways, that pioneered the first and

empirical studies find supportive evidence for the hypothesis that ICT is a GPT, i.e. that the use of ICT goods involves important externalities for the ICT intensive industries (Jorgenson, Ho, and Stiroh 2005a, Oliner and Sichel 2002, Bosworth and Triplett 2002, Basu, Fernald, Oulton, and Srinivasan 2003). The technology producing sector of the model of this Chapter captures important features of a GPT, but does not aim to explain the cycle involved in the introduction and adoption of a new large scale technology. Instead, it shows how uneven growth at the disaggregate level, caused by the lack of adoption of a new essential technology, can still be consistent with constant growth at the aggregate level.

Making use of United States data at the three-digit ISIC level, this Chapter provides some supportive evidence for the model's results given its assumption on the economy's structure, inter-industry relations and consumers' preferences. The model's main parameters are calibrated from the data. The data provide a measure for the magnitude of the price mechanism described in the model. They also support the model's prediction that the employment, value added and capital goods shares are equal in equilibrium. They show no reallocation of labour across these sectors. The quantitative analysis extends to a back-of-the-envelope calibration exercise to match the steady-state values of important allocation shares. The model's calibration matches closely the relative labor allocation in the two final good sectors. Even though the evidence on virtually constant labour allocations suggest that the steady-state is a reasonable approximation of the United States economy, the transition dynamics of the model are examined in relation to the growth acceleration of the United States economy that took place in 1995. A numerical exercise shows the first best allocations and dynamics in response to

second industrial revolutions (David 1991, David and Wright 2003). The features of a GPT, as given by Bekar, Carlaw, and Lipsey (1998), are: "wide scope for improvement and elaboration; applicability across a wide range of uses; potential for use in a wide variety of products and processes; strong complementarities with existing or potential new technologies".

an exogenous increase in the productivity of the ICT-producing sector and the results are contrasted to the observed patterns in the data.

This Chapter is organized as follows: Section 2.2 presents the model. Section 2.3 analyses the conditions for the existence of a unique steady-state and explores its properties and the implied comparative statics. Section 2.4 presents some supportive evidence by analyzing United States data over the period 1979-2001. Section 2.5 concludes.

2.2 The Model

2.2.1 Production side

The model examines a multi-sector economy. There are two final goods sectors in the economy that produce goods that can either be used for final consumption, or as intermediates. One uses ICT-capital (e.g. general purpose machinery or financial services) and the other does not (e.g. textiles or hairdressers). The third sector is the ICT-producing sector (e.g. computers or software), which performs R&D and discovers new ICT goods. These sectors interact through the production of intermediates and capital varieties. The intermediates produced by the ICT-using and non-ICT-using are combined to produce a composite intermediate good. This composite intermediate good is used for the production of all ICT and non-ICT-capital varieties in the economy. The production of every variety of ICT and non-ICT-capital is based on a "blueprint". Over time, ICT-producing sector delivers new blueprints for the ICT-capital. The set of blueprints of non-ICT-capital remains constant.

ICT Production

ICT-producing sector

The ICT-producing sector employs a fraction, u_N, of aggregate labour stock, L, and produces new ICT knowledge, $\dot{N}$.

$$\dot{N} = \lambda \left(u_N L \right) N \tag{2.1}$$

There are externalities present in the production due to learning-by-doing: as the variety of ICT, N, increases more new production ideas and practices become available. The parameter λ scales the knowledge-externality[7].

The output of the sector are "blueprints" for the production of ICT-capital varieties, priced at p_N in an auction process[8].

Final Goods Production

ICT-using Sector

The ICT-using sector absorbs a fraction, u_1, of labour and employs N varieties of ICT-capital goods, $\{x_1(j)\}_{j \in [0,N]}$, in order to produce output, Y_1. The ICT-capital goods embody the new technology (ICT), that has a scope for sustained improvement. The advances in the ICT-production imply that the available number of varieties expands over time.

$$Y_1 = (u_1 L)^{1-\alpha} \int_0^N x_1^{\alpha}(j) dj \tag{2.2}$$

[7] The choice of the ICT production function is for the merit of gaining intuition regarding the growth implications of the inter-sector dependence, within a standard endogenous growth setting. Allowing for a more general R&D function like in Jones (1995) does not affect the steady-state properties of the model.

[8] Given the specification a blueprint stands for a new ICT product or a major innovation in a particular technology (e.g. PC), rather than a marginal upgrade of an existing one (closely related generations of PCs). This is made mostly in order to highlight the main intersector transactions of interest. It is also one way to capture important features of a GPT. See discussion in the introduction of this Chapter.

This sector is perfectly competitive in the input and output markets and the price of its output is p_1. The final good is used either for consumption, c_1, or the production of intermediates, h_1.

$$Y_1 = c_1 + h_1 \tag{2.3}$$

Non-ICT-using Sector

The non-ICT-using sector employs a fraction, u_0, of labour and combines it with the sector-specific capital varieties, $\{x_0(i)\}_{i\in[0,A]}$, to produce final good, Y_0. It uses non-ICT-capital, which has a fixed number of varieties over time, A. This stands for the assumption that the non-ICT-using sector only makes use of capital goods that embody a technology with no further scope for improvement. As a result, it cannot directly benefit from the presence of the ICT technology[9,10].

$$Y_0 = (u_0 L)^{1-\alpha} \int_0^A x_0^\alpha(i)di \tag{2.4}$$

This sector is also perfectly competitive in the input and output markets and the price of its output is normalized to one. The final good is used either for consumption, c_0, or for the production of intermediates, h_0.

$$Y_0 = c_0 + h_0 \tag{2.5}$$

[9] Allowing for a different capital intensity in this sector would not affect the features of the equilibrium, while complicating the analytical expressions. The simplifying assumption of setting it equal to that of the ICT-using sector is used to highlight the differences across the two sectors that stem from the type of the capital used.

[10] Allowing both final goods sectors to use both ICT and non-ICT-capital at different intensities, would not change the main features of the equilibrium.

Intermediate Goods Production

The intermediates produced by the ICT-using and the non-ICT-using are used as inputs for the production of the composite intermediate good, H.

$$H = h_0^{\beta} h_1^{1-\beta} \tag{2.6}$$

This sector is perfectly competitive in input and output markets and the price of its output is p_H. The composite intermediate good is used for the production of all ICT-capital varieties, K_1 and non-ICT-capital varieties, K_0.

$$H = K_0 + K_1 \tag{2.7}$$

Capital Varieties Production

There is a fixed number, A, of firms that produce capital varieties that are used only by the non-ICT-using sector. There is also an expanding number, N, of firms that produce capital varieties that are exclusively used by the ICT-using sector. The firms operate under monopolistic competition. Infinite-horizon monopolistic rights for every firm come from exploiting a patent over a "blueprint".

A firm that produces the ICT-using capital variety j, has a nominal market value at time t, $V_1(j)(t)$. This would be paid out to the ICT-producing sector for the acquisition of a new variety patent due to free-entry in the ICT-capital varieties market. In order to fund the patent, the firm raises funds from the households and pays out all its future profits as dividends. The real value of the firm is equal to the present discounted value of the firm's stream of real profits in consumption units.

For every unit of production, the firm uses one unit of composite intermediate good. It selects its output price, $\hat{p}_1(j)$, to maximize its per-period profits, $\pi_1(j)$. The price of the composite consumption good, $p_c(t)$, the output of the ICT-using final output, p_1, and the real interest rate, $r(t)$ are taken as given.

$$\frac{V_1(j)(t)}{p_c(t)} = \int_t^{\infty} e^{-\int_t^{\tau} r(s)ds} \frac{\pi_1(j)(\tau)}{p_c(\tau)} d\tau \tag{2.8}$$

$$\pi_1(j) = \max_{\hat{p}_1(j), x_1(j)} \left\{ \hat{p}_1(j)x_1(j) - p_H x_1(j);\ s.t.\ p_1 \frac{\partial Y_1}{\partial x_1(j)} = \hat{p}_1(j) \right\} \tag{2.9}$$

A firm that produces the non-ICT-using capital variety i, has a nominal market value at time t, $V_0(j)(t)$ defined in a similar way. For every unit of production, the firm uses one unit of composite intermediate good, which is available at p_H. It maximizes its profits every period, $\pi_0(i)$, by selecting its output price $\hat{p}_0(j)$, given the demand from the non-ICT-using final good producers.

$$\pi_0(i) = \max_{\hat{p}_0(i), x_0(i)} \left\{ \hat{p}_0(i)x_0(i) - p_H x_0(i);\ s.t.\ \frac{\partial Y_0}{\partial x_0(i)} = \hat{p}_0(i) \right\} \tag{2.10}$$

Aggregate profits of the capital varieties producing firms are paid out as dividends and the demand meets the supply of the two types of capital varieties. Both types of capital depreciate fully within every period[11].

$$\Pi = \int_0^A \pi_0(i)di + \int_0^N \pi_1(j)dj \tag{2.11}$$

$$K_0 = \int_0^A x_0(i)di \tag{2.12}$$

$$K_1 = \int_0^N x_1(j)dj \tag{2.13}$$

[11]This assumption is mostly for analytical convenience. The production function for each final good sector rather resembles gross output production that combines labour with all other factors (capital and/ or intermediates are "bundled" together). See further dicussion in Section 2.4.

Labour Market

The labour market is perfectly competitive. The market clearing condition requires that all resources are allocated across all three sectors that use the fixed supply of labour.

$$L = u_0 L + u_1 L + u_N L \tag{2.14}$$

2.2.2 Consumption side

Households

There is a continuum of identical households of size one. The representative household gains utility from its consumption of ICT-using, c_1, and non-ICT-using, c_0, goods. These two distinct consumption goods are combined through a consumption technology that provides the composite consumption good, $\tilde{C}$. The joint CES and CRRA preferences allows both intertemporal and intratemporal substitution to come into play.

$$u(c_0, c_1) = \frac{\tilde{C}^{1-\sigma} - 1}{1-\sigma} \tag{2.15}$$

$$\tilde{C} \equiv [\theta c_0^{\epsilon} + (1-\theta)c_1^{\epsilon}]^{\frac{1}{\epsilon}} \ ; \theta \in (0,1), \epsilon < 1, \sigma > 0 \tag{2.16}$$

The labour stock is uniformly distributed across all agents in the economy, so that each of them offers L. In every period, the households finance their consumption expenditures, $c_0 + p_1 c_1$, and accumulate assets, S, by the income comes from the wage, w_L, they earn from supplying their labour,their labour income and their returns on their assets holdings. Every period, their asset holdings are paid the interest rate, r, every period and dividends, that reflect the profits of the firms they own, Π. It needs to be noted that the asset holdings (and their rate of return) are in units of the composite consumption good that enters the utility of the representative household (may be thought as "nominal" assets and rate of return). On the other hand, the aggregate profits, consumption expenditures and labour income are in units of the numeraire output and therefore need to be renumerated by the price of the composite consumption good, p_c:

$$\dot{S} = rS + \frac{w_L L + \Pi - c_0 - p_1 c_1}{p_c} \tag{2.17}$$

2.3 Steady-State Analysis

2.3.1 Existence of steady-state

A Constant Growth Path (CGP) is a steady-state equilibrium path along which the ICT-production stock, N, aggregate output, $Y = Y_0 + p_1 Y_1$, aggregate capital, $K = p_H K_0 + p_H K_1$, and aggregate consumption, $C = c_0 + p_1 c_1$, grow at a constant rate. Details of the proof are provided in Appendix A.1[12].

Proposition 1 *The necessary and sufficient condition for the existence of a CGP with N, Y, K and C growing at constant rates is that the preferences exhibit unit intratemporal elasticity of substitution, i.e. $\epsilon = 0$.*

For constant growth rate in the production side of the economy (N, Y, K), the only requirement is that the labour allocation in the ICT-producing sector is constant. Growth of the final goods sectors is driven by labour and capital growth. The volume growth of capital used in the ICT-using and the non-ICT-using sectors is the same. This is because the prices of the ICT and non-ICT-

[12] Appendix A.5 discusses the selected conditions for CGP and how the theoretical model aggregate output can be used to match the one in the data.

capital goods fall at the same rate. However, only the ICT-using sector experiences higher capital productivity growth, driven by the use of the expanding variety of the ICT-capital. At the aggregate output level, differences in the relative capital productivity growth between the two sectors are cancelled out by the relative prices growth. Any reallocation of labour between the two final goods sectors also cancels out given the condition on constant allocation for the ICT-producing sector. Therefore, aggregate output growth is proportional to the ICT-production growth. The same reasoning works for aggregate capital.

The restriction on the preferences is required for constant aggregate consumption growth. In the case of an intratemporal elasticity which is higher than one, the consumers would allocate an increasing share of their expenditures to the ICT-using good over time given its falling relative price. This is because their relative demand is price elastic, and therefore they respond to the price fall of the ICT-using good by a more than proportionate increase in their demand of its final good. Therefore, consumers gain from consuming more of a good that its price is lower than the price of the composite consumption good, this implies that the real interest rate would be decreasing, reducing their incentives to save. On the production-side, the ICT-using sector needs to increase its production accordingly. For this reason, labour would need to flow out of the non-ICT-using sector and into the ICT-using one. In order to sustain constant aggregate consumption growth, the net marginal product of capital in units of the ICT-using good would need to increase over time to revert the incentives for reduced savings. However, because the degree of substitution between capital varieties and labour is lower than the elasticity of the two final consumption goods, the reallocation of labour across the two final good sectors alone, is not sufficient to raise the marginal product of capital sufficiently so as to overcome the "relative-price" effect on the interest rate and consumption growth falls overall over time. The opposite dynamics would take place for an intratemporal elasticity of substitution, which is lower than one.

The unit intratemporal elasticity of substitution is the only case that there exists a CGP for the economy that satisfies static efficiency, i.e. when the marginal rate of substitution equals the marginal rate of transformation, and the resource constraints are met within every period and over time. This is because the substitution patterns in consumption are exactly matched by the substitution patterns of factors. This condition on the preferences implies constant expenditure shares, as well as constant labour allocations for the two final good sectors, due to the static efficiency conditions[13].

2.3.2 Features of the steady-state

Given Proposition 1, the steady-state of the decentralized equilibrium is derived by imposing unit intratemporal elasticity of substitution and constant labour shares on the model. The details are given in Proposition 2. The most interesting static equilibrium results are:

$$
\begin{aligned}
p_1 &= \left(\frac{A}{N}\right)^{1-\alpha} && (2.18)\\
p_H &= Bp_1^{1-\beta} \; ; \; B = B(\beta) && (2.19)\\
\hat{p}_0 &= \hat{p}_1 = \frac{p_H}{\alpha} && (2.20)\\
\frac{u_0}{u_1} &= \frac{(1-\alpha^2)\theta + \alpha^2\beta}{1-(1-\alpha^2)\theta - \alpha^2\beta} && (2.21)\\
p_c &= \Theta p_1^{1-\theta} \; ; \; \Theta = \Theta(\theta) && (2.22)
\end{aligned}
$$

Conditions (2.18)-(2.21) refer to the features of the static equilibrium in the

[13]The conditions for a CGP here are similar to the ones in Ngai and Pissarides (2007). They chose to deviate from the CGP assumption in order to match the observed reallocation of labour resources across sectors, given their disaggregation of the economy.

production side of the economy. Condition (2.18) shows that the relative price of the ICT-using good falls over time at a rate which is proportional to the growth rate of the ICT-production. The factor of proportionality is equal to the labour share in final goods production.

As condition (2.19) shows, the price of the composite intermediate good follows the changes of the ICT-using good relative price, since the output of the relative more productive ICT-using good is used for its production. The extent to which the relative price of the composite intermediate good reflects changes in the relative price of the ICT-using good depends on the contribution of the latter in its production (i.e. the share of the ICT-using good in the composite intermediate's production).

Given that the composite intermediate good is used for the production of all capital varieties in the economy, their relative price is a mark-up over its price. Over time, condition (2.20) shows that the relative prices of both types of capital goods fall, following the decline of relative price of the composite intermediate good. Therefore, the productivity gain of the non-ICT-using sector comes only indirectly. This sector uses a fixed number of capital varieties, but these varieties become cheaper and cheaper relative to the non-ICT-using final good. The falling prices generate increased demand for the existing capital varieties. Capital deepening is the only source of growth in this sector. At the same time, the ICT-using sector benefits from more varieties of capital becoming available. The benefits from more varieties complement those from cheaper varieties delivering faster growth for this sector relative to the non-ICT-using sector.

Condition (2.21) comes from equating the marginal rate of substitution to the marginal rate of transformation and using the market clearing conditions. It gives an expression for the relative labour shares in the two final goods sectors. This ratio depends on the expenditure share of the non-ICT-using good, θ, as long as it affects the marginal utility of consumption. It also depends on the output elasticity of capital, α, since it affects the marginal product of capital. The same parameter also specifies the size of the mark-up that the capital producers enjoy. Finally, it depends on the output elasticity of the non-ICT-using intermediate in the production of the composite intermediate good, β, that affects the marginal product of each type of intermediate good and equals the share of the non-ICT-using sector in the production of intermediates.

Finally, condition (2.22) presents a feature of the static equilibrium in the consumption side of the economy. It shows that consumers gain utility from the falling relative price of their composite consumption good over time. The falling price of consumption is driven by the falling relative price of the ICT-using consumption good. This benefit accrues to the consumers as part of the interest rate in consumption units and provides the incentives for savings over time that sustain endogenously the growth mechanism.

Proposition 2 *For preferences that satisfy $\epsilon = 0$, along the endogenous CGP the following are true*[14]*:*

The growth rate of every sector and of the aggregate economy is proportional to the growth rate of the ICT-producing sector, g_N^d:

$$\begin{aligned}
\frac{\dot{Y}_0}{Y_0} &= \frac{\dot{c}_0}{c_0} = \frac{\dot{h}_0}{h_0} = \frac{\dot{C}}{C} = \frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \alpha\,(1-\beta)\,g_N^d \\
\frac{\dot{Y}_1}{Y_1} &= \frac{\dot{c}_1}{c_1} = \frac{\dot{h}_1}{h_1} = (1-\alpha\beta)\,g_N^d \\
\frac{\dot{K}_1}{K_1} &= \frac{\dot{K}_0}{K_0} = \frac{\dot{H}}{H} = (1-\beta) g_N^d
\end{aligned}$$

[14]The sufficient conditions for an interior solution is that: $L > \bar{L}(\theta, \alpha, \lambda, \rho)$, i.e. the labour stock exceeds a lower bound. The latter is a function of the model's production and preference parameters.

The labour allocations are constant and depend on all parameters of the model and the aggregate labour stock:

$$u_z^d = u_z^d(\theta, \rho, \sigma, \alpha, \lambda; L); z = \{0, 1, N\}$$

Given the static optimization conditions described above, the features of the dynamic optimization conditions follow immediately. In particular, the ICT-producing sector is the engine of growth and exhibits the fastest growth in the economy. Its growth is driven from the externalities present in its production.

The ICT-using sector benefits from any advances in the ICT-production, in terms of capital deepening. Its capital embodies a constant growth in its productivity, because more varieties become available over time. Its growth would coincide with the growth rate of the ICT-producing sector, only if this sector would be the only capital producing sector in the economy. The use of the relatively expensive non-ICT-using good for the production of capital, it increases its production cost and thereby its final price above the "unit price" of the ICT-using good. As a result, the relative price growth of capital and therefore capital deepening for all sectors. In particular, for the ICT-using sector it generates disincentives to invest in the ICT-capital varieties since its relative prices fall at a higher rate compared to the ICT-capital prices. However, the horizontal expansion in technology is sufficient to revert this effect and create a productivity gap between the final good sectors.

The non-ICT-using sector exhibits the lowest growth. It grows due to capital deepening, which is only driven by the fact that non-ICT-capital is becoming cheaper over time. Therefore, the growth rate for the non-ICT-using sector is only a fraction of the ICT-production growth, with the fraction being equal to the product of the capital share in final good production and the ICT-using good share in the production of intermediates.

At the aggregate level, the differences in output growth between the two final good sectors are cancelled out by the growth rate of relative prices. The economy is along a constant growth path, where the consumption to output and capital to output ratios are constant within every sector, but different across sectors. The growth rate of the economy is a function of the preference and production parameters and the available labour stock.

2.3.3 Comparative statics

Proposition 3 *The growth rate of the economy is higher and the labour shares in the two final goods' sectors are lower, the more patient the agents in the economy are (the lower ρ is), the higher the intratemporal elasticity of substitution (the lower σ is) is and the more productive the ICT-producing sector is (the higher λ is). The effect of a higher output elasticity of capital (α), a higher intermediate output elasticity of the non-ICT-using good (β), or the expenditure share of the non-ICT-using good (θ) is ambiguous and depends on the values of different parameters of the model.*

Patient agents would be more willing to substitute current with future consumption. The additional savings direct resources to the ICT-producing sector. This is because as asset holdings increase, they drive interest rates down and therefore by increasing the present discounted value of the profit flow of each firm, they drive patent prices up. This enables higher growth in the long-run, since it provides incentives for higher ICT-production growth. An increased productivity in the ICT-producing sector would have the same effect. It would increase the marginal product of the labour in this sector, and thus would attract more labour. The incentives to produce more ICT would come from higher patent prices, that would result both from the increased productivity and the reduced interest rate.

The comparative statics following an increased preference towards the non-ICT-using consumption good show two opposite effects. On the one hand, since the marginal utility of consumption goes up in this sector, there are forces to increase resources in its production, that are being driven out of the other two sectors. On the other hand, reducing the resources from the ICT-producing sector implies that the rate at which the price of the non-ICT-using good increases relative to the ICT-using good falls as well. Hence, the rate of consumption growth of the economy would fall, which reduces incentives to direct resources to the non-ICT-using sector depending on how willing the consumers are to substitute present with future consumption. For unit intertemporal elasticity of substitution, this second effect is eliminated. Hence, stronger preference for non-ICT-using goods implies lower growth rate and a diversion of resources out of the ICT-using and producing sector and into the non-ICT-using sector.

The effect of higher importance of the non-ICT-using good in the production of intermediates is similar. Given that it increases the relative productivity of the non-ICT-using intermediate good, more resources would be driven towards the production of the non-ICT-using good, which has a negative effect on growth. At the same time, the relative prices growth is lower, which implies a lower interest rate in consumption units. The second effect is eliminated for unit intertemporal elasticity of substitution. Resources would be driven out of both the ICT-using and ICT-producing sector.

Finally, the case of higher output elasticity of capital is more complex. On the one hand, this reduces the mark-up that the capital producers enjoy, and thus increases the production of capital and output. The effect of capital accumulation upon growth becomes stronger. On the other hand, since the labour share in output falls, this reduces the incentive for growth as it mitigates the gap between the interest rate in consumption units and the subjective discount rate. That also depends on the way that the ICT-using and the non-ICT-using good are substituted in the production of consumption and intermediates. For unit intertemporal elasticity of substitution, the positive effect on growth dominates. Resources would be driven out of the non-ICT-using sector and into the ICT-producing and ICT-using sectors, if the share of the non-ICT-using output in consumption is higher than its share in the production of intermediates.

2.3.4 Social planner problem

Lemma 4 *The social planner that internalizes the externalities present in the ICT-producing sector and achieves first best allocations in the market of capital varieties, would achieve higher long-run growth rate by directing more resources into the ICT-producing and ICT-using sector. The growth rate of the social planner is a monotonically decreasing function of the contribution of the non-ICT-using sector into the production of intermediates,* β*. For a unit intertemporal elasticity of substitution , one can show that there is a unique value* β^* *that would make the allocations of the social planner to coincide with those of the decentralized equilibrium.*

The intuition for this result is straightforward. A social planner that internalizes the externalities present in the ICT-production, has incentives always to direct real resources in this sector, because it recognizes that it is the engine of growth. That ensures that the social planner's problem maximizes the growth potential for the economy overall. At the same time, given the consumption preferences, the social planner would direct more resources into the final-good sector that has stronger productivity growth, since he identifies the links across the different industries and the role of the ICT-using sector for transmitting growth to the sector with no direct growth opportunities due to technological advances, i.e. the non-ICT-using sector.

This already suggests the finding that the social planner's first-best allocation into the ICT-producing sector, and therefore the long-run optimal growth of the economy is strictly decreasing in the production parameter β. The higher is the contribution of the low productivity non-ICT-using sector into the production of intermediates this reduces the role of the ICT-using sector in transmitting ICT technology progress into the aggregate economy. This suggests that if different countries have achieved first best allocations with appropriate policies that allow the agents to internalize the knowledge externalities into ICT-production and correct the monopoly distortions (e.g. subsidies to ICT-related R&D and subsidies on the purchase of capital goods), they would still differ in their aggregate productivity due to differences in the production parameter β. This model highlights the importance of the ICT-using sector: the stronger the role of the ICT-using sector into providing intermediates, the stronger the aggregate growth will be[15]. In this stylized model, given that the share of the non-ICT-using sector is ruled by a technology parameter it is naturally treated as an exogenous variable, and given the absence of distortions in the production of intermediate goods, the model does not allow scope for growth promoting policy related to affecting β. However, in

[15]Note that even abstracting from the endogenous growth freamework, this claim would be even stronger. Given an exogenous common growth of ICT-production across different economies, the aggregate growth rate would differ due to differences in β (the capital share is also affecting but the data do not show sufficuient variebility accross countries).

practice, to the extent that β can be influenced by the government policies, i.e. becomes a function of some policy instruments, the choice would be to decrease the role of the non-ICT-using sector in providing with intermediates[16].

The proof of the above result is presented in Appendix A.4. It also shows that the market allocations could be brought closer to the social planner's ones for some values of β. To illustrate the result, under the simplifying assumption of unit intertemporal elasticity of substitution, it is shown that there is a unique value of β that would allow for the long-run growth rate and market allocations of the decentralized economy to match those of the social planner. Section 2.4.2 below presents the qualitative and quantitative features of the steady-state and transition dynamics of the first best economy, when all capital is being produced by the ICT-using sector. This exercise provides intuition of the model's implied welfare loss in terms of long-run growth due to the market distortions and intermediates production structure.

2.4 Supportive Evidence

As in the theoretical model, the industries are grouped into three major sectors: ICT-producing, ICT-using and non-ICT-using. See Appendix A.7 for precise sources and definitions of the data and details regarding the industries in each major sector and the aggregation method used[17].

[16]For example, suppose that the government has identified the set of the industries that are the highly intensive ones into the use of intermediates. Then it could design an industrial policy that would provide incentives across the different sectors in the economy to outsource activities that are related to the activities conducted by the ICT-using sector (as a real example, business services like accounting and advertising). On the other hand, it would strengthen the market incentives for vertical integration for the industries that are non-intensive into using ICT.

[17]Note that in the model real quantities are in units of the numeraire, i.e. the ICT-using good. Given that perfect competition implies that along the CGP the relative prices reflect the relative TFP productivity of the two final good sectors, the final output real growth is given by the growth of the non-ICT-using sector. The latter is ensured to be constant along the CGP.

In the benchmark model the ICT-using sector and the non-ICT-using sectors are the sectors that are assumed to provide consumption and intermediate goods for the economy. In order to check whether the resulting grouping of sectors supports this, the Bureau of Economic Analysis (BEA) "Use Table" of the "Benchmark 1997 Input-Output Tables" was used to calculate the production shares of the commodities of the ICT-producing, ICT-using and non-ICT-using sector. The uses considered are "total intermediates" and "personal consumption". The results are shown in Table 2.2. The ICT-using and the non-ICT-using sectors deliver together 99 per cent of the total consumption good and 96 per cent of the total intermediate good.

Table 2.2: United States sector-level production shares by commodity use

Producing sector/ Commodity use	Intermediates	Consumption
ICT-producing	4.4	0.9
ICT-using	35.8	22.3
non-ICT-using	59.8	76.8

Notes: columns sum up to 100%

Source: BEA, 1997 Benchmark Input Output Use Table

According to the model, the requirement for growth to be transmitted to the non-ICT-using sector is that the ICT-using sector is providing with intermediates the non-ICT-using sector. Table 2.3 shows the transactions of intermediates between the two final good sectors. The two sectors do exchange the intermediate goods that they produce. What is relevant for the existence of benefits for the non-ICT-using sector in terms of falling intermediate good prices, is that it receives intermediates from the ICT-using sector. When controlling for the overall

Note that due to the constancy of all relative prices growth rate and the constant expenditure and employment shares, it follows that aggregate measures in terms of any of the goods in the economy would also grow at a constant rate over time. That makes the choice of the numeraire irrelevant when the steasy-state path of the economy is under consideration. See further on this in A.5.

share of intermediates use of the sectors, the non-ICT-using sector receives 29 per cent of its intermediates from the ICT-using sector, while the ICT-using sector receives 41 per cent of its intermediates from the non-ICT-using sector[18].

Table 2.3: United States inter-sector transactions of intermediates

Shares of intermediates produced / used by:	ICT-using	non-ICT-using	aggregate production share
ICT-using	15.9	20.9	36.8
non-ICT-using	10.8	52.4	63.2
aggregate use share	26.7	73.3	100

Notes: matrix entries sum up to 100%

aggregate production and use shares sum matrix rows and columns respectively

Source: BEA, 1997 Benchmark Input Output Use Table

The model introduces the composite intermediate good production that combines the intermediates produced by the non-ICT-using and non-ICT-using sectors. Its production structure implies that the composite intermediate's output elasticity with respect to the ICT-using sector's intermediate good, β, is equal to the output share of that good in total intermediates' production. Table 2.3 shows that β is equal to 63 per cent. According to the model, $\frac{\dot{p}_H}{p_H} = (1-\beta)\frac{\dot{p}_1}{p_1}$. Hence, only 37 per cent of the growth of the ICT-using good relative price would show up as growth of the composite intermediate good relative price, so that the incentives for capital accumulation are dampened.

One implication of the model is that along the CGP the labour shares will be constant across the three sectors. As appears in Figure 2.1, the hours shares of the three sectors are virtually constant over the period 1979-2001. The share of the ICT-producing sector is around 2%, that of ICT-using changes from a minimum of 24% to a maximum of 26% and that of non-ICT-using changes from 74% to 71%[19].

[18] These numbers come from Table 2.3 by dividing the respective entries of the matrix by each

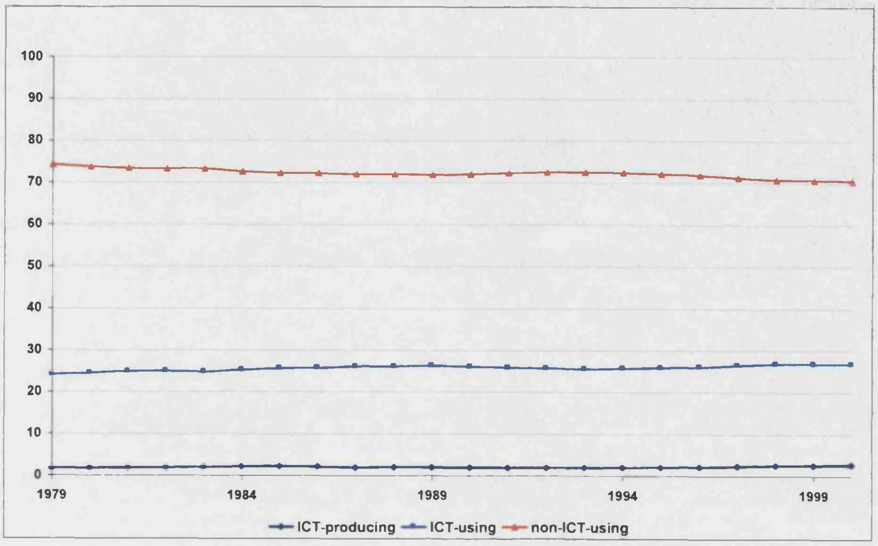


Figure 2.1: United States sector-level employment shares (hours)

2.4.1 Calibration exercise

As a back-of-the-envelope exercise, the model's parameters are calibrated and used to derive the model's predictions of the steady-state values for the following measures: The steady-state values for the growth rates of the two final goods sectors, $g_{Y_0} = \alpha(1-\beta)g_N$ and $g_{Y_1} = (1-\alpha\beta)g_N$. The relative allocation of labour in the two final good sectors, $\frac{u_1}{u_0} = \frac{1-\alpha^2\beta-\theta(1-\alpha^2)}{\alpha^2\beta+\theta(1-\alpha^2)}$. The intensity of the two final good sectors in producing consumption rather than intermediates, $\frac{c_1}{h_1} = \frac{(1-\theta)(1-\alpha^2)}{\alpha^2(1-\beta)}$ and $\frac{c_0}{h_0} = \frac{\theta(1-\alpha^2)}{\alpha^2\beta}$. Their intensity in using rather than producing intermediates, $\frac{p_H K_0}{h_0} = \alpha^2 + \frac{\theta}{\beta}(1-\alpha^2)$ and $\frac{p_H K_1}{p_1 h_1} = \alpha^2 + (1-\theta)(1-\alpha^2)$. Finally, the share of intermediates output in each sector's final production, $\frac{h_0}{Y_0} = \frac{\alpha^2\beta}{\alpha^2\beta+\theta(1-\alpha^2)}$ and $\frac{h_1}{Y_1} = \frac{\alpha^2}{1-\theta(1-\alpha^2)}$.

The growth rate of the ICT-producing sector along the CGP is calibrated by

sector's aggregate share in use.

[19]As a contrast during the same period there is up to 10 pp. labour reallocation between manufacturing and services.

the average 1970-2000 TFP growth rate of the ICT-producing sector as provided by Jorgenson, Ho, and Stiroh (2005b), $g_N = 0.130$. The measure of the TFP rather than real value added growth is chosen because it corresponds closer to the production of ideas by this sector[20]. The data from the Input Output Table provide with the share of the non-ICT-using sector in the production of intermediates in the economy, $\beta = 0.63$ (see Table 2.3). The 1979-2000 average expenditure share of the non-ICT-using sector pins down parameter $\theta = 0.79$. The output elasticity of capital, α, can be calculated using these calibrated parameters, together with the model's CGP condition on the value added, hours and intermediates used share of the non-ICT-using sector: $\frac{u_0}{u_0+u_1} = \frac{K_0}{K} = \frac{Y_0}{Y} = \alpha^2\beta + \theta(1-\alpha^2)$. The non-ICT-using 1979-2001 average hours share of 74 per cent, implies $\alpha = 0.59$. Its 1979-2001 average value added share of 71 per cent suggests that $\alpha = 0.71$. The share in intermediates use for 1997 of 73 per cent, gives $\alpha = 0.61$[21]. The predicted output elasticity of the non-labour input is uniformly higher than the capital share of 0.33 in the aggregate United States accounts. However, once the focus is shifted from the value added to the gross output, then the estimates of the non-labour inputs in production are much higher. The 1997-2005 BEA data on gross output and intermediates for the United States private industries show that the share of capital and intermediates in gross output is 0.7. That of intermediates alone is 0.45 and finally when the output production considers only labour and intermediates, the intermediates share becomes 0.61. The latter is adopted for the baseline calibration. Table 2.4 summarizes the calibrated parameters along with the model's predicted steady-state variables.

[20]This measure is consistent with the average growth in the number of patents of the ICT-producing sector. The USPTO data imply average growth of 12.82 per cent for the 1985-2004 period.

[21]Noteworthy, the model's prediction that the output and input shares for the non-ICT-using sector should be in line is reasonably held by the data.

Table 2.4: Calibration of the United States economy 1970-2000

	Benchmark parameters: α=0.61 β=0.63 θ=0.79 g_N=0.130	
	model	*data*
g_{Y_0}	0.029	0.022
g_{Y_1}	0.080	0.032
$\frac{u_1}{u_0}$	0.363	0.356
$\frac{c_0}{h_0}$	2.120	1.027
$\frac{c_1}{h_1}$	0.945	0.512
$\frac{p_H K_0}{h_0}$	1.161	1.160
$\frac{p_H K_1}{p_1 h_1}$	0.501	0.725
$\frac{h_0}{Y_0}$	0.321	0.493
$\frac{h_1}{Y_1}$	0.742	0.661

The model matches reasonably well the growth rate of the non-ICT-using sector, but over-predicts the ICT-using sector growth. The degree of this mismatch depends highly on the extent that the measure of the ICT-producing growth employed here overstates the actual applications of ICT (the implicit assumption is that the innovations are automatically used in the production)[22]. The model predicts closely the relative labour allocations in the two final good sectors[23]. The rest of the ratios are matched reasonably well. The model does predict correctly that the non-ICT-using sector is more intensive compared to the ICT-using sector in using rather than in producing intermediates, i.e. $\frac{p_H K_1}{p_1 h_1} < \frac{p_H K_0}{h_0}$. This holds true as long as the parameters satisfy the condition: $\theta - \beta > -\beta\theta$. This condition is held by the calibrated parameters. Moreover, the ICT-using sector appears to be more intensive in producing intermediate goods as opposed to the non-ICT-using

[22]Note that for the limit case of $\beta = 0$, then $\frac{g_{Y_1}}{g_{Y_0}} = \frac{1}{\alpha}$, implying a larger wedge in the growth rate of the two final good sectors, i.e. the model's prediction power has increased by acknowledding that $\beta > 0$, i.e. the role of the non-ICT-using sector in providing with intermediates. The wedge would close also with an extension of the model that would employ the empirically more relevant assumption, that both sectors use both types of capital yet at different intensities. This analysis was not chosen here as it would complicate the analytical results that constitute the core analysis of this Chapter.

[23]The lower bound in the predicted labour allocations is 0.288, for $\alpha = 0.33$, and the upper bound is 0.433, for $\alpha = 0.7$.

sector, i.e. $\frac{c_1}{h_1} < \frac{c_0}{h_0}$. The condition for this by the model, $\theta > \beta$, is also held by the data. The calibration exercise is extended in the following Section, for the analysis of transition dynamics of the model in relation to the growth acceleration in 1995.

As a final note, Table 2.1 showed the striking growth accounting finding that only the ICT-producing sector has positive TFP growth. This is consistent with the model under the assumption that all the productivity embodied in the capital is fully accounted in the data[24]. On the other hand, when the productivity of the ICT-capital is not be fully captured, i.e. when only the accumulation of capital services is accounted, then the resulting TFP growth for the aggregate final good economy will appear positive and be a fraction of the TFP growth of the ICT-producing sector[25]. This fraction depends on the output elasticity of labour and the value added share of the ICT-using sector. That poses an upper limit on what would be accounted as a Solow residual due to data limitations.

2.4.2 Transition dynamics

The theoretical framework that was developed in the main body of this Chapter does not allow for transition dynamics. The reason for that is the existence of a unique state variable, which has constant rate of return along the CGP. The latter

[24] Jorgenson, Ho, and Stiroh (2005b) report that the quality of capital accounts for 0.78 of the 1.74 percentage points of the capital's contribution to growth.

[25] Within the "Aggregate Production Possibility Frontier" aggregation method, real value added growth, $\frac{\dot{\tilde{Y}}}{\tilde{Y}}$, is a weighted average of all sectors' real output growth, with the weights being the average value added shares of the two final good sectors. $\frac{\dot{\tilde{Y}}}{\tilde{Y}} = \frac{p_{Y_0} Y_0}{p_{Y_0} Y_0 + p_{Y_1} Y_1} \frac{\dot{Y_0}}{Y_0} + \left(1 - \frac{p_{Y_0} Y_0}{p_{Y_0} Y_0 + p_{Y_1} Y_1}\right) \frac{\dot{Y_1}}{Y_1}$. Using the results under Proposition 2, under the assumption that the expansion of the varieties of the ICT-capital is not accounted for:

"Solow-Residual"$\equiv \frac{\dot{\tilde{Y}}}{\tilde{Y}} -$

$$\left\{ \frac{p_{Y_1} Y_1}{p_{Y_0} Y_0 + p_{Y_1} Y_1} \left[(1-\alpha) \left(\frac{\dot{u_1 H}}{u_1 H} \right) + \alpha \frac{\dot{K_1}}{K_1} \right] - \left(1 - \frac{p_{Y_1} Y_1}{p_{Y_0} Y_0 + p_{Y_1} Y_1} \right) \left[(1-\alpha) \left(\frac{\dot{u_0 H}}{u_0 H} \right) + \alpha \frac{\dot{K_0}}{K_0} \right] \right\}$$

$$= \frac{p_{Y_1} Y_1}{p_{Y_0} Y_0 + p_{Y_1} Y_1} (1-\alpha) \frac{\dot{N}}{N}$$

is due to the externalities present in the production function of the ICT-producing sector. As a result, following a structural change in one of the key parameters, this economy only exhibits discrete shifts from the original CGP to the new one, without an intermediate phase of smooth transition path.

Under the assumption of unit intratemporal elasticity of substitution, the introduction of a slowly depreciating physical capital in the model can deliver transition dynamics. This makes the model highly nonlinear and requires the use of a numerical solution method. This Section shows the transition dynamics for the special case of the social planner's economy. Despite the fact that the allocations for the social planner's economy are different from the decentralized one (as seen in Section 2.3), the direction of the transition dynamics is the same in the two settings due to the main equilibrium conditions of the model. Besides, the social planner's solution serves as a useful benchmark as the social planner maximizes utility along the entire path of the economy.

The social planner's economy of Section 2.3.4 (also Appendix A.4) is modified so that all capital varieties are produced by the ICT-using sector, i.e. when $\beta = 0$, and there is geometric depreciation of the ICT-capital stock, K_1, at a constant rate δ. As a result, the ICT-using sector good is used for consumption, c_1, and the production of all new capital (ICT, K_1, and non-ICT, K_0), and the depreciation needs of the ICT-capital stock, δK_1. In every period the state of the economy is summarized by the ICT-capital stock and the ICT-production stock, $\{K_1, N\}$, and the control variables are:$\{c_0, c_1, K_0, u_0, u_1\}$. The details are provided in Appendix A.6.

The transition dynamics are derived with the "time elimination" method, which was proposed for non-linear growth models by Mulligan and Sala-i-Martin (1993). As a first step towards its implementation, the model is expressed in terms of the variables that remain constant along the CGP. The model's equilibrium conditions are redefined in terms of one "state-like" variable, $\left\{k_1 \equiv \frac{K_1}{N}\right\}$, and five "control-like" variables, $\left\{k_0 \equiv \frac{K_0}{N}, \omega_0 \equiv \frac{c_0}{N^\alpha}, \omega_1 \equiv \frac{c_1}{N}, u_0, u_1\right\}$. The linear dependence between the two final good sectors, since $u_0 = u_0(u_1(k_1), \omega_1(k_1), k_1)$, $k_0 = k_0(\omega_1(k_1))$ and $\omega_1 = \omega_1((u_0(k_1), k_0(k_1))$, allows for reduction of the dimension of this system, into the one involving the laws of motion of the unique "state-like" variable, k_1, and two "control-like" variables; the ones that are related to the ICT-using consumption, ω_1, and labour allocation, u_1.

The steady state, comparative statics and transition dynamics of this dynamic system are derived numerically in MATLAB following the steps required by the "time elimination" algorithm. Details on the method and the selected parameter values for the numerical analysis are provided in Appendix A.6.

The implied comparative statics of the social planner's equilibrium are summarized in Table 2.5 below[26]. The growth rate of the economy increases in response to an increase in the productivity of the ICT-producing sector, increase in the patience of the consumers (decrease in the time preference rate or increase in the intertemporal elasticity of substitution, $\frac{1}{\sigma}$), decrease in the depreciation rate of the ICT-capital stock, decrease in the preference for the non-ICT-using good and decrease in the output elasticity of capital. It is only in response to a change in the preference for the non-ICT-using consumption good or the output elasticity of capital, that allocations in the final good sectors move in the opposite direction. In the former case, this is because the preference parameters affects asymmetrically the marginal utility of consumption of the two consumption goods. In the latter case, the increase in the output elasticity of capital increases the marginal product of capital and thus increases demand for capital. Therefore, resources need to be

[26]The comparative statics exercise involves increase of the baseline parameter values by 10%, ceteris paribus.

driven into the capital producing sector of the economy in order to boost capital supply in response to its demand.

Table 2.5: Comparative statics following increase in the parameter value

	k_1	k_0	u_1	u_0	u_N	ω_1	ω_0
Baseline	0.001	0.006	0.367	0.286	0.347	0.003	0.027
δ	(-)	(-)	(+)	(+)	(-)	(-)	(+)
λ	(-)	(-)	(-)	(-)	(+)	(-)	(-)
θ	(-)	(+)	(-)	(+)	(-)	(-)	(+)
σ	(+)	(+)	(+)	(+)	(-)	(+)	(+)
ρ	(+)	(+)	(+)	(+)	(-)	(+)	(+)
α	(-)	(-)	(+)	(-)	(-)	(-)	(-)

Notes: (+) denotes increase over baseline, (-) decrease

The transition dynamics of the model economy are determined by the single state-like variable, k_1, and the two control-like variables, u_1 and ω_1, and can can be described by a phase diagram in the $[u_1, \omega_1, k_1]$ space. The stable arm is represented by the two policy functions $u_1(k_1)$ and $\omega_1(k_1)$. The policy functions of the remaining control-like variables are determined as functions of these two policy functions. Figure 2.2 shows the policy functions for all control-like variables for a range of the state-like variable $[k_1(0), k_1^*]$[27].

[27]Where k_1^* is the steady-state value of the state-like variable, while $\{u_1^*, u_0^*, u_N^*, \omega_1^*, \omega_0^*\}$ are the steady-state values for the control-like variables. The dynamics in Figure 2.2 use $k_1(0) = \frac{k_1^*}{2}$.

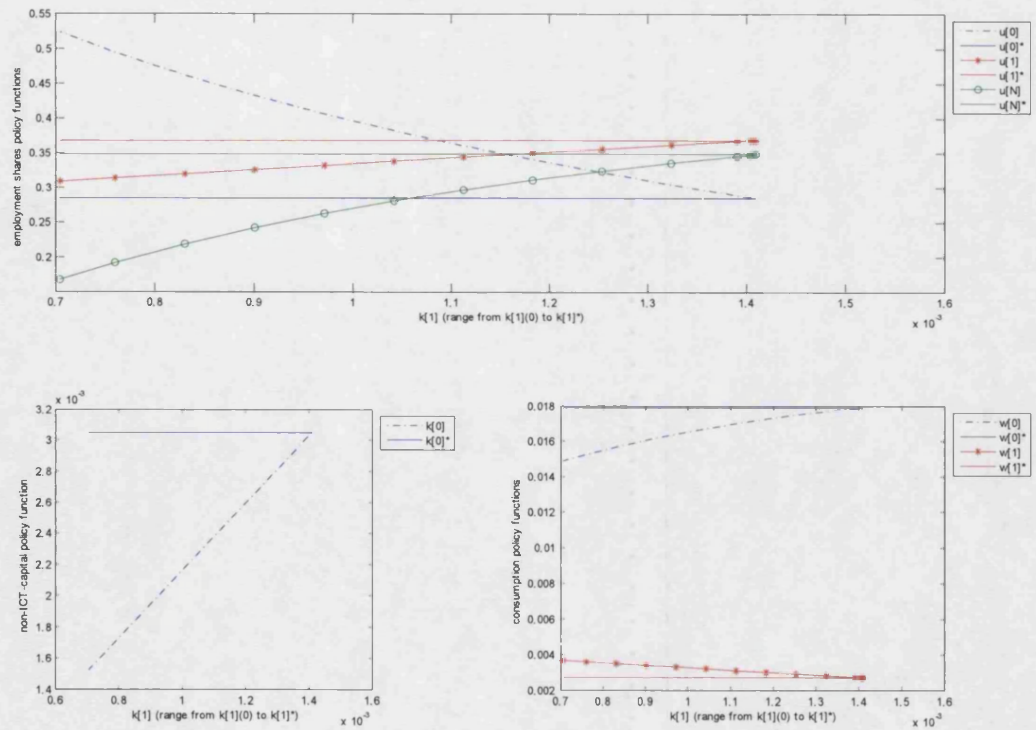


Figure 2.2: Transition dynamics

The analysis that follows presents an application of the present analytical framework in relation to the growth experience of the United States economy during the 1990s. The empirical literature (Jorgenson, Ho, and Stiroh 2005b, Bosworth and Triplett 2004, Oliner and Sichel 2002) identifies 1995 as being a threshold year, after which the United States economic growth accelerated. The underlying cause is conjectured to be an increase in the productivity of the ICT-producing sector.

For this application, the United States is viewed along a transition path to the steady state, during which it experienced an increase in the productivity of ICT-production, which had an impact on both its steady-state and transition path[28]. In particular, this analysis focuses on the dynamics of the employment allocations in the three sectors, since these are the control-like variables that have a direct observational equivalent. Even though the data show (Figure 2.1) that the employment shares remained virtually constant over time, suggesting that the steady-state assumption is a reasonable approximation of the United States growth experience, here the steady-state assumption is abandoned. Doing so provides additional insights regarding the dynamics that the model delivers within the first-best frontier.

In order to investigate possible changes in the evolution of the employment share series, each series is presented separately in the three figures below, together with a fitted line trend before and after 1995. For the ICT-producing sector there is a clear upward trend in the employment share and a upward turn in 1995. The employment share in the non-ICT-using sector falls monotonically with a downward turn in 1995. The opposite is the case for the ICT-using sector.

[28]Jones (2002) interprets the United States constant long-run growth rates at the aggregate level as the outcome of transition dynamics and their interplay with the economy's structural characteristics.

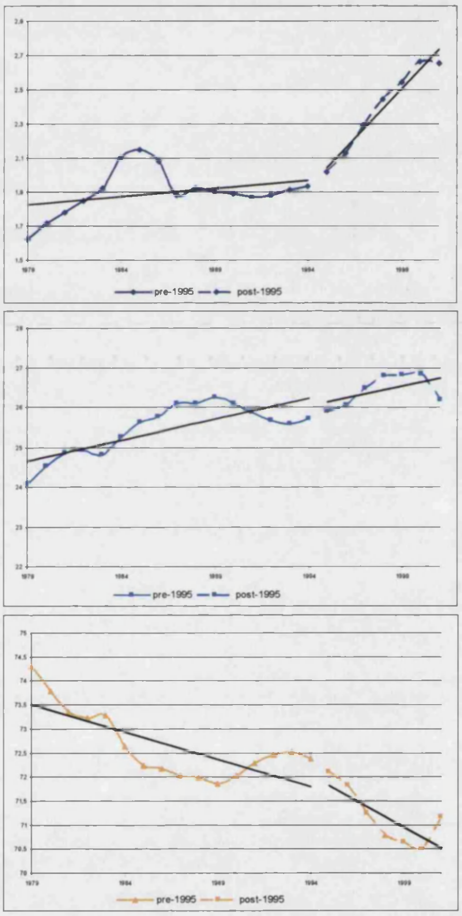


Figure 2.3: Employment allocation dynamics pre/ post 1995 (hours)

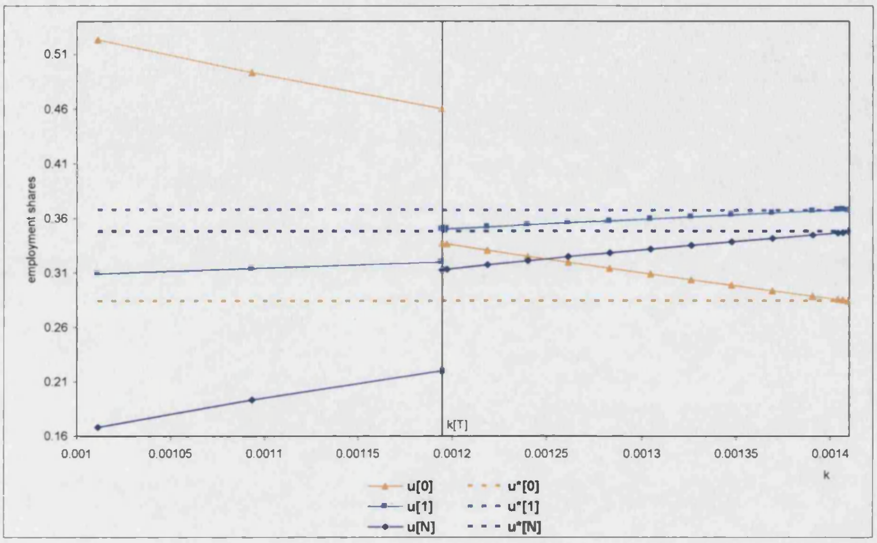


Figure 2.4: Impact of an increase in the ICT-producing sector productivity in T

In terms of the model economy, higher ICT-producing productivity corresponds to an increase in λ[29]. As already shown in Table 2.5, the effect of such change is that the steady-state value of the ICT-producing sector employment share goes up, while that of the two final good sectors declines. The steady-state value of the state-like variable declines as well. Given the policy functions derived above, a trajectory of the social planner's economy that would be close to that of the data, is that of an economy that moves towards its steady-state starting from $k_1(0) < k_1^*$, and experiences an increase in the productivity of the ICT-producing sector in period T, i.e. when the "state-like" equals $k_1(T)$, where $k_1(0) < k_1(T) < k_1^{*'} < k_1^*$[30]. The resulting pattern in the employment shares is given in Figure 2.4.

While the results are reasonably consistent with the actual trends in the data qualitatively, the quantitative differences are striking. For any level of productivity

[29]The value of λ for the pre-1995 and post-1995 period is the time average of the series that comes from dividing average annual TFP growth of the ICT-producing sector by its average employment share. The estimated value is $\lambda = 6.19$ for pre-1995 and $\lambda = 7.17$ for post-1995.

[30]The assumption that k_1 increases along this transition path matches the fact that growth in ICT-capital is stronger than TFP growth for the aggregate economy.

in ICT-production, the social planner would choose to allocate a large fraction of the labour resources into R&D. This would have dramatic effects on the output growth. The response of the social planner to the higher productivity in the ICT producing sector, is a sharp increase in its labour allocation. Table 2.6 presents the steady-state predictions of the model under various specifications (with or without depreciation, with or without multi-sector structure). The case of no depreciation and no multi-sector setting is equivalent to Romer (1990). The results indicate that it is a standard property of such endogenous growth model to deliver very large steady-state allocations in the technology producing sector and relatively minor responses to productivity changes. The predicted employment allocation moves closer towards matching the data for the decentralized equilibrium solution and even more so when the multi-sector endogenous growth setting is considered.

Table 2.6: Steady-state ICT-producing sector labour allocation under different assumptions

period	1979-1994	change in 1995-2001 less 1979-1994 (pp)
u_N data	1.90	0.49
SP		
$\beta = 0; \theta\ , \delta > 0$	34.81	0.02
$\beta = \delta = 0;\ \theta > 0$	39.78	0.04
$\delta = 0; \beta,\ \delta > 0$	39.42	0.08
$\beta = \delta = \theta = 0$	39.82	0.02
CE		
$\delta = 0; \beta,\ \delta > 0$	10.00	0.04
$\beta = \delta = \theta = 0$	19.47	0.02

2.5 Conclusions

This Chapter develops a theoretical framework that accounts for growth in the ICT era. The source of growth are the externalities present in the ICT-production. It analyzes the mechanism through which growth is transmitted from the ICT-producing sector to the aggregate economy. The sector using ICT-capital goods benefits from the use of the new technologies, by experiencing accumulation of capital that embodies these advances. This results in falling capital prices, because the ICT-using good is used for the production of intermediates. The falling intermediate good prices drive capital deepening in the sector that does not use ICT-capital. Therefore, despite the fact that only one sector uses ICT-capital goods, the benefits from their use spread throughout the economy. These benefits are stronger, the more the ICT-using sector contributes to the production of intermediates.

At the same time the mechanism that drives growth in this model, i.e. the falling capital prices, may explain growth caused by any technologies that expand the production possibility frontier of the capital-producing industries in an economy. In that sense, the model is more general than its selected application in this Chapter (i.e. to account for growth in the ICT context). On more general grounds, this Chapter provides insight into how multiple sectors of different growth potentials interact within an economy in a way that allows for a CGP at the aggregate level, where growth is sustained endogenously.

Along the steady-state growth path, there is no reallocation of labour across sectors. The ICT-producing sector is the fastest growing sector. The ICT-using sector does not grow as fast as the ICT-producing sector, despite the fact that it uses capital varieties that follow the growth of the ICT-production stock. This is because the use of the low productivity non-ICT-using good in the production of intermediates implies lower growth for the capital prices and therefore weaker incentives for capital accumulation. The non-ICT-using sector is the slowest growing sector as it only accumulates a fixed set of capital varieties. The aggregate growth rate is driven by the advances in the ICT-production. It is endogenously determined as a function of the preference and production parameters of the model and the size of the labour stock. The aggregate consumption to capital and output to capital ratios are constant over time. The real interest rate is also constant over time. The main implications of the model are broadly consistent with data of the United States economy.

Chapter 3

Patterns of intermediates' use in the United States and the United Kingdom

3.1 Introduction

During the 1970-2004 period, the United States and the United Kingdom economies have a monotonically increasing share of services-intermediates in their gross output and a monotonically decreasing share of goods-intermediates. For the United States economy, in 1970, 29 c. out of every \$1 of production was spent on the goods-intermediate inputs and 19 c. for services-intermediates. By 2004, only 21 c. were allocated for goods-intermediates, while the expenditure on services-intermediates had reached 23 c. For the United Kingdom, the trends were more dramatic over the same period. There was a decrease in the expenditure on goods-intermediates by 10 p. out of every GBP of production, along with an increase in the expenditure on services-intermediates by 6 p.

These trends suggest that at the aggregate level there is a substitution of goods-intermediates with the services-intermediates in aggregate input expenditures of the United States and the United Kingdom. This Chapter intends to understand the factors that drive these patterns and investigate the impact of this substitution pattern on the aggregate economy. These questions are addressed based on information from the Input-Output (I-O) tables of these countries at the sector and two/ three digit-level for goods and services-producing industries.

The interest in examining separately goods and services-producing industries is motivated in several ways. Disaggregating the economy into goods and services-producing industries is standard in the structural change literature (Baumol 1967, Ngai and Pissarides 2007, Kongsamut, Rebelo, and Xie 2001). These studies are originally motivated by the dramatic increase of the value added and employment share of the services-sector over time, which is mostly accounted by the decline of the goods-sector, despite the relatively higher productivity of the latter. Recently, there is a growing body of both theoretical and empirical research that examines the role of intermediates in the face of structural change. Oulton (2001) challenges the original prediction of a declining aggregate growth rate by allowing the low productivity sectors to produce intermediates. His work is motivated by the unprecedented output and productivity performance of the services-sector during the 1990s in both the United Kingdom and the United States (Oulton 2001, Griffith, Harrison, Haskel, and Sako 2003, Bosworth and Triplett 2004, Jorgenson, Ho, and Stiroh 2005b). However, as emphasized further in Ngai and Pissarides (2007), his result depends critically on the elasticity of substitution among factors in production.

At the same time, the revival of the United States productivity of the goods-sector in the 1980s and 1990s (Jorgenson, Ho, and Stiroh 2005b, Oliner and Sichel

2002) provides a scope for the analysis of the role of the "Baumol's cost disease" in this process. In their work on this, ten Raa and Wolff (2001)

propose that in the face of low productivity in the production of services-goods, the goods-industries shift the production of the services required in their production to specialized services-industries, allowing them to increase their productivity by allocating their resources into higher productivity activities. Through a productivity analysis based on the I-O tables, they find support for this. However, while the 1980s was a period of structural transformation of the goods-producing industries (Basu, Fernald, Oulton, and Srinivasan 2003) and a shift of the production towards the services-producing industries (Abramovsky and Griffith 2007), the performance of the goods-sector does not resemble the one of its United States counterpart.

The disaggregation of the economy into goods and services-producing industries is currently also central for the analysis of outsourcing and/ or offshoring in the productivity and trade literature. Outsourcing is the relocation of activities of a firm to external providers regardless of their location, while offshoring regards to outsourcing to providers from abroad (see discussion in Abramovsky and Griffith 2007, Olsen 2006)[1]. These issues increasingly gained attention in the literature especially due to the emergence of outsourcing in services-producing industries that is to an important extent enabled by Information and Communication Technologies. While the measurement of these issues is still preliminary, the existent evidence for both the United States and the United Kingdom (e.g. Abraham and Taylor 1993, Girma and Görg 2004, Yuskavage, Strassner, and Medeiros 2006, Abramovsky and Griffith 2007) points out the important role of the services-sector (and in particular the "Business services") in accounting for

[1] Overall, there is no commonplace terminology of these issues in the theoretical and empirical literature of this area.

most of the outsourcing and offshoring.

Overall, the literature suggests that one would expect an important role of the services-sector in both producing and using intermediates and its role in this process needs to be studied separately. This need is accommodated by the newly available data. The data on intermediates disaggregate only at the materials, energy and services purchases level. This suggests a natural grouping into goods and services-intermediates, alongside with a grouping of industries into goods and services-producing. To the extent that the domestic demand is covered by the domestic supply, the analysis of the use patterns across goods and services-sector provides some indication of the underlying production patterns. Finally, by utilizing this criterion for grouping the industries this Chapter's results directly contrast and complement the ones in the relevant literature.

In examining the drivers of the pattern in aggregate use of intermediates for the United States and the United Kingdom, this Chapter isolates the role of structural change in the composition of final output. The results show that the substitution pattern present at the aggregate level is not driven solely by a "size effect", i.e. , the high input needs of the growing services-sector, given its high intensity in using services-intermediates for its production. To the contrary, the decomposition of the aggregate pattern highlights the existence of a pure "substitution effect", i.e. of a change in the intensity of goods and services-intermediates use[2].

For the average industry there is a negative trend (statistically significant) in the expenditure share of goods-intermediates. At the same time there is a negative trend in the relative volume and price of the goods-intermediates[3]. These findings are consistent with existent studies based on information from the I-O tables for

[2] Appendix B.1 presents analytical definitions of these different effects.

[3] See Figures in Section 3.2.3 and Appendix B.4. Details on the data sources and their properties are in Section 3.2.

the 1997-2004 period. These comes from the Bureau of Economic Analysis for the United States (Strassner, Medeiros, and Smith 2005) and Abramovsky and Griffith (2007) for the United Kingdom. The latter is also complemented by the analysis of Greenhalgh and Gregory (2001) based on the information for 1979 and 1990.

In order to uncover the determinants of the average industry's choice of intermediates, this Chapter derives on the standard growth accounting assumptions that separate the intermediates from the primary inputs in production, under perfect input and output markets (Fraumeni, Gollop, and Jorgenson 1987). It assumes that the two types of intermediates are combined into a CES composite[4]. There are two sets of factors allowing to affect an industry's choice of its goods-intermediates expenditure share. First, the relative prices of these intermediates that the user industry faces, and second, its own productivity in using each type of intermediates. The degree of substitutability between the two types of intermediates is the technology parameter regulating the relative importance of these two factors for the industry's choice of intermediates.

The theoretical framework suggests an empirical specification that allows to uncover this parameter of interest given the available goods-intermediates expenditure and relative prices data that are available at the industry-level. The industry-specific productivity factors are captured by controls with cross-sectional and time-variation. The results show a statistically significant and below one elasticity of substitution for both the goods and the services-sector and for both countries[5]. The degree of substitution of the two types of intermediates is higher

[4]Such production technology is common in the literature that discusses the substitution among different types of inputs (Krusell, Ohanian, Rios-Rull, and Violante 2000, Acemoglu 2002).

[5]This result is intuitive. For example, the "Food production" industry produces its value added with the use of goods-intermediates, like agricultural products, and services ones, like advertising, insurance or wholesale. Its final output is produced given a particular combination

for the goods-sector for both the United States and the United Kingdom. This result is robust under alternative specifications of the unobserved factors. The regression results also highlight the importance of controlling for unobservable factors at the aggregate, sector or industry-level.

Furthermore, this Chapter extends its analysis for the United States in an attempt to identify a potential link between the industries' choice of intermediate inputs and the final output (value added) performance. First, it looks closer at the patterns of intermediates' use of the Information and Communication Technologies (ICT) producing sector in the United States[6]. While this sector diverges from the rest of the United States industries, the low degree of substitution between goods and services-intermediates applies to this sector as well. Second, using a standard growth accounting approach it finds a negligible impact on the aggregate labour productivity growth and unit costs of production[7]. Third, using its available information and the estimated elasticity of substitution, this Chapter derives a measure of the latent factors driving the goods-intermediates use for the services-sector in the United States and the United Kingdom. For the United Kingdom, this suggests that throughout the 1980s and 1990s these industries have a relatively high productivity in using goods-intermediates. For the United States services-sector, while in the 1980s there are results qualitatively similar to the United Kingdom, in the 1990s there is no support for an advantage in efficiency in using a particular type of intermediates.

To summarize, this Chapter's empirical investigation concludes that as the goods-intermediates become relatively inexpensive over time due to the higher

of these types of intermediate inputs that are not directly substitutable with each other.

[6]See discussion in Chapter 1 regarding the evidence on the role of this newly established sector (post 1985) in driving the United States productivity growth.

[7]This confirms a preliminary report of the Bureau of Labour Statistics (BLS) (BEA 2004) regarding the impact of outsourcing and offshoring on its productivity measures.

productivity of the goods-intermediates producers, they "free" resources for the finance of the services-intermediates expenditures. By uncovering a low substitutability in goods and services-intermediates, it complements the findings of low substitutability of goods and services' final output (consumption) (e.g. Stockman and Tesar 1995, Ngai and Pissarides 2004). However, this Chapter also provides suggestive evidence that input prices alone cannot fully account for the observed input choices.

This study contributes to the literature on the substitution in factors in production. This literature mostly concerns the primary factors in production, i.e. capital and labour (e.g. for aggregate-level studies see Krusell, Ohanian, Rios-Rull, and Violante 2000, Antràs 2004). In a recent study of the United States industries over the period 1958-2004, Jin and Jorgenson (2007) find that an industry's demand of inputs is affected by both input prices and its technology in using its inputs. Their results indicate a positive correlation between "input-using" technical bias and high input prices, and a "material-saving" technical bias for the average industry in their sample. Given that in their analysis "materials" are the non-energy intermediates (i.e. they group non-energy materials and services), they do not explicitly account for the substitution between goods and services-intermediates and the growing importance of the latter.

It is important to acknowledge up-front that the analysis of this Chapter is subject to a common criticism for all studies aiming to account for the intermediates' use based on information from the I-O tables. Any inference regarding the patterns in intermediates' used based on the I-O tables bears several limitation due to the feature of these data. This is because the I-O tables only account for the intermediates' purchases of domestic firms from suppliers that come from the same or different industry and are located domestically or abroad. Therefore, the importance of factors like industrial structure (degree of vertical integration) and imports in driving the intermediates' use patterns cannot be fully understood and quantified without additional firm-level information. Section 3.2.6 discusses the limitation of the data employed for this Chapter and how its results are affected. Nevertheless, any investigation with a more aggregate-level and long time-horizon interest is restricted to the use of I-O based data, due to the lack of consistent micro-level data.

This Chapter is organized as follows: Section 3.2 presents the data sources and their characteristics and provides the definitions of the main variables used. The main body of the empirical analysis is in Section 3.2.3. Section 3.2.6 uses the results of this Chapter to get insights on the aggregate economic performance over time and across countries. Section 3.4 concludes.

3.2 Data Sources and Definitions

3.2.1 The EU KLEMS dataset

The data used for this analysis come from the first public version of the EU KLEMS database (version March 2007). This database is part of a research project financed by the European Commission, which aims to accommodate research on productivity analysis at the industry level in the European Union. It includes data for the so-called "sister"-KLEMS databases of the United States and Japan. The database includes measures of gross output, value added, employment and capital formation. The input measures include both primary inputs in production, capital (K) and labour (L), as well as secondary inputs in production, energy (E), materials (M) and service intermediates (S). The growth accounts are consistent with the standard practices developed in the literature (Fraumeni, Gollop, and Jorgenson 1987). This analytical framework is based on well-defined production functions at the industry and aggregate level and has the benefit of a sound economic growth theory background.

The data for the United States economy are based on the annual industry accounts provided by the Bureau of Economic Analysis (BEA). The data are available at both the Standard Industry Classification (SIC) and North American Industry Classification (NAICS) level over the period 1970-2004, since the United States have moved into the NAICS in 1998. This implies that the United States SIC data are based on SIC KLEMS data for 1970-2000 and are extrapolated forward using NAICS. The analysis of this Chapter uses the SIC-based data, because only these have information on the different types of intermediates used. The sources for nominal and volume measures regarding the inter-industry accounts come from the National Accounts. For the 1960-2000 period, the data are taken from Dale Jorgenson. The details for the method followed for the construction of these data is provided in Chapter 4 of Jorgenson, Ho, and Stiroh (2005b). The breakdown of their 44-industry level into the industry detail of EU KLEMS database is made on the basis of weights, that are calculated with the use of Benchmark Input-Output (I-O) tables from BEA. For the 2000-2004 period, there is forward projection of the data on intermediate inputs from the Bureau of Labour Statistics (BLS) Office of Employment Projections, using the BEA GDP by industry accounts. Original Industry classification for the dataset follows NACE ("Nomenclature statistique des Activités économiques dans la Communauté Européenne", i.e. Statistical classification of economic activities in the European Community). Details on the mapping to NACE for the United States economy is found in the country notes details of the dataset.

Regarding the data for the United Kingdom economy, there are several data issues that need to be taken into account that can affect the analysis. The source of the data is the same[8]. For the period 1992-2004, the data are based on the Supply and Use Tables (SUTs) that are compatible to the UK SIC (2003) industry classification that is meant to reflect NACE. Prior to 1992 the information comes from the I-O tables of various years (last available in 1989) and the Blue Book. These I-O tables were using older industry classifications that do not map directly to UK SIC (2003). For details on the data see country notes for the UK from EU KLEMS documentation and the relevant ONS information. Despite the care taken in order to eliminate the impact of the linkage among the different information sets, there is an obvious "break" in the series in 1992. There was a change in the industry classification system, that affected rather the classifications within each SIC division rather than the classification of industries into goods and services. In the analysis that follows, care is being taken in considering the differences across the two sample periods (1970-1991, 1992-2004).

Apart from the data breakpoint, there is an additional factor that needs to be taken care of when contrasting the United Kingdom to the United States economy with respect to their use of the different types of intermediates. For the United Kingdom, the intermediate inputs are valued at purchasers' prices and include the trade margins. On the contrary, for the United States the trade margins are allocated as services provided from the respective industry. That suggests that the data are not directly comparable with respect to the level of the shares of the different types of intermediates. In particular, the shares of goods-intermediates are expected to be higher. However, there is still role for cross-country comparison of the trend of the goods-intermediate share. Examining directly at the I-O Tables

[8]The UK KLEMS data were provided directly from M. O' Machony and J. Woltjer of NIESR as they include necessary corrections over the United Kingdom data-file in EU KLEMS March 2007 release. They are provisional until the next EU KLEMS release. M. O' Machony and Marcel Timmer clarified on properties of this dataset.

from BEA showed that in the United States the trend would have been the same, should the intermediates were valued inclusive of the trade margins.

Further points that need to be emphasized regarding the properties of the EU KLEMS accounts for either country are the following. First, the intermediates purchases are calculated from the I-O (or SUTs) by including all the intermediates purchases of the industry, i.e. both the intra-industry and inter-industry ones[9]. Second, the intermediate purchases for every industry include the intermediates imported[10]. Third, the intermediates purchases (whether from domestic or foreign sources) are the result of trade of firms within the same or across industries. As a result, these data do not provide any information on the intermediates' use produced within the firm itself. They also do not distinguish between purchases of intermediates within firms that belong to the same group (vertically integrated) and the ones across firms that are not related through the firm's structure[11].

3.2.2 Industry classification

The industry "Public administration and defence; compulsory social security" is excluded throughout, in order to focus more on market activities. The remaining 2-digit level NACE industries are aggregated at the sector-level of "goods" and "services". The goods-sector includes all the non-services industries, i.e. Agricul-

[9]For growth accounting at the aggregate "sector-level", based on the "sectoral output" concept, one needs to rather exclude the intra-industry transactions of intermediates. This is the practice in the multifactor productivity analyis program of BLS.

[10]For the United States, the intermediates purchases of commodities that do not have a domestic analog are classified as "non-comparable imports" and are reported at a separate line in the I-O Tables. For teatment of these see Chapter 4 of Jorgenson, Ho, and Stiroh (2005b). For the United Kingdom the intermediates purchases include also the imports. The UK Analytical I-O Tables include details on the imported intermediates by industry. See discussion in Abramovsky and Griffith (2007).

[11]The intra-firm and within-firm transactions of intermediates relate to the degree of vertical integration of an industry. For the UK, there is establishment-level data that are consistent with the information contained in the I-O Tables (see details in Abramovsky and Griffith (2007)). For the US, there is no equivalent source of information to complement the official I-O Tables.

ture, Hunting, Forestry and Fishing, Mining and Quarrying, Manufacturing, Utilities and Construction. The analysis is repeated at a more detailed 40-industry-level. In this level of analysis, the 23 goods-industries and 17 services-industries aggregate to the sector-level analysis goods and services data respectively. The total market economy is the aggregate of the goods and services-sector. Table 3.1 presents the set of industries that were used at the sector and industry-level analysis, together with their NACE codes.

Table 3.1: Industry NACE classication and grouping into goods and services-sector

GOODS-sector		SERVICES-sector	
Sector-level analyis			
Industry name	NACE code	Industry name	NACE code
AGRICULTURE, HUNTING, FORESTRY AND FISHING	AtB	WHOLESALE AND RETAIL TRADE	G
MINING AND QUARRYING	C	HOTELS AND RESTAURANTS	H
TOTAL MANUFACTURING	D	TRANSPORT AND STORAGE AND COMMUNICATION	I
ELECTRICITY, GAS AND WATER SUPPLY	E	FINANCE, INSURANCE, REAL ESTATE AND BUSINESS SERVICES	JtK
CONSTRUCTION	F	EDUCATION	M
		HEALTH AND SOCIAL WORK	N
		OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES	O
		PRIVATE HOUSEHOLDS WITH EMPLOYED PERSONS	P
		EXTRA-TERRITORIAL ORGANIZATIONS AND BODIES	Q
40-Industry-level analysis			
Industry name	NACE code	Industry name	NACE code
Agriculture	1	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	50
Forestry	2	Wholesale trade and commission trade, except of motor vehicles and motorcycles	51
FISHING	B	Retail trade, except of motor vehicles and motorcycles; repair of household goods	52
MINING AND QUARRYING	C	HOTELS AND RESTAURANTS	H
FOOD , BEVERAGES AND TOBACCO	15t16	TRANSPORT AND STORAGE	60t63
TEXTILES, TEXTILE , LEATHER AND FOOTWEAR	17t19	POST AND TELECOMMUNICATIONS	64
WOOD AND OF WOOD AND CORK	20	FINANCIAL INTERMEDIATION	J
Pulp, paper and paper	21	Real estate activities	70
Printing, publishing and reproduction	22	Renting of machinery and equipment	71
CHEMICAL, RUBBER, PLASTICS AND FUEL	23t25	Computer and related activities	72
OTHER NON-METALLIC MINERAL	26	Research and development	73
BASIC METALS AND FABRICATED METAL	27t28	Other business activities	74
MACHINERY, NEC	29	EDUCATION	M
Office, accounting and computing machinery	30	HEALTH AND SOCIAL WORK	N
Insulated wire	313	OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES	O
Other electrical machinery and apparatus nec	31x	PRIVATE HOUSEHOLDS WITH EMPLOYED PERSONS	P
Radio, television and communication equipment	32	EXTRA-TERRITORIAL ORGANIZATIONS AND BODIES	Q
Medical, precision and optical instruments	33		
Motor vehicles, trailers and semi-trailers	34		
Other transport equipment	35		
MANUFACTURING NEC; RECYCLING	36t37		
ELECTRICITY, GAS AND WATER SUPPLY	E		
CONSTRUCTION	F		

3.2.3 Variables definitions and aggregation method

For each industry detailed in Table 3.1 the following value variables are available[12]:

[12]Details on the definitions in original United States National Accounts.

Gross Output at current basic prices (millions of \$US/ GBP). Basic prices are the prices received by the producer for each unit of its production. They include subsidies to production.

Intermediate inputs at current purchasers' prices (millions of \$US/ GBP). Purchasers' prices are the prices paid by an industry for a unit of intermediates. They reflect the marginal cost paid by the using industry, and thus they include any taxes on commodities paid by the user (non-deductible VAT included), while they exclude any subsidies on commodities[13].

Energy, Materials and Services Intermediate inputs at current purchasers' prices (millions of \$US/ GBP). Energy intermediates are all the energy mining (NACE 10-12), oil-refining (NACE 23) and electricity and gas (NACE 40) products. services-intermediates are all services (NACE 50-99) products. The rest of the products are classified as materials. *Goods-intermediates* is the aggregate of the energy and materials products.

Value Added (gross) at current basic prices (millions of \$US/ GBP).

The aggregation over industries at the sector or total market economy-level is straightforward. In every period t the value of gross output of an industry i, $p_Y Y_{it}$, is the sum of its value added, $p_V V_{it}$ and intermediate input, $p_I I_{it}$. The value of intermediates used is the sum of the goods, $p_{I_G} I_{Git}$, and services-intermediates, $p_{I_S} I_{Sit}$.

Gross Output Volume Index (1995=100). Each industry i produces a set of M

[13]These prices should include the margins of trade and transportation as well. However, when trade and transportation products are listed seperately, then all margins should be allocated to them. This is the case for the US SIC-based data. The data in EUKLEMS for the rest of the countries do not report the margins on trade and transportation costs separately. That leads to biases on the potential contribution of each type of intermediate on output growth. For the United States, the BEA I-O Use Tables data show that there is an upward bias in the level of the share of use of goods intermediates. The trend over time is not affected.

distinct products. The growth of industry gross output, Y_i, is the Törnqvist index of the growth rates of each product k, Y_{ik}. Hence, at every point in time the annual real gross output growth rate is given by the following formula: $\Delta \ln Y_{it} = \sum_{k=1}^{M} \bar{v}_{kit} \Delta \ln Y_{kit}$, where $\bar{v}_{kit}$ is the $(t-1,t)$ period average share of product k in the value of the industry$i$ output. The aggregation at the sector (or total economy-level) is done in a similar manner, where weights are the industry output shares in the sector (total economy) output.

Intermediate Inputs Volume Index (1995=100). Each industry i uses a set of X distinct commodities. The growth of the aggregate intermediate input quantity of the industry, I_i, is calculated is the Törnqvist aggregate over the growth rates of all type-x intermediates, I_{ix}. Hence, at every point in time the annual intermediate input volume growth rate is given by: $\Delta \ln I_{it} = \sum_{x=1}^{X} \bar{v}_{xit} \Delta \ln I_{xit}$, where $\bar{v}_{xit}$ is the $(t-1,t)$ period average use share of type-x intermediate. For the aggregation at the sector (or total economy-level) the industry-level intermediate inputs volume growth is weighted with the industry output shares in the sector (total economy) output.

Energy, Materials and Services Intermediate inputs Volume Index (1995=100). Each of these indexes is defined in the same way as the total intermediate input volume index for the particular type of intermediates (energy, materials, services). While the services-intermediates volume index is directly available at the industry-level, the goods-intermediates one is constructed as the Törnqvist aggregate index of the energy and materials intermediates volume indexes. Hence, for every industry, it is the weighted sum of the volume indexes of material and energy intermediates, with weights the use share of each type in total goods-intermediates.

Value Added Volume Index (1995=100). Given that, $p_Y Y_{it} = p_V V_{it} + p_I I_{it}$, the implicit Törnqvist index for the growth volume growth of an industry i is given as: $\Delta \ln Y_{it} = \bar{v}_{it}^{V} \Delta \ln V_{it} + \left(1 - \bar{v}_{it}^{V}\right) \Delta \ln I_{it}$, where $\bar{v}_{it}^{V}$ is the average share of value added in gross output. Therefore, the implicit value added growth index is: $\Delta \ln V_{it} = \frac{1}{\bar{v}_{it}^{V}} \left[\Delta \ln Y_{it} - \left(1 - \bar{v}_{it}^{V}\right) \Delta \ln I_{it}\right]$. Aggregation at the sector (economy)-level is the Törnqvist index of the volume growth of all different industries within the sector (economy), where weights are the average value added shares of each industry.

The gross output and intermediates price indexes are constructed by the difference between the value and the volume growth of the corresponding series for both the industry and the aggregate level.Data Analysis

3.2.4 The United States economy

Sector-level analysis

The gross output of an industry equals the value added produced and the intermediates used for its production. In a constant-returns-to-scale framework, the value of output is equal to the value of all inputs, i.e. the primary (value added) inputs, capital and labour, and the intermediates used. Hence, for a sector j the following identity holds in every period t[14,15]:

$$p_Y Y_{jt} = p_V V_{jt} + p_I I_{jt}$$

In the United States economy, the composition of every unit of gross output production has a trend towards a shift away from the use of intermediates. The

[14]Note that the use of term "value" in text refers to measures in nominal terms, as opposed to "volume" that is used for measures in real terms (see Section 3.2).

[15]In the text, the constant-returns-to-scale and competitive markets assumption is sufficient, yet not necessary. The dual growth accounting approach would suggest that one just needs to assume that the national income identity implies that total income equals the aggeragate returns on the production factors (here capital, labour and intermediates). See ? for the standard growth accounting assumptions on which the interpretation of the National Accounts statistics rely.

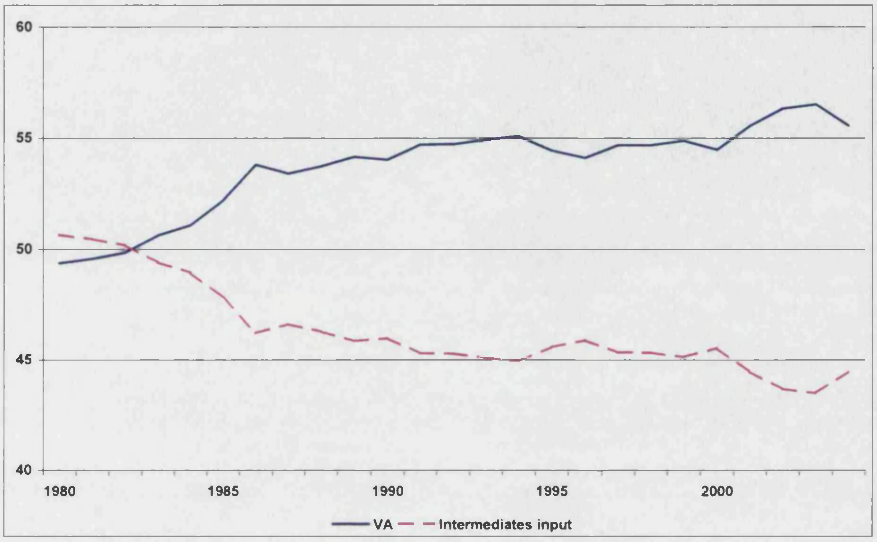


Figure 3.1: United States gross output composition in terms of value added and intermediate inputs

share of intermediate inputs in gross output has decreased by 3pp over this period (48% in 1970, 45% in 2004). This reallocation of the gross output supports a statistically important upward trend in the value added share of 0.34% over the entire period. Figure 3.1 presents the data over the 1980-2004 period[16,17].

Examining within the set of intermediates used, the intermediate inputs used for the production of gross output of a sector j are either goods or services-intermediates:

$$p_I I_{jt} = p_{I_G} I_{Gjt} + p_{I_S} I_{Sjt}$$

Figure 3.2 shows the shares of goods and services-intermediates in gross output

[16] The spike in the data in 1983 is likely to be driven by the change in the source of information for the US industries. The year 1983 is the point where the old, 1970-1995, and the new, 1983-2000, BLS-EMP datasets were linked. These two datasets are consistent with a different industry classification system that affected the ratio of value added to intermediates in particular industries (e.g. oil and gas mining). They were linked in 1983 using the iterative propotional fitting process (RAS). For details see Chapter 4 in Jorgenson, Ho, and Stiroh (2005b).

[17] The year 1987 is another important breakpoint. The information for the period 1983-1987 is based on the SIC 1972, whereas for the 1987-2000 is based on SIC 1987 industry classification. Finally, year 2000 is the point where the SIC data are extrapolated forward using NAICS.

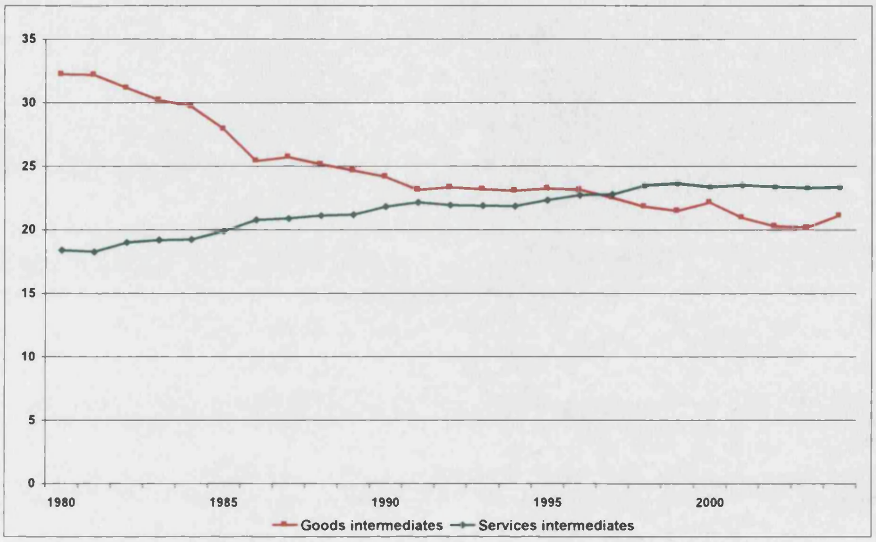


Figure 3.2: United States composition of gross output in terms of goods and services-intermediates

for the United States economy. It reveals a monotonic downward trend in the share of goods-intermediates in gross output and an upward one for the services-intermediates. In 1970, 29 c. out of every $US of production was allocated for the goods-intermediate inputs and 19 c. for services-intermediates. By 2004, only 21 c. were allocated for goods-intermediates, while the expenditure on services-intermediates had reached 23 c. of every $US of production. These patterns reveal a substitution of the goods-intermediates with the services ones in the production of aggregate output.

Over the same period, the size of the services-sector has been increasing, while that of goods has been decreasing. Table 3.2 shows how the share of goods and services-sector in gross output or value added has been evolving over the same period. Over the 1970-2004 period there has been a 14 pp reallocation of value added towards the services-sector. This trend is repeated in terms of the gross output produced by the United States industries.

Table 3.2: United States goods and services-sector value added and gross output shares

Sector shares in	Value added		Gross output	
year	Goods	Services	Goods	Services
1980	44.6	55.4	56.7	43.3
1985	39.4	60.6	53.7	46.3
1990	35.1	64.9	48.4	51.6
1995	32.9	67.1	43.8	56.2
2000	31.7	68.3	41.4	58.6
2004	29.2	70.8	39.1	60.9

Moreover, during this period the services-sector has caught up with the goods-sector in terms of its share in the production and use of intermediates. In 1970, the services-sector was producing only 39% of all the intermediates produced in the economy and was using 33% of all intermediates produced. By 2004, the production and use shares for the services-sector increased to 53% and 49% respectively. Table 3.3 presents these shares in selected years.

Table 3.3: United States goods and services-sector intermediates use and production shares

Share of intermediates	produced by		used by	
year	Goods	Services	Goods	Services
1980	63.6	36.4	68.4	31.6
1985	58.4	41.6	64.8	35.2
1990	52.5	47.5	59.2	40.8
1995	51.0	49.0	56.7	43.3
2000	48.7	51.3	53.0	47.0
2004	47.5	52.5	51.4	48.6

To conclude, in terms of the intermediates production and use, the aggregate United States economy data indicate a substitution of goods-intermediates with services-intermediates. This pattern might be driven purely from a "size effect"[18].

[18]For constant value added to intermediates shares across sectors and constant composition of intermediates for every sector, the share of goods-intermediates in gross output would change, driven purely by changes in the size of the sectors (composition of value added and total intermediates). See discussion in Appendix B.1.

In order to isolate the size effect for every sector, the same exercises as above are repeated at the goods and services-sector level.

Table 3.4 presents the composition of the gross output of the goods and services-sector in terms of value added, intermediate inputs, and goods and services-intermediates. The following facts come out. The goods-sector uses more intermediates for the production of its gross output, as opposed to the services one. Each sector uses more intensively the intermediates produced by the sector itself, i.e. the goods-sector uses more goods-intermediates, while the services-sector uses more services-intermediates. The trend in the goods-intermediates share in the gross output at the aggregate level is driven by the substitution of goods-intermediates with services-intermediates by both sectors. This substitution was stronger for the goods-sector[19].

Table 3.4: United States goods and services-sector gross output composition

Gross output composition						
	Value added		Goods-Intermediates		Services-Intermediates	
year/ sector	Goods	Services	Goods	Services	Goods	Services
1980	38.8	63.1	47.7	12.0	13.5	24.8
1985	39.9	65.3	44.3	10.5	15.8	24.2
1990	41.1	65.2	41.6	9.2	17.3	25.7
1995	41.0	64.9	41.7	8.9	17.3	26.2
2000	41.7	63.5	41.1	8.8	17.3	27.7
2004	41.5	64.6	40.9	8.4	17.5	27.1

The results so far indicate that the production structure of the goods and services-sectors (i.e. that goods use more goods-intermediates and services more services-intermediates) together with the change in the size of each sector cannot fully account for the substitution of goods-intermediates with the services-intermediates present at the aggregate level. This is because each sector has also moved into the same substitution, allocating a higher share of its gross production

[19]Both the goods and services-sectors have increased their share of value added in their output in the beginning of 1980s. See discussion in Section 3.2.4 above for this period.

for the use of services.

The next step is to get a measure of the quantitative importance of the underlying substitution trends. Define the share of the value of type-i intermediates used by sector j, $p_{I_i}I_i^j$, in the value added of the using sector, $p_V V_j$: $\frac{p_{I_i}I_i^j}{p_V V_j}$. There are two types of intermediates and two sectors: $i, j \in \{G, S\}$[20]. Define also the value of total intermediates used by sector j as $p_I I^j$. By construction, $p_I I^j = p_{I_G}I_G^j + p_{I_S}I_S^j$. Therefore, the share of type-i intermediates used in the sector's value added can be written as follows[21]:

$$\frac{p_{I_i}I_i^j}{p_V V_j} = \frac{p_{I_i}I_i^j}{p_I I^j}\frac{p_I I^j}{p_V V_j}$$

The first component is the expenditure share of type-i intermediates, while the second component is the share of all intermediates used in the sector's value added. The implied decomposition of the exponential growth rate, g, of this share is:

$$g_{p_{I_i}I_i^j/p_V V_j} = g_{p_{I_i}I_i^j/p_I I^j} + g_{p_I I^j/p_V V_j}$$

Therefore, the growth of the share of type-i intermediates used in the sector's final output can be driven by a pure substitution effect, i.e. the change in the expenditure share of the type-i intermediates, and/ or overall changes in the production structure of the sector in terms of combining the set of primary inputs with that of secondary ones[22]. Table 3.5 presents the decomposition of the average annual growth of the value added share of goods and services-intermediates for both sectors for the 1981-2004 period[23].

[20]The goods-intermediates are produced by the goods-sector and the services-intermediates are produced by the services-sector.

[21]Note that for the United States the prices exclude the trade and transportation margins. See discussion in Section 3.2.1.

[22]See Appendix B.1 for details on the decomposition and the interpretation of the various effects.

[23]There is no bias due to the data-break point in 1983. The 1985-2004 period analysis gives similar qualitative and quantitative results.

Table 3.5: United States trends in the goods and services-sector shares of intermediates in value added and their decomposition

Sector using intermediates:	Goods		Services	
Goods-intermediates share in value added	$\frac{p_{I_G} I_G^G}{p_V V_G}$	-0.91	$\frac{p_{I_G} I_G^S}{p_V V_s}$	-1.60
contribution by:				
expenditure share of goods-intermediates	$\frac{p_{I_G} I_G^G}{p_I I^G}$	-0.45	$\frac{p_{I_G} I_G^S}{p_I I^S}$	-1.35
all intermediates share in value added	$\frac{p_I I^G}{p_V V_G}$	-0.47	$\frac{p_I I^S}{p_V V_S}$	-0.26
Services-intermediates share in value added	$\frac{p_{I_S} I_S^G}{p_V V_G}$	0.81	$\frac{p_{I_S} I_S^S}{p_V V_S}$	0.27
contribution by:				
expenditure share of services-intermediates	$\frac{p_{I_S} I_S^G}{p_I I^G}$	1.28	$\frac{p_{I_S} I_S^S}{p_I I^S}$	0.52
all intermediates share in value added	$\frac{p_I I^G}{p_V V_G}$	-0.47	$\frac{p_I I^S}{p_V V_S}$	-0.26

Notes: units in 1981-2004 average annual exponential growth (%)

In a similar manner, define the share of the value of type-i intermediates that are used by sector j out of the value added of type-i intermediates' producing sector, $p_V V_i$. This share can be decomposed in a way that sheds light on the demand-side factors driving the production of intermediates in sector i. Define total value added, $p_V V$, as $p_V V = p_V V_G + p_V V_S$. Then:

$$\frac{p_{I_i} I_i^j}{p_V V_i} = \frac{p_{I_i} I_i^j}{p_I I^j} \frac{p_I I^j}{p_V V_j} \frac{p_V V_j}{p_V V} \frac{p_V V}{p_V V_i}$$

The first two-components refer to the using sector j and are defined as above. The third component is the value added share of the using sector, while the last component is the inverse of the value added share of the producing sector. The implied decomposition of the exponential growth rate of this share is:

$$g_{p_{I_i} I_i^j / p_V V_i} = g_{p_{I_i} I_i^j / p_I I^j} + g_{p_I I^j / p_V V_j} + (g_{p_V V_j / p_V V} - g_{p_V V_i / p_V V})$$

Therefore, the growth of the share of type-i intermediates that are used by sector j in the producing sector's value added is driven by the pure substitution that the using sector undergoes in terms of the mix of intermediates that it uses, the substitution between intermediates and primary inputs and finally the relative size of the using sector.

Both sectors' final output is used increasingly by services as intermediates. In particular, the share of the goods-sector final output that is used by services grows at 1.17% annually. The share of the services-sector final output used by goods grows at -1.96%. The relative size of the services-sector grows at an annual rate of 2.77%.

However, the data of Table 3.5 do suggest that the change in the size of the goods and services-sectors alone, is not the only driver of the substitution of goods-intermediates with the services ones. Both sectors have decreased their use share of goods-intermediates and the average negative growth was stronger for the services-sectors. Also, both sectors have decreased their share of intermediates in value added.

The downward trend in the goods-intermediates use share is statistically significant. For the entire 1971-2004 period, a linear trend model fits the goods-intermediates use share data almost perfectly (R^2=0.99). It identifies a statistically significant negative trend for the expenditure share of goods-intermediates. This equals -1.15% (s.e. 0.07) for the services-sector and -0.41% (s.e. 0.07) for the goods-sector. Alternatively, when controlling for a set of time-dummies one can identify the time period that drives this negative trend. This shows that the only period that the share was actually increasing was in the period of the oil-shocks (1974-1982). During this period there was a big increase in the goods-intermediates prices (especially energy). Overall though, the trend is negative and indicates a statistically significant fall of this share by 6 pp over the entire period.

Industry-level analysis

The data support that there is a significant negative trend in the expenditure share of goods-intermediates at the aggregate and sector-level. The next step is to confirm that this trend is present also at the more detailed industry-level. That would confirm that the trend present at a higher level of aggregation is driven by similar patterns of the individual industries within each sector, rather than changes in their relative size. Appendix B.1 provides details regarding how the sector-level share in goods-intermediates is decomposed between the size and the substitution effect.

Figure 3.3 presents the dispersion of the data for the 40 industries at the two and three-digit level selected (23 goods industries and 17 services), along with the trends at the sector-level calculated expenditure share of goods-intermediates. Two properties of the industry-level data come out. First, for both sectors this aggregation level reveals also a falling trend in the expenditure share for goods-intermediates. Second, there is greater variation among industries in the services-sector.

Figures 3.4 and 3.5 illustrate how the goods and services (respectively) sector-level growth of the goods-intermediates use share is decomposed into the "within-industry" and "between-industry" effects. In both cases, the within-industry effect accounts almost completely for the sector-level growth data. In particular, the industry-level growth rates of the goods-intermediates growth share account for 98% (statistically significant) of the variation of the sector-level growth, for both goods and services. The between-industry effect is bigger in the services-sector. The growth rates of the intermediates use shares at the services-sector industry-level can account up to 40% of the services-sector goods-intermediates use share.

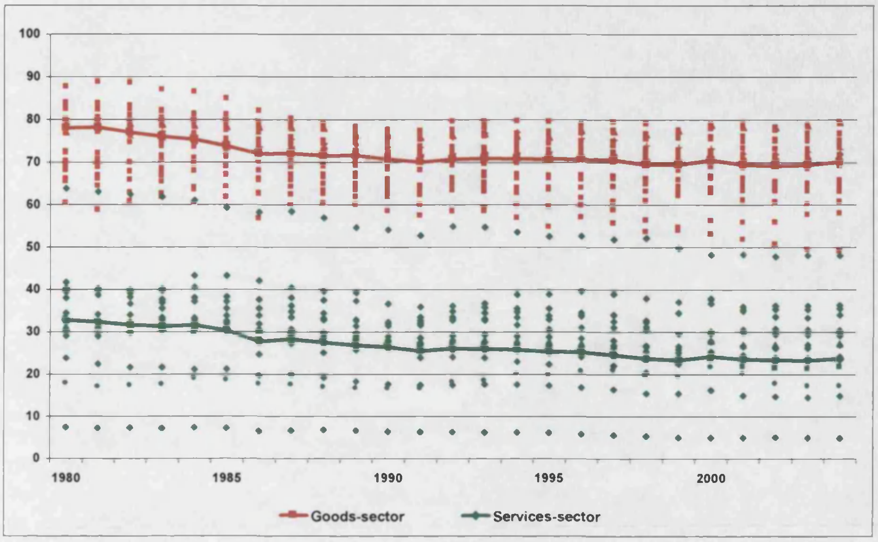


Figure 3.3: United States use share of goods-intermediates (industry/ sector)

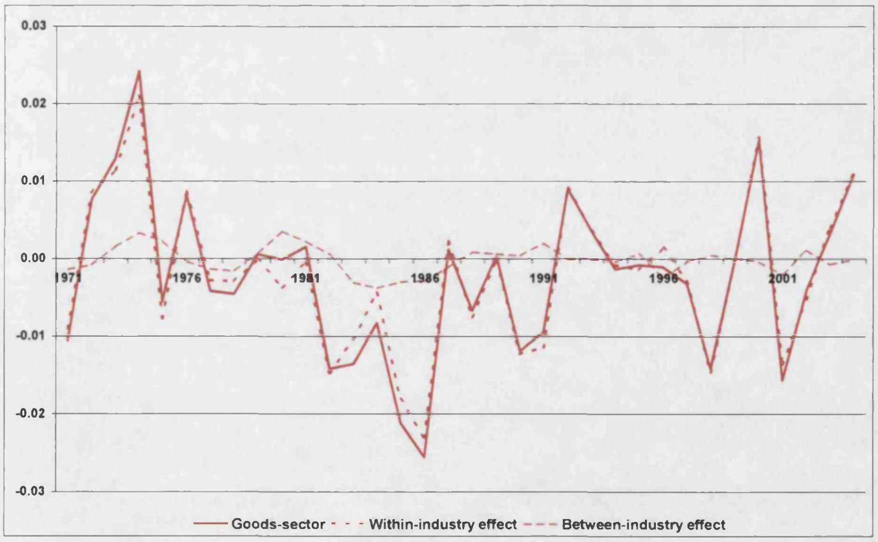


Figure 3.4: United States decomposition of the growth of the goods-sector's goods-intermediates use share

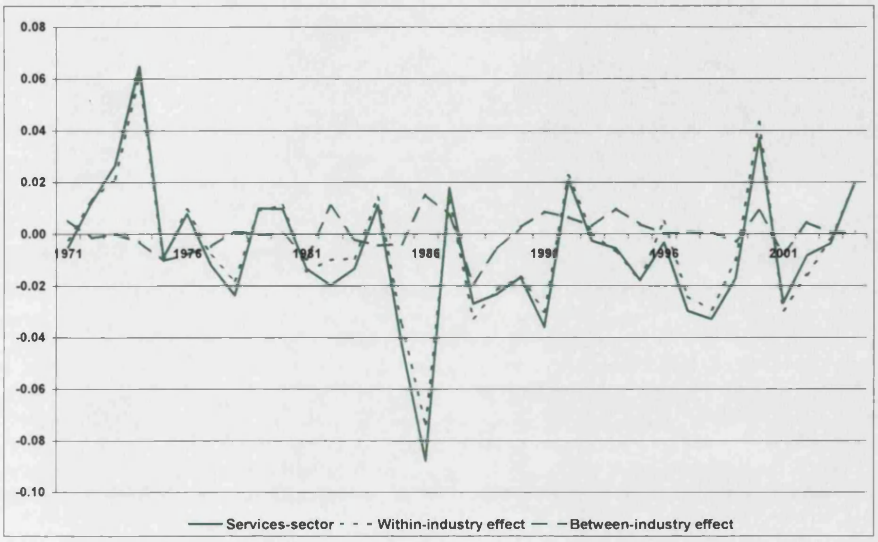


Figure 3.5: United States decomposition of the growth of the services-sector's goods-intermediates use share

In order to complete the analysis, Table 3.6 summarizes the information from the industry-level data regarding the existence of a substitution between goods and services-intermediates and the statistical significance of it. It presents the result of regressions of the logarithm of the goods-intermediates use share (γ_{it}) on a linear trend. Specification (1) uncovers a statistically significant decrease of the goods-intermediates use share for the average industry in the economy. Controlling for the variation at the sector-level accounts for 70% of the original industry-level variation. Specification (3) shows that the industries have different shares on average, but share a common trend. Finally, specification (4) is presented for comparison reasons and shows the overall variation at the industry level if an industry-specific linear model is applied[24].

To conclude, this evidence confirms that the existence of a substitution of

[24]The hypothesis of the existence of a common trend among industries in the same group is rejected at 5%. For identification purposes, in the analysis that follows, the common slope hypothesis is maintained, in order to exploit the within-industry source of variation.

Table 3.6: United States industry-level trends in the goods-intermediates use share

Dependent variable: $\ln \gamma_{it}$				
Controls:	(1)	(2)	(3)	(4)
constant	x	x	x	x
trend	x	x	x	
sector-trend		x	x	
industry fixed-effects			x	x
industry-trends				x
obs	1330	1330	1330	1330
$\bar{R}^2$	0.01	0.71	0.98	0.99
F-test	12.28	1073.83	2054.65	2261.99
Implied average annual trend (%) in industry group				
Goods-sector	−0.53 (0.15)***	−0.32 (0.11)***	−0.32 (0.03)***	-
Services-sector	−0.53 (0.15)***	−0.86 (0.13)***	−0.86 (0.03)***	-

Notes: s.e. in parentheses

(***) denotes significance at the 1%; (x) denotes inclusion of control(s)

goods-intermediates with services-intermediates at the sector level is originated at the industry-level. On average, the linear trend implies that there was a statistically significant fall in the goods-intermediates of 4 pp during the 1985-2004 period.

Econometric analysis

There are two main assumptions made in order to be able to analyze the intermediates' allocation decisions across industries and over time:

First, every industry's gross output production function is a homogeneous of degree one function of the primary inputs , capital and labour and the secondary, intermediate inputs and separable in its value added and intermediates component, i.e. $Y_i = F\left(VA^i(K,L), I^i(I_G, I_S)\right)$. This specification is consistent with the growth accounting framework. Each of the two components of the gross output production function, value added $VA^i(K,L)$ and intermediates $I^i(I_G, I_S)$, is also a homogeneous of degree one function of the respective inputs in production. These two assumptions on the production technology allow for the industry production control problem to take place in two stages. In the first one, there is decision about the level of intermediate inputs required to be combined with the primary inputs. In the second one, described in (3.1), the mix of the two types of intermediates is decided.

Second, there are perfect input and output markets, which is also an important assumption maintained in standard growth accounting. Given the assumption of perfect output markets, the prices of intermediates match the marginal costs in their production. Under perfect input markets, the different industries compete in the market for the available supply of intermediates and in equilibrium the price equates the marginal rates of transformation in their own production between the two types of intermediates[25]. Under these assumptions, the following industry-level allocation problem is summarized as follows:

Each industry i, belonging to sector $j \in \{G, S\}$, at every point in time chooses its demand of either type of intermediates (goods, I_G^i, and services, I_S^i), given their prices (p_{I_G}, p_{I_S})[26], its own productivity in using goods-intermediates (A_G^i) and services-intermediates (A_S^i) and the level of the total expenditure for intermediate inputs, $p_I I^i$:

$$\max_{\{I_G^i,\, I_S^i\}} \left\{ \left[\theta_i \left(A_G^i I_G^i\right)^{\rho_j} + (1-\theta_i)\left(A_S^i I_S^i\right)^{\rho_j}\right]^{\frac{1}{\rho_j}} ;\ p_I I^i = p_{I_G} I_G^i + p_{I_S} I_S^i \right\} \tag{3.1}$$

, where θ_i is a distribution parameter and ρ_j, $\rho_j < 1$, is a parameter specifying the elasticity of substitution of the two types of intermediates, $\sigma_j = \frac{1}{1-\rho_j}$; $\sigma_j > 0$.

[25] This assumption is consistent with the way that National Accounts construct the series of intermediates' prices.

[26] Every industry takes as given the "price" of its own intermediates "basket" used in production, where in the problem specification is normalised to 1.

The solution of the allocation problem (3.1) gives the following condition that describes the relative demand of the two types of intermediates for every industry:

$$\frac{I_S^i}{I_G^i} = \left(\frac{1-\theta_i}{\theta_i}\frac{p_{I_G}}{p_{I_S}}\right)^{\sigma_j}\left(\frac{A_S^i}{A_G^i}\right)^{\sigma_j - 1}$$

Therefore, for industry i, the goods-intermediates' use share, $\gamma_i \equiv \frac{p_G I_G^i}{p_G I_G^i + p_S I_S^i}$, grows at rate, g_{γ_i}, characterized by:

$$\frac{g_{\gamma_i}}{1-\gamma_i} = (1-\sigma_j) g_{\frac{p_{I_G}}{p_{I_S}}} + (1-\sigma_j)\, g_{\frac{A_S^i}{A_G^i}} \tag{3.2}$$

, where $g_{\frac{p_{I_G}}{p_{I_S}}}$ is the growth of the relative prices of goods-intermediates and $g_{\frac{A_S^i}{A_G^i}}$ is the growth of the relative productivity of the services-intermediates. For no change in the productivity in using the intermediates, i.e. $g_{\frac{A_S^i}{A_G^i}} = 0$, then the falling prices for the goods-intermediates imply that the use share of goods-intermediates decreases over time, only if the two types of intermediates are gross substitutes, i.e. when $\sigma_j < 1$. When there is scope for technical progress, then the observed patterns of the data would only be consistent with a lower relative productivity of the services-intermediates when $\sigma_j < 1$, or a higher relative productivity of the services-intermediates when $\sigma_j > 1$[27].

The factor augmenting technical progress is assumed to be industry-specific. This assumption allows for the productivity of each unit of intermediate resources of the same type to vary across industries and intends to account for the fact that the use of every type of intermediates has a "special" use for every industry that is related to its own production structure and needs. The progress in the factor augmenting technology is assumed to be exogenous to each industry[28]. Given the

[27] This result is driven by using the data on prices and shares to solve condition (3.2) for the locus of the potential combinations of $\left(\sigma_j, g_{A_S^i/A_G^i}\right)$.

[28] Therefore, this specification abstracts from a case that every industry responds to market

assumption on perfect input markets and the industry-specific factor augmenting technology, the prices of intermediates are set through the competition of the different industries to get intermediates that have a use that is specific to their production needs and equilibrium prices cannot capture the efficiency of each industry in combining and using the different types of intermediates. Hence, there is a separate role for the technology that is entirely from the demand-side. This assumption, arguably very restrictive, together with the assumption that there is perfect competition on the supply side, allows identification of the parameters of interest of the empirical specification suggested by (3.2) and using the available panel data.

Using time-series data in order to econometrically identify the role of technology and prices in determining the patterns of intermediates' use, however runs into an identification problem discussed in-depth in the seminal work of Diamond, McFadden, and Rodriguez (1978). They show that when using time-series data, the elasticity of substitution between two factors of production cannot be identified when employing a general neoclassical production function which allows for technical progress. Assuming factor augmenting technical progress reduces the non-identification problem, as it puts more structure to the expected observed patterns of the data, but does not resolve the non-identification problem. Employing a CES production function puts further structure to the data as it reduces the estimation of elasticity to the estimation of a single parameter[29]. Furthermore, one requires further assumptions regarding the form of the factor augmenting technical progress in order to reach to a separate identification between the elasticity

conditions and develops technology that is directed at specific factors in its production (in the spirit of Acemoglu (2002)). This is due to lack of data at the industry-level regarding research and development.

[29] Allowing for a production function different than a standard Cobb-Douglas and common production function across all industries within the same sector is regarded as reasonable here given the characteristics of the data as described in the pervious Sections.

of substitution and the factor augmenting technical progress. In particular, the rates of change for the factor augmenting technology are assumed to be unknown linear functions of time. The specific functional forms employed in the econometric analysis are further discussed in detail below[30].

The assumptions described above, together with the use of data that have industry-level and time variation allows for the identification of the parameter of interest. At the industry-level, the relative prices of the goods-intermediates vary across industries, because in practice every industry uses a distinct variety of each type of intermediates (goods or services). As a result, there is variation in prices that is specific to the industry that allows for unbiased estimates of the underlying true correlation between relative prices and the goods-intermediates' expenditure share growth.

Condition (3.2) suggests the following regression specification:

$$\left(\frac{g_\gamma}{1-\gamma}\right)_{ijt} = b_1 g_{\frac{p_G}{p_S}it} + b_2\left(g_{\frac{p_G}{p_S}it} * D_j\right) + x'_{ijt} b_3 + \varepsilon_{ijt};\ i = 1..N,\ j \in \{G, S\},\ t = 1...T \tag{3.3}$$

The coefficient b_1 corresponds to an estimate of $(1 - \sigma_S)$, while b_2 estimates $\sigma_S - \sigma_G$. The control vector x'_{ijt} accounts for the evolution of technological (or other) factors related to the use of intermediates. In different specifications, different assumptions are employed regarding their source of variation, and where appropriate a set of these controls is considered at the same time. The following variables can be elements of the control vector. First, a constant accounts for factors fixed over time and common across all industries. Second, a sector fixed-effect accounts for factors fixed over time, different across sectors, but common across industries in the same sector. Third, a set of industry-specific fixed-effects

[30] Appendix B.2 presents the results from aggregate-level data applied on the relevant empirical specification as implied by (3.2) and the availability of information. The results suggest some bounds one the expected variation in the full-information panel data set.

accounts for factors fixed over time that differ across industries. Fourth, a sector-specific linear trend accounts for factors that evolve at a fixed rate over time, and which are common across all industries in the same sector, but different across sectors. Fifth, a set of industry-specific linear trends that accounts for a set of factors that evolve at a fixed rate over time.

Details on the availability of data on intermediates' prices are found in Appendix B.3. Table 3.7 summarizes the results, when the control is the growth in goods-intermediates relative prices with only time variation. When growth in the relative prices of intermediates is common across industries, then the time variation captured by them cannot be distinguished from other factors that can have the same source of variation. In particular, the relative prices would be collinear with a set of time fixed-effects that account for year-specific common shocks across different industries. Table 3.8 repeats the exercise, when the control is the growth in goods-intermediates relative prices with both time and industry variation. This allows scope for examining the role of time-varying factors common across industries, other than the relative prices of the intermediates.

The regressions of Table 3.7, show that controlling for sector or industry fixed-effects does not reveal a different degree of substitution between the goods and services-intermediates across the two sectors. The implied elasticity of substitution is below one, statistically significant, and does not vary significantly across specifications. The evidence with respect to the role of additional factors affecting the growth in the expenditure share of goods-intermediates indicates that there is role for a common constant factor across industries in the economy (specification (1)). Specification (2) shows that this is driven by the variation coming from the services-sector industries. Controlling for industry-specific characteristics eliminates the statistical importance of such factors, whether constant or time varying.

Overall, the results are rather inconclusive[31].

The regressions of Table 3.8, show that the model's overall fit is improved substantially when exploiting the information regarding the different relative prices of goods and services-intermediates across industries. Nevertheless, similar to the regressions of Table 3.7, most of the specifications do not identify any statistically significant difference in the degree of substitution of the two types of intermediates across the two sectors. Importantly, in all specifications the implied elasticity of substitution is below one. The only case that a difference is identified, is in specification (7), where there is control for the sector and industry-level time fixed-effects. Then the estimated elasticity comes out to be higher for the goods-sector, but still below one. The estimated effect of the growth in relative prices for the services-sector is relatively more sensitive now to the inclusion of alternative controls, driven by the higher variation observed across the services-industries. The estimated elasticity is bounded between 0.3 and 0.5.

All specifications indicate the scope for additional factors being important in determining the use patterns of intermediates across industries. Consistent with the descriptive evidence provided in the earlier sections, the estimation suggests that factors are industry-specific rather. Therefore, while the explanatory power of the relative prices survives in accounting for the industries' patterns in using intermediates, there are additional factors that are to be identified at the industry-level affecting the choice of the used "basket" of intermediates.

[31] Given the estimated $b_1 = 1 - \sigma$ and the constant in specification (1), condition (3.2) implies $g_{\frac{A_S}{A_G}}$ = -0.84%. Hence, it suggests that on average the industries experience technical progress in using the relatively inexpensive goods-intermediates.

Table 3.7: United States goods and services industry-level regressions when prices have only time variatiation

Dependent variable: $\left(\frac{g_\gamma}{1-\gamma}\right)_{jit}$

Controls:	(1)	(2)	(3)	(4)	(5)
constant	-0.005 (0.001)***	-0.006 (0.002)**			
$g_{\frac{PG}{PS}t}$	0.598 (0.050)***	0.542 (0.080)***	0.543 (0.080)***	0.541 (0.083)***	0.541 (0.084)***
D_j		0.000 (0.003)			
$g_{\frac{PG}{PS}t} * D_j$		0.091 (0.103)	0.092 (0.103)	0.138 (0.108)	0.138 (0.108)
industry fixed-effects			yes	yes	yes
trend				-0.000 (0.000)	
trend $* D_j$				0.000 (0.000)	
*trend * industry fixed-effects*					yes
obs	1292	1292	1292	1292	1292
$\bar{R}^2$	0.10	0.10	0.11	0.10	0.09
$F - test$	142.36	47.68	5.11	4.40	2.63
implied σ_S	0.40 (0.050)***	0.46 (0.080)***	0.46 (0.080)***	0.46 (0.084)***	0.46 (0.084)***
implied σ_G	0.40 (0.050)***	0.37 (0.064)***	0.37 (0.064)***	0.32 (0.068)***	0.32 (0.068)***

Notes: s.e. in parentheses, (***) denotes significance at 1%, (**) at 5%, (*) at 10%

(yes) denotes control for fixed-effects; (yes**) denotes the F-test rejects the H_0 of no joint-significance at 5%

Table 3.8: United States goods and services industry-level regressions when prices have time-industry variation

Dependent variable: $\left(\frac{g_\gamma}{1-\gamma}\right)_{jit}$

Controls:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
constant	−0.006	−0.005					
	(0.001)***	(0.002)*					
$g_{\frac{p_G}{p_S}it}$	0.484	0.478	0.568	0.624	0.734	0.565	0.697
	(0.030)***	(0.052)***	(0.055)***	(0.060)***	(0.063)***	(0.056)***	(0.076)***
D_j		−0.002					
		(0.003)					
$g_{\frac{p_G}{p_S}it}*D_j$		0.011	−0.036	−0.049	−0.119	−0.068	−0.242
		(0.064)	(0.067)	(0.072)	(0.075)	(0.057)	(0.087)***
industry fixed-effects			yes**	yes**	yes**	yes**	yes**
trend				0.001			
				(0.000)**			
$trend * D_j$				0.000			
				(0.000)			
*trend * industry fixed-effects*					yes**		
time fixed-effects						yes**	yes**
time fixed-effects * D_j							yes**
obs	1292	1292	1292	1292	1292	1292	1292
$\bar{R}^2$	0.16	0.16	0.20	0.21	0.24	0.44	0.45
$F - test$	255.99	85.35	9.32	9.41	6.12	14.99	11.13
implied σ_S	0.52	0.52	0.43	0.38	0.27	0.44	0.30
	(0.030)***	(0.052)***	(0.055)***	(0.060)***	(0.063)***	(0.056)***	(0.076)***
implied σ_G	0.52	0.51	0.47	0.43	0.39	0.50	0.55
	(0.030)***	(0.037)***	(0.038)***	(0.040)***	(0.040)***	(0.039)***	(0.041)***

Notes: s.e. in parentheses, (***) denotes significance at 1%, (**) at 5%, (*) at 10%

(yes) denotes control for fixed-effects; (yes**) denotes the F-test rejects the H0 of no joint-significance at 5%

Information and Communication Technologies sector

A set of industries that have gained a lot of attention in the productivity literature (Oliner and Sichel 2002, Bosworth and Triplett 2004, Jorgenson, Ho, and Stiroh 2005b) are the industries that produce Information and Communication Technologies (ICT)[32]. The question addressed is whether this newly developed and fast growing sector has a different behavior compared to the average industry of the United States with respect to the use of the goods and services-intermediates. A first inspection of the data indicates that the answer is positive. Figure 3.6 shows how the ICT-producing sector compares to the aggregate economy in terms of the use share of goods-intermediates. It shows that this set of industries have actually increased their use share of goods-intermediates during the first period of high growth of this sector, 1985-1995. In the 1995-2004 period, the trend in the use share matches the one in aggregate economy. Figure 3.7 shows the same picture when inspecting separately the goods and services ICT-producing industries. The average annual growth of the goods-intermediates use share during the 1981-2004 for the goods ICT-producing industries is 0.07%, while for the services ones is 0.47%. These contrast to the goods and services-sector trends that were presented in Table 3.5.

The next step is to investigate whether there is support for a different elasticity of substitution between the goods and services-intermediates for this particular set of industries. Specification (7) of Table 3.8 was applied with the addition of the interaction between the goods-intermediates relative price growth and a dummy that takes the value of one to indicate an ICT-producing industry. The explanatory

[32]The ICT-producing manufacturers include: "Office, accounting and computing machinery" (30), "Insulated wire" (313), "Radio, television and communication equipment" (32). The ICT-producing services include "Computer and related services" (72).

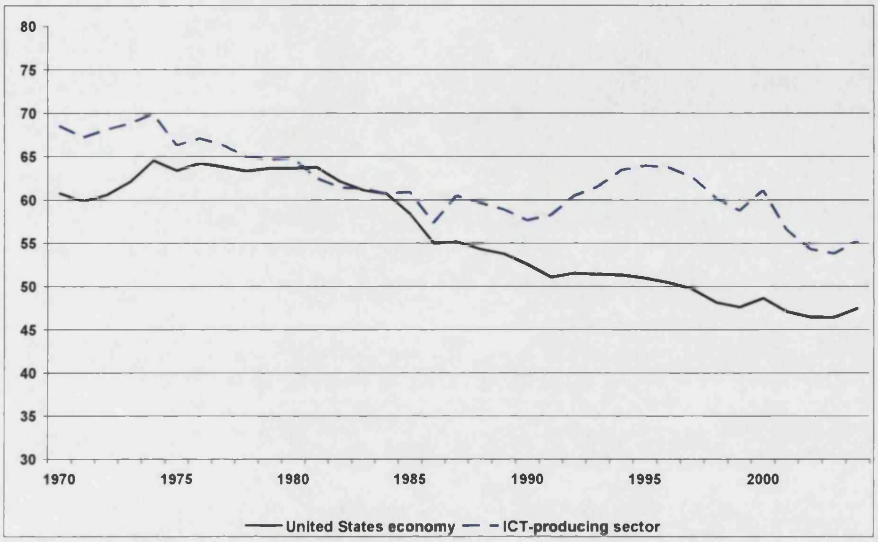


Figure 3.6: United States economy and ICT-producing sector goods-intermediates use share

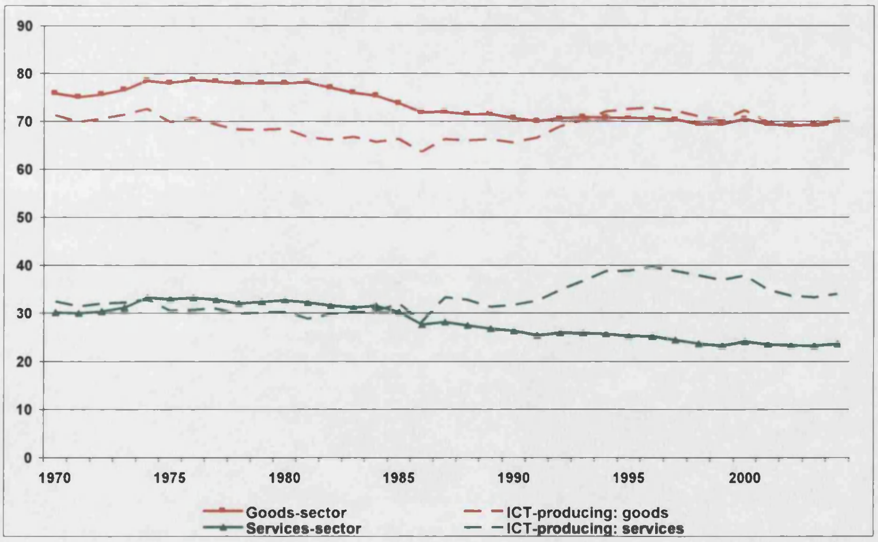


Figure 3.7: Goods-intermediates use share at the goods and services sector-level decomposition of the ICT-producing sector

power of the regression model increases with this additional control ($\bar{R}^2 = 0.47$) and the interaction term is statistically significant. The estimated elasticity of substitution for the non-ICT-producing services-sector now falls to 0.08 (s.e. 0.08), that of non-ICT-producing goods-sector to 0.46 (s.e. 0.04) and that of the ICT-producing sector is 0.61 (s.e. 0.09). This suggests that the exclusion of the services ICT-producing industries affects the inference made from the sample, while this is not the case for the goods-sector[33]. Nevertheless, the estimates are still in the direction that is compatible with economic theory, i.e. disclosing a very low substitution between goods and services-intermediates in the presence of falling relative prices of the goods-intermediates.

3.2.5 The United Kingdom economy

This Section investigates the patterns of intermediates use for the United Kingdom economy by applying the methodology followed in Section 3.2.4. The results are contrasted to the ones that were derived from the analysis of the United States economy.

Sector-level analysis

The composition of every unit of gross output production in the United Kingdom economy in terms of intermediates and value added during the period 1980-2004 shows that in contrast to the United States, the intermediate inputs share is higher than that of value added. The trends of these shares are similar to the United States, with the share of intermediates decreasing by 5 pp. (from 57% to 52%)

[33] If the same specification controls for the sector within the ICT-producing sector, the estimated elasticities of substitution are the following: 0.49 (s.e. 0.04) for the goods non-ICT-producing sector, 0.37 (s.e. 0.13) for the goods ICT-producing sector, 0.75 (s.e. 0.10) for the services ICT-producing sector and not statisticaly significant for the services non-ICT-producing sector.

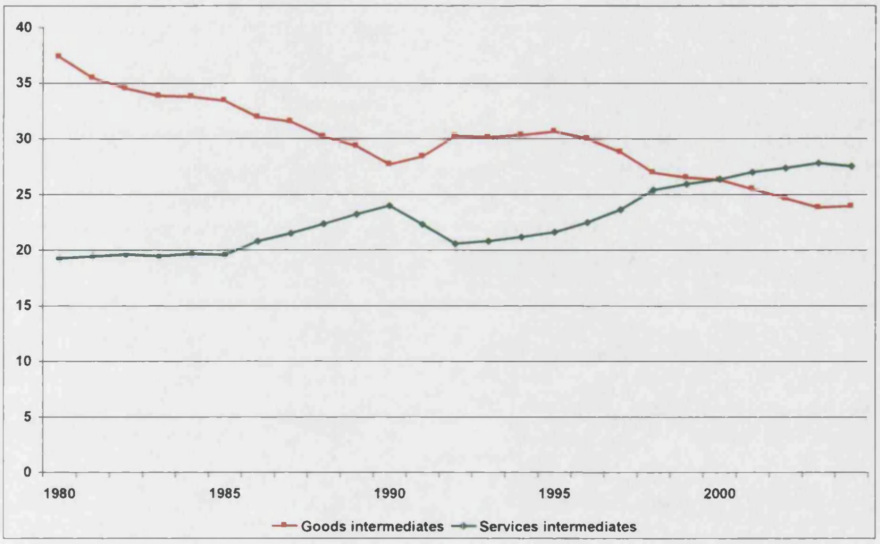


Figure 3.8: United Kingdom composition of gross output in terms of goods and services-intermediates

and that of value added increasing by the same magnitude (from 43% to 48%).

The composition of the gross output in terms of goods and services-intermediates reveals similar trends to the United States, with an increasing share of services-intermediates in gross output. By 2004, 28 p. of every pound-worth of production was spend on services-intermediates (Figure 3.8).

Table 3.9 shows that similar to the United States, the goods-sector in the United Kingdom decreases in "size" over time. However, the revealed trend of this change is stronger for the United Kingdom. Along with its increasing share in the final output, the services-sector has caught up with the goods-sector in terms of its share in the production and use of intermediates in the economy.

Table 3.10 presents the composition of the goods and services-sector gross output in terms value added and intermediate inputs, as well as goods and services-intermediates for selected years. It shows that first, like for the United States, goods-sector uses more intermediates compared to the services-sector. Also, the

Table 3.9: United Kingdom goods and services-sector value added and gross output shares

Sector shares in	Value added		Gross output	
year	Goods	Services	Goods	Services
1980	49.4	50.6	59.7	40.3
1985	46.6	53.4	61.6	38.4
1990	39.5	60.5	52.5	47.5
1995	35.2	64.8	45.0	55.0
2000	30.0	70.0	37.9	62.1
2004	25.8	74.2	33.8	66.2

goods-sector uses more goods-intermediates, while the services-sector uses more of services-intermediates.

The trends revealed from the sector-level data though point out to differences compared to the United States goods and services-sector. For both sectors there is only 1 pp. decrease in the share of total intermediate inputs used over the period 1980-2004. The striking difference comes from the behavior of the goods-sector, where the share of goods-intermediates essentially varies around the same level over time. Only in the services-sector there is a substitution of goods-intermediates with the services-intermediates by 9 pp., which is stronger compared to the United States. However, any conclusions derived from this first inspection of the data may be erroneous as there is a big scope for noise that is introduced by the data breakpoint in 1992. In the analysis of the time series properties of the data that follows, there is explicit account for any data considerations.

Table 3.11 presents the decomposition of the goods and services-intermediates share in value added of the using sectors, goods and services for the 1992-2004 period. In most respects, the behavior of the goods and services-sectors in the United Kingdom follows closely that of the United States (see Table 3.5). Like for the United States there is an undergoing substitution of goods-intermediates with the services ones. The substitution pattern is stronger for the United Kingdom

Table 3.10: United Kingdom goods and services-sector gross output composition

Gross output composition						
	Value added		Goods-Intermediates		Services-Intermediates	
year/ sector	Goods	Services	Goods	Services	Goods	Services
1980	35.9	54.5	49.7	19.1	14.4	26.4
1985	39.2	57.0	48.5	14.2	12.3	28.8
1990	38.8	57.7	45.7	10.1	15.5	32.2
1995	37.4	56.2	51.1	13.9	11.6	29.8
2000	37.4	53.4	49.1	12.3	13.4	34.3
2004	37.1	54.3	49.6	10.8	13.2	34.8

services-sector. Unlike the United States though, in both sectors the intermediate inputs had a stronger growth compared to the sector value added.

At the same time, the share of services-intermediates used by goods to services value added had an average annual growth of -2.29% over this period (-4.77% for 1981-2004). The share of the goods-intermediates used by services to the value added of goods had an average annual growth of 2.34% (1.95% for 1981-2004). These production patterns are mainly driven by the relative sizes of the services-sector that had average annual growth of 3.84% (4.29% for 1981-2004).

As expected, the data breakpoint in 1992 affects importantly the results obtained if the data for whole 1981-2004 period are considered. In this case, the data would support still a strong substitution of the goods-intermediates with services ones for the services-sector (-2.37%). However, they would indicate that the goods-intermediates use share has stayed constant for the goods-sector (0.07%).

To conclude, the analysis so far points out that in contrast to the United States, there is a bigger role for the size effect. In terms of the sector-level data, there is indication of substitution of goods-intermediates with services ones by both goods and services-sector. The data support that there is an important break in 1992 that needs to be accounted for by applying different trend model over the two sample periods (1970-1991, 1992-2004). This substitution is stronger for both sectors for

Table 3.11: United States trends in the goods and services-sector shares of intermediates in value added and their decomposition

Sector using intermediates:	Goods		Services	
Goods-intermediates share in value added	$\frac{p_{I_G} I_G^G}{p_V V_G}$	0.26	$\frac{p_{I_G} I_G^S}{p_V V_s}$	-1.50
contribution by:				
expenditure share of goods-intermediates	$\frac{p_{I_G} I_G^G}{p_I I^G}$	-0.26	$\frac{p_{I_G} I_G^S}{p_I I^S}$	-2.73
all intermediates share in value added	$\frac{p_I I^G}{p_V V_G}$	0.56	$\frac{p_I I^S}{p_V V_S}$	1.23
Services-intermediates share in value added	$\frac{p_{I_S} I_S^G}{p_V V_G}$	1.55	$\frac{p_{I_S} I_S^S}{p_V V_S}$	2.31
contribution by:				
expenditure share of services-intermediates	$\frac{p_{I_S} I_S^G}{p_I I^G}$	1.03	$\frac{p_{I_S} I_S^S}{p_I I^S}$	1.07
all intermediates share in value added	$\frac{p_I I^G}{p_V V_G}$	0.52	$\frac{p_I I^S}{p_V V_S}$	1.23

Notes: units in 1993-2004 average annual exponential growth (%)

the 1992-2004 period. While the goods-sector has similar behavior as in the United States, the services-sector has shifted more towards using services-intermediates. In particular, for the goods-sector there is no statistically significant trend in the goods-intermediates use share of -0.12% (s.e. 0.11) for the 1970-1991 period that turns significant and equal to -0.4% (s.e. 0.07) for the 1992-2004 period. For the services-sector the change is always statistically significant increasing from -2.12% (s.e. 0.40) to -3.21% (s.e. 0.19)[34].

Industry-level analysis

Figure 3.9 reveals that the industry-level variation in the United Kingdom economy is high, especially for the services-sector. This can generate additional noise that can affect any conclusions drawn at a higher level of aggregation.

Figures 3.10 and 3.11 present the decomposition of the within-industry and between-industry effect in determining the sector-level growth in the use share of goods-intermediates. The within-industry effect still accounts for most of the

[34]Applying the linear trend model in the 1992-2004 subsample for the United States, reveals milder trends rather than the whole sample estimation: -1.01% (s.e. 0.14) for services and -0.18% (s.e. 0.05) for goods.

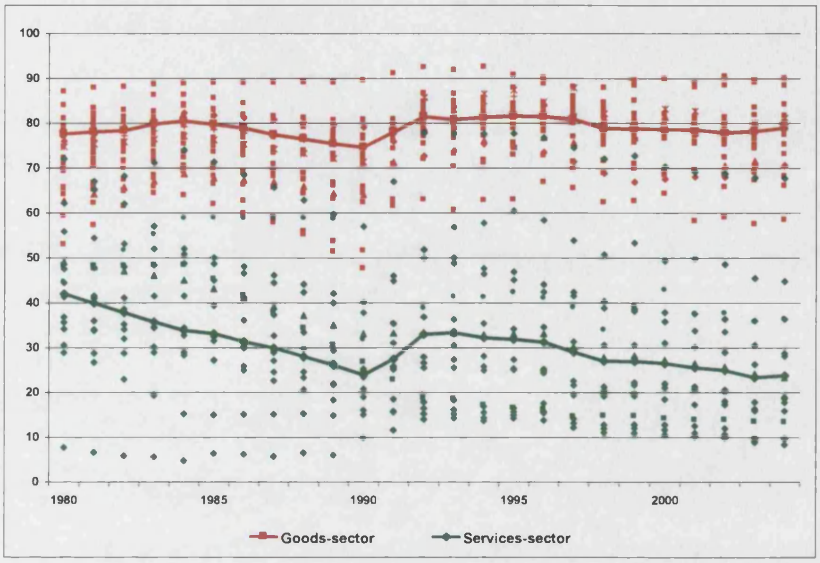


Figure 3.9: United Kingdom use share of goods-intermediates (industry/ sector)

original variation (99% for the goods-sector and 95% for the services-sector). The between-industry effect is much stronger for the services-sector (explains 46% of the original variation) as opposed for the goods-sector (5%). Apart from the clear spikes in the data in 1971 and 1992, there is greater between-industry variation during the post-1992 period. In particular, while the within-effect is almost the same over the two periods for both goods and services industries, the role of the between-effect increases significantly post-1992, and particularly so for services (its explanatory power increases from 20% to 46%).

Finally, Table 3.12 presents the statistical importance of the underlying trends at the industry-level data[35]. Similar to the United States, there is a lot of industry-level variation that needs to be controlled for in order to disclose the underlying trend in the data. In all cases, the data point out to important differences in trends across sectors and across the two sample periods.

[35]The linear trend model with no additional controls has a very low explanatory power ($\bar{R}^2$=0.01).

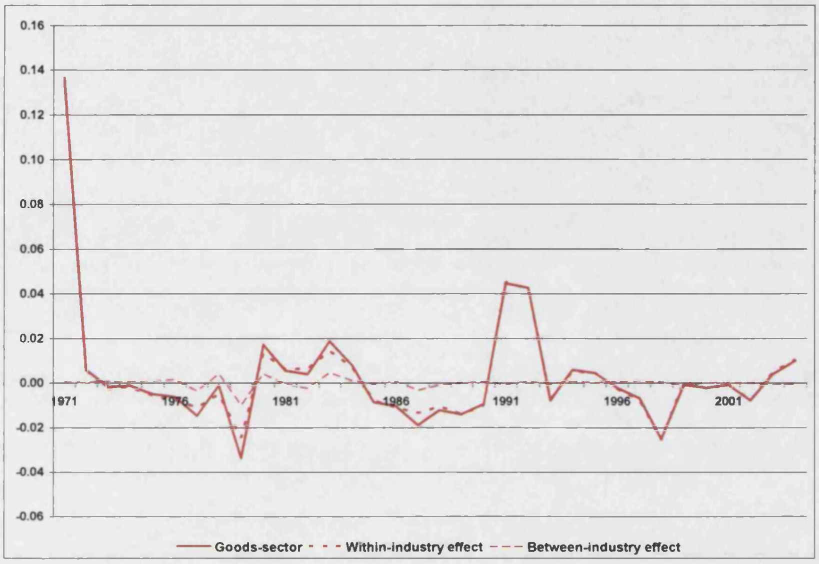


Figure 3.10: United Kingdom decomposition of the growth of the goods-sector's goods-intermediates use share

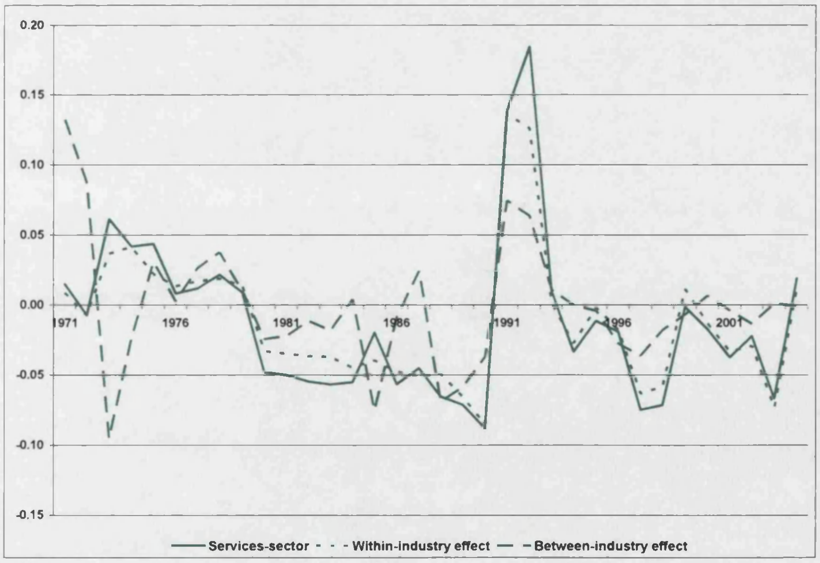


Figure 3.11: United Kingdom decomposition of the growth of the services-sector's goods-intermediates use share

Table 3.12: United Kingdom industry-level trends in the goods-intermediates use share

Dependent variable: $\ln \gamma_{it}$						
Controls:	(1)	(2)	(3)		(4)	
			pre-'92	post-'92	pre-'92	post-'92
constant	x	x	x		x	
trend	x	x	x			
sector-trend		x	x			
industry fixed-effects			x		x	
industry-trends					x	
obs	1330	1330	836	494	836	494
$\bar{R}^2$	0.01	0.66	0.92	0.99	0.95	0.99
F-test	19.01	867.94	246.96	1394.45	198.12	1769.84
Implied average annual trend (%) in industry group						
Goods-sector	−0.65 (0.15)***	0.15 (0.11)***	−0.20 (0.10)**	−0.49 (0.10)***	-	-
Services-sector	−0.65 (0.15)***	−1.90*** (0.14)***	−1.92 (0.12)***	−3.04 (0.12)***	-	-

Notes: s.e. in parentheses, (***) denotes significance at the 1%; (x) denotes inclusion of control(s)

Econometric analysis

The econometric analysis of Section 3.2.4 is repeated for the United Kingdom[36]. However, the regressions would not deliver any significant fit of the regression model. This is due to the presence of high noise in the data, introduced mainly by the data breakpoint of 1992. This mostly affects the application of the sector-level data, due to their very limited time and cross-sectional dimension. Regarding the industry-level data, the only specification that allows for a significant fit is the one that controls for time fixed effects. By doing so, the time dummies absorb the contemporaneous effect of the data breakpoints and allow for the regression to make use of the information in the entire sample. This also indicates that the data breakpoint had a homogeneous and transitory effect rather on the level (not

[36]Measures of the goods-intermediates relative price growth were constructed, in the same way as for the United States (see Section 3.2.4 for details). For all industries in the sample but "Chemicals, rubber, plastics and fuel" and "Wholesale and retail" the relative prices of the goods-intermediates remained flat for the 1970-1979 period. Lack of data is the most likely driver of this result, even though this is yet to be confirmed.

the trend) of the growth variables. Table 3.13 presents the results.

Table 3.13: United Kingdom goods and services industry-level regressions when prices have time-industry variation

Dependent variable: $\left(\frac{g_\gamma}{1-\gamma}\right)_{jit}$		
Controls:	(1)	(2)
$constant$	yes	yes
$g_{\frac{PG}{PS}it}$	0.411 (0.153)***	0.759 (0.204)***
D_j	yes	yes
$g_{\frac{PG}{PS}it} * D_j$	−0.246 (0.155)	−0.623 (0.240)***
$time\ fixed\text{-}effects$	yes**	yes**
$time\ fixed\text{-}effects * D_j$		yes**
obs	1292	1292
$\bar{R}^2$	0.25	0.33
$F-test$	13.19	10.10
$implied\ \sigma_S$	0.59 (0.153)***	0.24 (0.204)***
$implied\ \sigma_G$	0.83 (0.115)***	0.86 (0.126)***

Notes: s.e. in parenthesis, (***) denotes significance at 1%, (**) at 5%, (*) at 10%

(yes) denotes control for fixed-effects; (yes**) denotes the F-test rejects the H0 of no joint-significance at 5%

Specification (1) controls for factors that are common across industries in the same group and constant over time. The sector-level dimension of such factors comes out insignificant[37]. It also allows for time fixed-effects that are common across all industries that capture common macro shocks over time. Controlling for such time-varying trends that are common across industries is not a sufficient statistic for the relative prices of intermediates. This allows for the identification of the elasticity of substitution between the two types of intermediates.

Allowing for common macro shocks that are specific to the sector in specification (2) is important in order to identify the sector-specific elasticities of substitution. The identified elasticities of substitution are in the direction expected. In the presence of falling relative prices of the goods-intermediates, the use share

[37]Using industry fixed-effects is not supported by the data. The joint significance test rejects the importance to control for time-invariant industry-specific factors.

of goods-intermediates falls so long as the goods are gross-substitutes. Moreover, the goods-sector has a significantly higher degree of substitution compared to the services-sector. This is due to the important difference in the time pattern of intermediates use of the two sectors.

3.2.6 Discussion of the results

As already pointed out in Section 3.2, given that the EU KLEMS data base their information on intermediates on the I-O tables, they bare some limitations. Furthermore, these data limit the scope for analysis to (dis)aggregation consistent with the original "EMS". This Section discusses these issues in view of the results reported above. The main highlighted fact is the shift in the demand of intermediates towards services-intermediates. This evidence indirectly gives support to the literature regarding the emergence of services' outsourcing and offshoring in the advanced economies since the 1980s. Such studies mostly focus on computer, engineering and accounting services ("Business services") that are considered directly related to outsourcing. The role of communications, finance and insurance and other services is usually not accounted, because such services inputs are commonly considered as the ones that cannot be produced within the firm.

Given that the focus of this study is the services-intermediates and services-sector as a whole, there may be a concern that the trends in the aggregate data are entirely driven by outsourcing of services, or essentially business services. Overall, the literature on outsourcing and offshoring lacks well-established tools to quantify these issues and the KLEMS, by reporting only intermediates-purchases, limits the scope for such analysis. This Section brings in (admittedly scattered) indirect information regarding the growing importance of the business services in the United States and the United Kingdom. Business services exhibit an outstanding increase in their size in both economies. According to Oulton and Srinivasan (2005) its value added share increased from 6% in 1970 to 17% in 2000 in the United Kingdom, which corresponds to an increase from 12% to 26% share in value added of the services-sector. For the United States, the value added share of business services increased from 6% to 13% during the 1970-2000, which corresponds 11% to 19% increase in its share in value added of the services-sector. At the same time, both of these countries experience a trade surplus in their services.

As an indication of the importance of outsourcing, Strassner, Medeiros, and Smith (2005) report that the outsourcing-related services increased as a share of total services from 30.8 in 1997 to 33.9 in 2004, while the share of outsourcing-related services that were imported increased from 2.1 to 2.7 during the same period. For the same period, the durable goods-producing industries had the largest increases in its share of outsourcing (from 31% to 37%), while the business services have the highest share in outsourcing among all private economies (50%). For the United Kingdom, the report of Abramovsky and Griffith (2007) suggests that the during the 1984-2001 period, growth of specialization and outsourcing contributed 6.5% of total UK output, when services-intermediates overall contributed 19.5%, while on average imported intermediates account for almost 22% of total intermediates expenditures[38]. Moreover, while the increase in outsourcing during 1984-1990 is driven by the goods-producing industries (in particular manufacturing) during , in the 1990s it is driven by services-producing industries.

The afore-summarized evidence suggests that outsourcing has an important role, as it accounts for up to 1/3 of total services-intermediates use. The role of imported services is very limited in the United States compared to the United Kingdom. Overall though, most of the growth of services-intermediates in either

[38]The information regarding the imported intermediates comes from the 1995 detailed Input-Output table.

country is not related to outsourcing for the period under investigation. This suggests that this Chapter's "aggregate-level" evidence does reveal increased demand of services-intermediates. Furthermore, by allowing for industry-specific efficiency in using goods and services-intermediates this Chapter does not preclude important factors for the choice of outsourcing, such as transaction costs and agency issues that are related to firm/ industry-specific characteristics[39].

However, the empirical study of this Chapter shares limitations with studies of outsourcing that are based on the I-O tables in that there is no direct information of the degree of vertical integration of industries. This affects any inference on the degree of services-intermediates (whether or nor directly related to outsourcing) for two reasons. On the one hand, as one cannot measure at all the intermediates produced within the firm, then the actual use of intermediates is mismeasured[40]. This would be particularly important for manufacturing. Its decrease in its use of goods-intermediates may just be driven from an increased vertical integration within the goods-producing sector. On the other hand, as one cannot measure which part of the observed transactions are due to vertical integration across industries, then to the extent that firms are integrated across different industries matters for the observed transaction patterns. Such concerns are for both the domestically produced and the imported intermediates[41].

These issues may be addressed only with the use of plant-level data that provide detailed information on ownership and are ideally linked to the basis of information of I-O Tables. The ONS of the United Kingdom, has micro-level datasets that bear this property. Abramovsky and Griffith (2007) use these data and their findings

[39]Recent examples in this area of theoretical research includes Antràs and Helpman (2004) and Grossman and Helpman (2002).

[40]Note that this suggests that the production of intermediates within the firms is rather accounted as part of the industry's gross value added.

[41]It is worth noting that by not excluding the intra-industry intermediates' transactions, the EU KLEMS does not bias further the inference.

for the 1997-2005 period may be summarized as follows[42]. First, only a small fraction of firms are vertically integrated (around 4% for the goods-sector and 5% for the services-sector in 2005), yet these account for over half of total employment. Second, there is a decrease in the degree of vertical integration in goods-producing industries (manufacturing and utilities) and an increase in the degree of vertical integration in financial intermediation. Third, the proportion of firms that are vertically integrated into outsourcing-related services appears on average higher among services-producing industries[43]. In a study of the United States industries based on the Commodity Flow Survey of the United States Economic Census, Hortaçsu and Syverson (2007) provide with evidence that vertical integration is stable at the aggregate level over the 1977-1997 period. Moreover, the vertically integrated firms are on average larger. Interestingly, only little output of upsteam establishments in vertically integrated structures is shipped in the same firm.

In view of this evidence, for the United States, the restructuing of the industries does not come out as a driving force of the shift of the economy towards using more services-inetermediates. On the other hand there is more role for this factor for the United Kingdom. As discussed further in the following Section, most of the action for the United Kingdom goods-producing industries took place during the 1984-1990 period. Nevertheless, the above evidence suggests that lower vertical integration for the late 1990s period implies, if anything, higher purchases of goods-intermediates in the market. For the services-sector instead this evidence shows that vertical integration implies the observed trend in the data with increased services-expenditure share. To summarize, the restructuring

[42] Within the same context, these data are used also in Aghion, Griffith, and Howitt (2006).

[43] As of 2005 and at the two-digit industry-level, there is evidence that vertical integration is mostly within the same sector, goods or services. This is true also at the two-digit goods-producing industries. For the services-producing industries, they are vertically integarted with the Business Services.

of the industries together with the rising importance of outsourcing and offshoring of services play a role in the trends observed at the aggregate-level of the United Kingdom. This is consistent with the conclusions of this Section regarding the importance of the "production technology effect" and the industry-specific productivity in using intermediates. Further investigation of the importance of these issues is left for future research.

3.3 Impact of the Pattern in Intermediates' Use: An Accounting Exercise

The present Section intends to analyze the impact of the change in intermediates' composition effect for the aggregate economy. First, through growth accounting, it examines the effect of the observed substitution patterns for the aggregate and sector-level unit costs and labour productivity growth. The results are presented only for the United States only, as the conclusions driven for the United Kingdom are qualitatively similar[44]. Second, this Section focuses on the services-sector and uses the estimated elasticities of substitution into the intermediates demand function in order to compare the patterns of intermediates use across the United States and the United Kingdom. The focus on the services-sector is not only due to the large size of the sector, but also because it is the sector that has a substantively different behavior across the two economies. The Section concludes with a discussion of potential drivers of the differences.

[44]There are some small quantitative differences, but they may be driven by the existence of more noise in the United Kingdom economy data.

3.3.1 Unit costs

A sector's gross output price index is an aggregate over the prices of its value added and intermediate inputs. Hence, the current-dollar components of its gross-output can be used to assess the contribution of each component to the gross output price index. Changes in the composition of the current-dollar cost of gross output out of every unit of real gross output affect the contribution of each component to the aggregate price index[45].

Figure 3.12 presents the United States gross output price index and the part of the price index associated with each component. The levels of the individual components show which component is more important in determining the unit cost of every unit of gross output. Their trends over time indicate the contribution of each component to the current-dollar unit cost of gross output, for every real unit of gross output. During the 1981-2004 period, the average gross output price growth was 2.39%, the value added component average growth was 2.88%, the goods-intermediates average growth was 0.63%, while that of services-intermediates was 3.38%. Together with the increasing share of services-intermediates in the gross output, this suggests that the large increase in the cost of services-intermediates became a larger part of the gross output price index of the United States economy compared to that of goods-intermediates.

The same pattern is present when examining the goods and services-sectors. Table 3.14 provides the contribution of each component to the average growth of the gross output price index for goods and services-sectors over the 1981-2004 period. The following facts emerge. First, the services have a higher average growth in their gross output price index. Second, in both sectors the value added component accounts for most of the growth in gross output prices. Third, in both

[45]This is the standard analysis performed by the BEA to account for the different components' contribution to the growth of gross output prices.

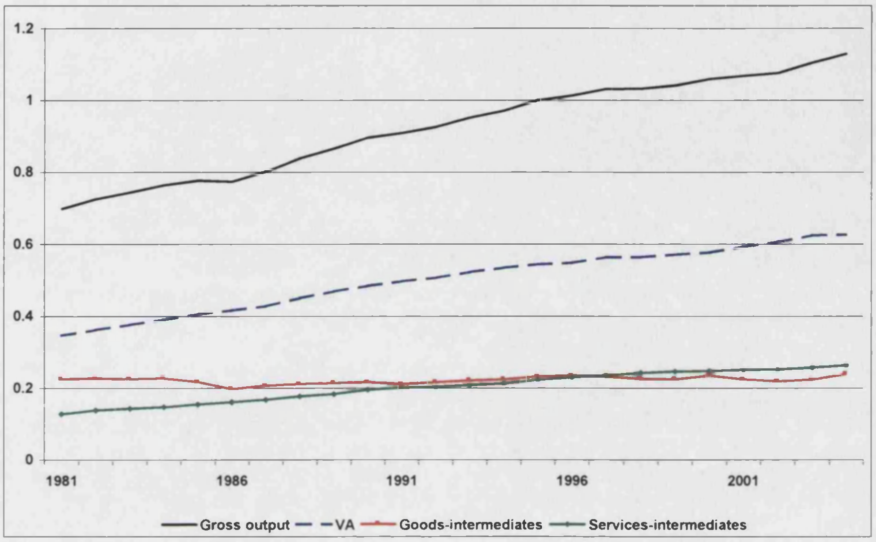


Figure 3.12: United States economy current-dollar cost per unit of real gross output

sectors, but more so in services, the contribution of the services-intermediates is higher than that of goods-intermediates.

Table 3.14: United States gross output price growth decomposition

Sector average growth 1981-2004	Goods	Services
Gross output price index growth	1.57	3.14
contribution by:		
value added	0.75	2.09
goods-intermediates	0.40	0.16
services-intermediates	0.42	0.89

Nevertheless, when accounting for the extent to which the change in the composition of the intermediates has affected the average growth of the aggregate price growth of gross output, it comes out that this effect is quantitatively insignificant[46].

[46] In order to account for this, the growth of the unit costs associated with each type of intermediates within every period were netted out form the effect of the changing composition of the intermediate input used. As a result, the implied current values cost of the two types of intermediates has the same growth rate. The implied counterfactual growth in the gross output prices does not change within the first three decimals.

3.3.2 Growth accounting

Aggregate economy

The standard framework in growth accounting exercises conducted at the industry-level is the "Aggregate Production Possibility Frontier" (Jorgenson, Ho, and Stiroh 2005b). Within this framework, industries are allowed to have different value added functions, in which case there is no perfect substitution among their real value added. The aggregate value added is defined as the Törnqvist index of the industry i value added: $\Delta \ln V_t = \sum_i \bar{w}_{it} \Delta \ln V_{it}$, where $\bar{w}_{it}$ is the two-period average share in aggregate value added of industry i. The real value added growth for each industry is defined implicitly by the gross output growth equation: $\Delta \ln V_{it} = \frac{1}{\bar{v}_{it}^V}\left[\Delta \ln Y_{it} - \left(1 - \bar{v}_{it}^V\right)\Delta \ln I_{it}\right]$[47]. As a result, aggregate labour productivity growth, which is defined as the real aggregate value added per total hours worked, $\nu = \frac{VA}{H}$ grows at rate:

$$
\begin{aligned}
\Delta \ln \nu_t &= \Delta \ln VA_t - \Delta \ln H_t \\
&= \sum_i \bar{w}_{it} \Delta \ln Y_{it} - \sum_i \bar{w}_{it} \frac{1-\bar{v}_{it}^V}{\bar{v}_{it}^V}\left(\Delta \ln I_{it} - \Delta \ln Y_{it}\right) - \Delta \ln H_t \\
&= \underbrace{\sum_i \bar{w}_{it} \Delta \ln y_{it}}_{\text{"Direct productivity effect"}} \\
&\quad \underbrace{-\left[\sum_i \bar{w}_{it} \frac{1-\bar{v}_{it}^V}{\bar{v}_{it}^V}\left(\Delta \ln I_{it} - \Delta \ln Y_{it}\right)\right]}_{\text{"Intermediates reallocation effect"}} \\
&\quad \underbrace{+\left(\sum_i \bar{w}_{it} \Delta \ln H_{it} - \Delta \ln H_t\right)}_{\text{"Hours reallocation effect"}}
\end{aligned}
$$

, where $\Delta \ln y_{it}$ is the labour productivity of industry i (gross output per hour worked), $\Delta \ln H_{it}$ is the growth in hours of industry i, and $\bar{w}_{it} \frac{1-\bar{v}_{it}^V}{\bar{v}_{it}^V}$ is the share of

[47] See details in Section 3.2.3.

the value of intermediates in total value added.

This decomposition shows that the variation in intermediates input intensity across industries affects aggregate labour productivity growth. The "intermediates reallocation effect" has a negative impact on aggregate labour productivity when $\Delta \ln I_{it} > \Delta \ln Y_{it}$. This is because when an industry uses more intermediates to deliver the same units of gross output, this corresponds to a decrease in the industry's productivity and thus such reallocations need to be excluded. In the presence of two types of intermediates, goods and services, then the intermediates growth index for industry i is given as: $\Delta \ln I_{it} = \bar{v}_{Git} \Delta \ln I_{Git} + \bar{v}_{Sit} \Delta \ln I_{S_{it}}$, where $\bar{v}_{Git}$ is the two-period average use share of goods-intermediates, $\bar{v}_{Git} + \bar{v}_{Sit} = 1$.

Given the actual growth rates in the volume of gross output and goods and services-intermediates for every industry, three composition effects that are related to the intermediates use can have a role in affecting the intermediates reallocation. First, there could be an industry-size composition effect, related to the industry value added share, $\bar{w}_{it}$. Second, there could be an industry VA-intermediate input composition effect, related to the substitution between intermediate inputs and value added in the gross output production of every industry, $\frac{1-\bar{v}_{it}^{V}}{\bar{v}_{it}^{V}}$. Finally, there could be an intermediates use composition effect that comes from the variation in the use of different types of intermediates, $\bar{v}_{Git}$ and $\bar{v}_{Sit}$[48]. The aggregate composition effect relates to the interplay of all these individual components.

In order to get the magnitude and direction of each of these composition effects, for each of the 14 NACE industries of Table 3.1 (sector-level analysis), one-by-

[48]Note that constructing the counterfactual series for γ_G by controlling g_{γ_G}, is equivalent to controlling for $(1-\sigma)\left(g_{\frac{p_{I_G}}{p_{I_S}}} + g_{\frac{A_S}{A_G}}\right)$, given the equilibrium path. Under the counterfactual it is assumed that the growth in the relative real demand, $g_{\frac{I_S}{I_G}}$, stays unchanged. therefore, since $g_{\frac{I_S}{I_G}} = g_{\frac{p_{I_G}}{p_{I_S}}} + (1-\sigma)\left(g_{\frac{p_{I_G}}{p_{I_S}}} + g_{\frac{A_S}{A_G}}\right)$ the assumption on unchanged $g_{\frac{I_S}{I_G}}$ is equivalent to pinning down $g_{\frac{p_{I_G}}{p_{I_S}}}$ under the counterfactual that would meet all the requirements.

one the corresponding shares were fixed at their average 1970-1971 in order to calculate the reallocation effect ceteris paribus. Figure 3.13 presents the benefit in terms of aggregate labour productivity from the composition changes undergone during this period[49]. A positive benefit arises when the reallocation observed is lower than the one implied by a constant composition effect.

Figure 3.13 shows the following. First, the average benefit implied by each composition effect 1970-2004 period is negligible (ranging from -0.06% for the size-effect to 0.03% for the intermediates-use composition effect). The actual average reallocation effect during this period (-0.05%) has also no important impact on aggregate labour productivity growth. Second, while there are trends over time in the underlying shares, the variance of the implied benefit does not increase over time, which suggests that the cross-sectional source of variation is more important. Third, the variance increases significantly during particular periods that the data revealed important changes in the industries' size and production functions (1981-1984, 2002-2004). The results for the goods and services-sectors alone are very similar.

Information and Communication Technologies producing sector

The analysis of Section 3.2.4 shows that the ICT-producing sector had a distinct time pattern in terms of its intermediates use. The question addressed in this Section is whether and to which extent this affected the final performance of the ICT-producing sector. This question could be addressed by calculating the counterfactual value added growth of the sector should the pattern of its intermediates use coincide with the average industry in the United States.

[49] The benefit is defined as the difference between the actual and the counterfactual (no composition changes) average labour productivity, which is given by the difference between the counterfactual and actual intermediates reallocation effect.

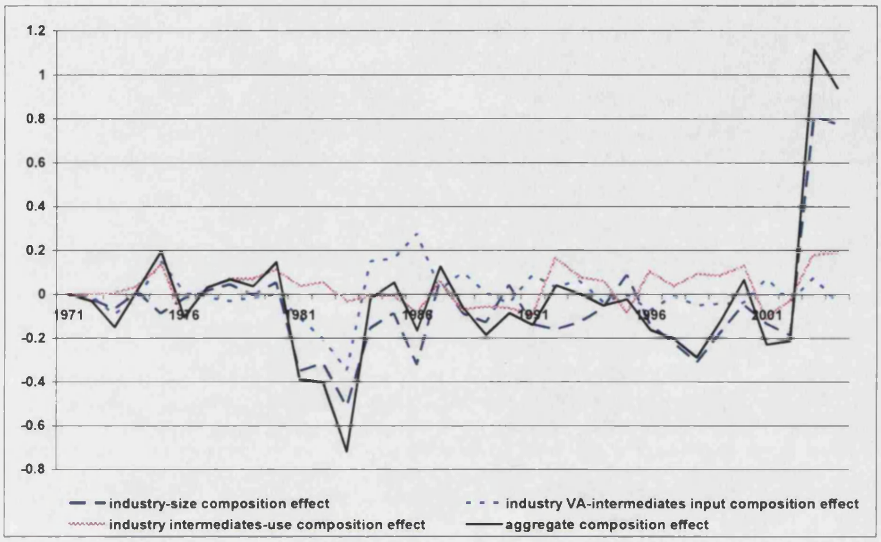


Figure 3.13: Benefits for the United States labour productivity growth due to composition effects

Recall that the value added of an industry is implicitly given by $\Delta \ln V_{it} = \frac{1}{\bar{v}_{it}^{V}} \left[\Delta \ln Y_{it} - \left(1 - \bar{v}_{it}^{V}\right) \Delta \ln I_{it}\right]$, where $\Delta \ln I_{it} = \bar{v}_{Git} \Delta \ln I_{Git} + (1 - \bar{v}_{Git}) \Delta \ln I_{\mathrm{S}it}$. The contribution of the ICT-producing sector to the aggregate productivity is given as $C_{ICT-p} \equiv \sum_{i \in ICT-p} \bar{w}_{it}^{V} \Delta \ln V_{it}$. The counterfactual is calculated as follows: the 1970 share of goods-intermediates is fixed at its actual level and the growth of this share for the United States goods-sector is applied to the goods ICT-producing industries and that of the services-sector is applied to the services ICT-producing industry. Ceteris paribus, the counterfactual contribution of the ICT-producing sector is calculated for the 1985-2004 period.

Table 3.15 summarizes the results of this exercise, by presenting the actual and counterfactual value added growth of every industry and the contribution of the sector to the aggregate economy value added growth. It shows that there would be benefits for the productivity of the individual industries by behaving as the average United States industry in terms of their intermediates use. This benefit is delivered through a lower growth of the intermediates aggregate volume. The result is driven from the fact that there was a strong and volatile (large positive values in the early 1990s and negative in 2001) volume growth of the goods-intermediates. Hence, there is a benefit from decreasing the share of this intermediate in the basket of intermediates used. Overall the exercise accounts for a 4% increase in the contribution of the ICT-producing sector to aggregate value added growth[50].

Table 3.15: United States ICT-producing sector's potential value added growth from an average-industry trend in the goods-intermediates use share

ICT-producing industry	share	Value added actual growth	Value added counterfactual growth
Office, acc. and comp. mach.	0.45	36.40	37.02
Insulated wire	0.08	3.81	3.82
Radio, TV and comm. equip.	0.97	13.77	14.24
Computer and related svcs.	1.53	8.43	9.07
Aggregate	3.04	0.43	0.45

Note: Average over 1985-2004 (%)

3.3.3 Services-sector's cross-country differences

The results of the previous Sections show that the main difference across the United States and the United Kingdom is the strong shift of the services-sector towards the use of services-intermediates. The econometric analysis does not uncover significant difference in terms of the degree of substitution of the two types of intermediates for the services-sector across the two economies. This Section investigates the patterns of intermediates use by examining directly the relative volumes and prices of the goods and services-intermediates.

[50] A test of common means indicates that the difference in the average actual and counterfactual growth rate is statistically significant in all cases but for the "Office, accounting and computing machinery" industry.

The evolution of the relative volume and prices of goods and services-intermediates for the services-sector in the United States and the United Kingdom economies is presented in Figure 3.14[51]. For the 1980-1990 period, services-sectors in both countries increase their volume of services-intermediates relative to the goods-intermediates. This coincides with a decrease in the relative prices of the goods-intermediates. For the 1992-2004 period, they decrease in the goods-intermediates relative prices continues. However, while the relative volume of the services-intermediates rather stayed constant in the United States, in the United Kingdom the sharp increase of the 1980s is continued. Figure 3.15 presents the same data for the entire economy[52]. Given its size, the services-sector has a big impact on the observed patterns at the aggregate level. Nevertheless, the differences across the two countries are more pronounced.

The producer problem of Section 3.2.4 is employed to examine the technological factors driving the observed patterns in intermediates' use[53]. Given the data on relative prices and volumes of intermediates and the estimate of the elasticity of substitution between goods and services-intermediates for the services-sector in economy, the optimization condition implies a measure of the relative productivity in using services-intermediates. Figure 3.16 presents the results in terms of an index[54].

During the 1980s, for both countries the model implies that there is decrease in the services-sector relative productivity in using services-intermediates. Given

[51] Given the data breakpoint in the United Kingdom data in 1992, all indexes are normalised to 100 for 1992. The level spike in 1991 for the United Kingdom is due to the same reason.

[52] The Figures in this Section present the volume and index series for the United Kingdom without omitting the data for 1991, when the break in the series takes place. As was the case for the previous Sections, any attempt to enforce smoothing in the data series is avoided in order not to affect the original information of the data.

[53] The optimal intermediate inputs choice is described by: $\frac{I_S^i}{I_G^i} = \left(\frac{1-\theta_i}{\theta_i}\frac{p_{I_G}}{p_{I_S}}\right)^{\sigma_j}\left(\frac{A_S^i}{A_G^i}\right)^{\sigma_j-1}$, which implies: $g_{I_S^i/I_G^i} = \sigma_j g_{p_{I_G}/p_{I_S}} + (\sigma_j - 1) g_{A_S^i/A_G^i}$.

[54] The index series for the United Kingdom is scaled in the secondary axis and the scale is chosen to closer highlight the underlying differences in trends.

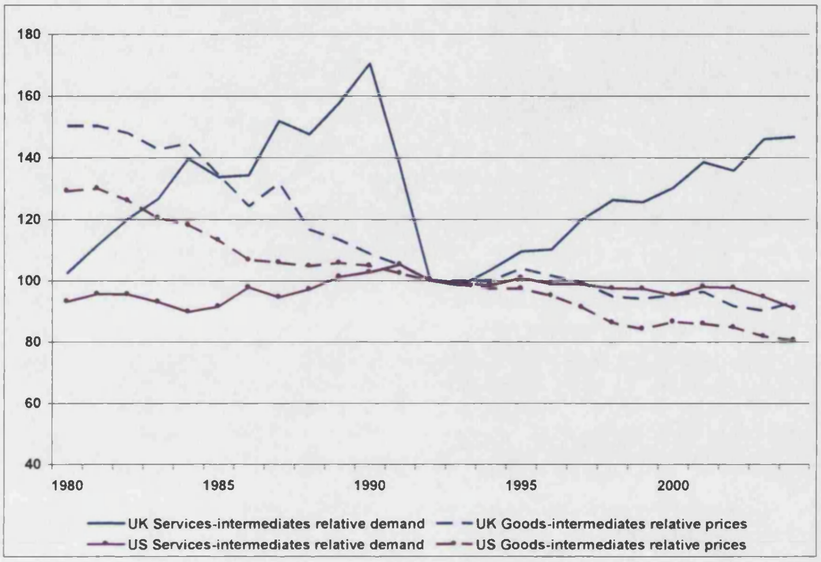


Figure 3.14: United States and United Kingdom services-sector's relative volumes and prices of goods and services-intermediates.

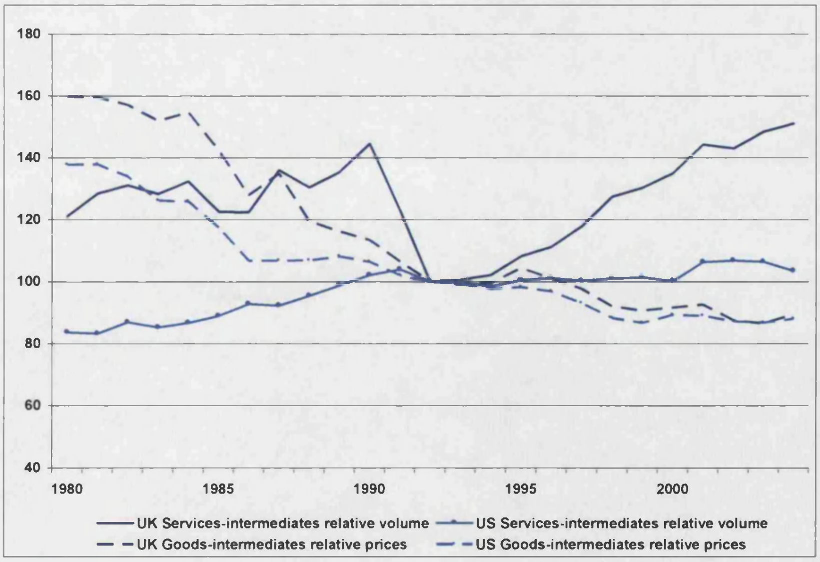


Figure 3.15: United States and United Kingdom services-sector's relative volumes and prices of goods and services-intermediates.

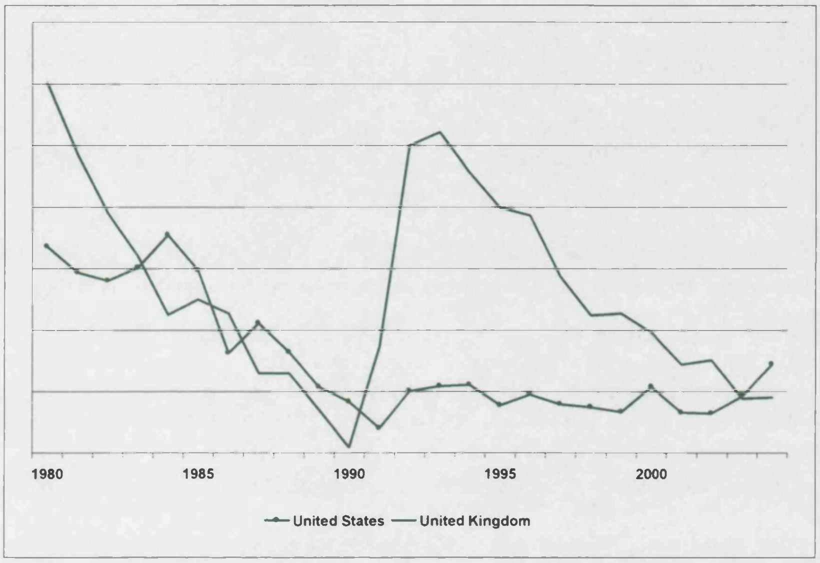


Figure 3.16: Model's predicted services-sector relative productivity in using services-intermediates for the United States and the United Kingdom.

the low degree of substitution between the two types of intermediates, such productivity change corresponds to an outward shift of the demand for services-intermediates ceteris paribus. This is because if the services-sector uses every unit of goods-intermediates more efficiently, then it needs to use more services-intermediates in order to deliver the production. As a result, the equilibrium prices of the services-intermediates increase. The productivity effect boosts the fall in the relative prices of the goods-intermediates and drives a falling expenditure share for the goods-intermediates. The stronger change in the United Kingdom suggests that the outward shift of the demand function is stronger.

During the 1990s, the same pattern is repeated for the United Kingdom. For the United States, the model suggests that there is no change in the productivity advantage in using either of the two types of intermediates. In other words, the relative prices change is sufficient to explain the change in the relative volume. However, for the United Kingdom there is still a large unexplained component in the observed trends.

The first step towards understanding the drivers of these patterns is to apply the same method at the disaggregate method and identify the industries that have the biggest impact on the sector-level trend. The industries that can mostly affect the sector due to their size (together they absorb 62% of the sector's intermediates input) are the following: Wholesale and Retail (50-51) Financial intermediation (J), Business services (71-74), Transport and Storage (60t63). The one with the sharpest increase in its size is the Business services industry (from 12% in 1992 to 17% in 2004). The Financial intermediation and Business services track down mostly the sector-level outcome. Figure 3.17 presents the time pattern for these industries in the United Kingdom.

Turning to the United States, Figure 3.18 suggests that most of the industries followed the same pattern that comes out at the aggregate level. At the same time, the same four industries absorb most of the intermediate inputs in the sector (52%). The striking exception is the Business services that experiences rather an increase in their relative productivity in using services-intermediates. On the other end of the industry-level trend is the Financial intermediation with a decline in the relative productivity in using services-intermediates.

The analysis of this Section points out the cross-industry cross-country differences in terms of their observed patterns in intermediates use. The industries under focus have gained a lot of attention in the productivity analysis of the United Kingdom economy, since Financial intermediation and Wholesale trade are the two services-industries that account for most of the productivity gap between the United Kingdom and the United States in the 1990s, while for the Business services it has narrowed down significantly (Griffith, Harrison, Haskel, and Sako 2003). The results above indicate that United Kingdom industries have relatively lower

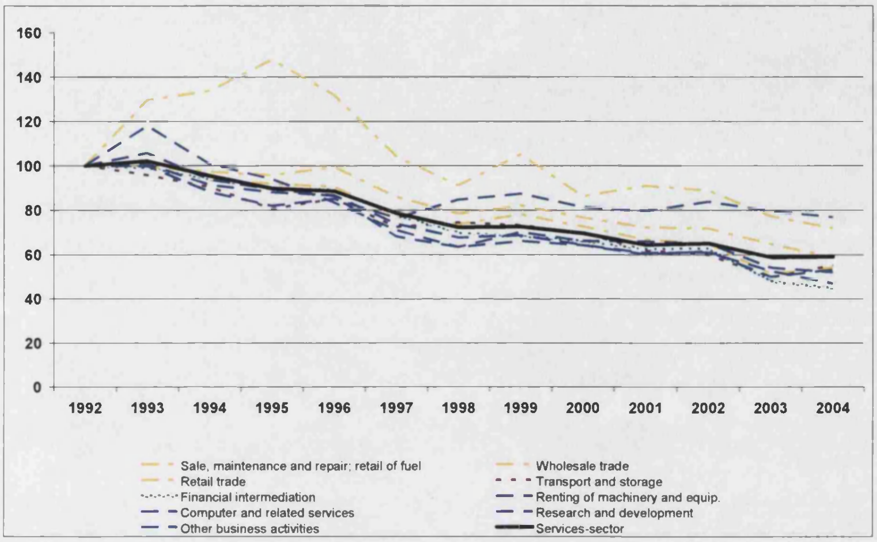


Figure 3.17: United Kingdom services-intermediates relative productivity in selected industries

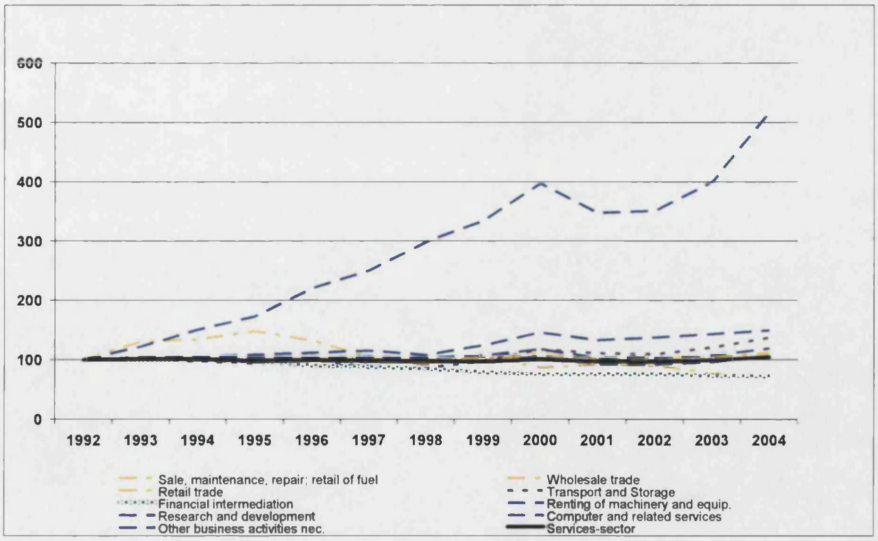


Figure 3.18: United States services-intermediates relative productivity in selected industries

efficiency in using services-intermediates, suggesting that the industries have not figured out uses of such intermediates in a way that would contribute to their ability to save on them, as much as they have done so for the goods-intermediates. Hence, the open question is what drove this asymmetry in the United Kingdom with respect to the efficiency in using services and goods-intermediates.

Among the factors that can drive the patterns for the United Kingdom is the lack of good management and organizational skills in the firms that does not allow scope for making the most of the services-intermediates. There is literature that highlights the role of organizational capital and points out important differences across the United States and the United Kingdom (Brynjolfsson and Hitt 2000, Bloom, Sadun, and Reenen 2007). Another set of factors could be related to the existent regulation that affects the use of more specific type of services-intermediates. For example, Griffith, Harrison, Haskel, and Sako (2003) discuss the effect of land regulation/ planning on retail, while Haskel and Khawaja (2003) examine the importance of competition affecting entry and exit. Related to this, one potential explanation for this outcome is that in the 1980s the United Kingdom underwent important deregulation of the goods-producing industries (e.g. see discussion in Basu, Fernald, Oulton, and Srinivasan 2003, Card and Freeman 2002). This could have had a long-lasting effect on the ability of the users of the goods-intermediates to manage these resources more efficiently. Finally, a set of factors could be related to the use of particular inputs in the production of goods. A primary example that is brought up from the recent literature (e.g. Basu, Fernald, Oulton, and Srinivasan 2003) is the ICT-capital. There is support that investment in ICT has not only direct productivity benefits, but also indirect ones, i.e. there are important externalities in the use of capital. To the extent that ICT has affected more the firms' ability to use its materials and products and to manage more efficiently its inventory, would have an impact on the firm's intrinsic efficiency in using goods-intermediates.

To conclude, the drivers of the unexplained industry-level patterns in using intermediates could be related to a set of factors related to policy or technology.

3.4 Conclusions

This Chapter employs a new dataset to examine the patterns of intermediates use of the United States and the United Kingdom during the 1970-2004 period. For both economies there is a substitution of goods-intermediates with services ones. At the same time, the size of the services-sector increases relative to that of goods and so has its share in the use and production of intermediates. The analysis decomposes the observed patterns of intermediates use into the different effects that can drive them: the size of the different sectors in the economy, their production technology and their substitution between the different types of intermediates. The exercise is conducted at the goods and services-sector, as well as at the two and three-digit industry level.

The main conclusions are the following. First, while the size effect is important, it cannot fully account for the decrease in gross output share of goods-intermediates and the increase of services-intermediates' one. The observed patterns are also driven by a substitution between the primary and secondary factors of production, as well as between the secondary factors of production. Second, the negative trend in the use share of goods-intermediates is driven by changes in the different industries' intermediates composition, rather than changes in the relative sizes of these industries.

This Chapter adopts a partial equilibrium analysis and uses a CES intermediate inputs production to account for the factors that drive intermediate inputs choice. The theory suggests a regression specification that needs to control for the importance of the relative prices of the two types of intermediates, along with other factors related to the industry-specific productivity of use of the different types of intermediates.

The regression results may be summarized as follows. First, the two types of intermediates are gross substitutes. This is more so for the services-sector. This result is plausible within the theoretical assumptions employed. Furthermore, it is consistent with estimates of the degree of substitution between the output of goods and services-sectors in terms of their final use (consumption). Second, the results allow scope for the importance of additional factors like technology. Even though the results are inconclusive with respect to the magnitude and the structure of such factors, there is evidence of important variation at the industry-level. Importantly, the effect of the relative prices remains robust to the addition of such controls. Third, the regression results for the United Kingdom point out to a bigger difference across the goods and services-sector with respect to the degree they can substitute the two types of intermediates. The estimated elasticity of substitution for the goods-sector is closer to one, reflecting the broadly rather constant goods-intermediates expenditure share of this sector.

This Chapter also examines the quantitative importance of the intermediates pattern of use for the two economies. Using the United States data, it shows that the data do not support the existence of an impact of the composition effects on aggregate economic performance. This result is delivered using a value added-based measure of productivity and data at a higher level of aggregation.

Finally, this Chapter uses the estimated elasticity along with their intermediates relative prices data, in order to derive measures of the additional, technology-related factors that drive the observed patterns in the services-sector intermediates volumes across the two countries. It highlights important differences across the two economies and over time in terms of their efficiency in using the different types of intermediates. It uncovers the industries that drive the results at the sector-level and discusses their behavior. Accounting for additional factors (e.g. technology, policy) comes out as an important factor that needs to be taken into account when examining the choices of different industries with respect to the composition of their intermediates.

Chapter 4

Equity Mispricing and R&D Growth

4.1 Introduction

This Chapter proposes a mechanism through which information imperfections in equity markets have a long-run economic impact. This mechanism works through R&D activities that rely on equity funding. Equity market participants that have imperfect information take into account public information (e.g. their perception of market sentiment), which results in equity mispricing. When the market is optimistic, there are two opposing effects on aggregate consumption. On the one hand, such optimism drives equity prices above the underlying fundamentals, generating more funds for the R&D firms. As a result, more innovation activities take place and their output expands permanently the production possibility frontier, generating higher wages and aggregate consumption. On the other hand, investors eventually realize losses in the equity market that reduce their consumption. The latter effect reflects the standard intratemporal trade-off between current consumption and R&D expenditures given the limited resources. In the setting of the economy of this Chapter, this trade-off takes the form of utility transfers across generations of investors. This Chapter investigates the conditions under which the first positive welfare effect dominates. This study is motivated by the developments in the stock market prices of the United States' technology intensive firms in the early 1990s, and the vivid discussion regarding the existence of scope for policy intervention.

In the baseline model of this Chapter, the information imperfections in the equity market imply that equity prices are determined not only by the underlying fundamental (true productivity), but also by a public signal and a noise trading shock. The effect of each of these factors on the final outcomes of the model economy is analyzed and contrasted to the ones delivered by the perfect information economy, where equity market participants are perfectly informed. The welfare criterion employed is the aggregate consumption path. The results show that the model economy can achieve higher consumption compared to the perfect information one, when equity prices rise above fundamentals due to an optimistic public signal, or a noise trading shock for all generation of investors. This is true for all generations of investors, except for the one assuming the cost of R&D expenditures that are not justified by the underlying fundamentals. However, when optimism is persistent (due to subsequent releases of positive public signals), then the productivity gains from R&D can allow for the consumption in the model economy to be always higher that then one in the perfect information economy. This is because the R&D costs are assumed over more generations of investors. These results depend on the extent of congestion in R&D sector and the degree of equity mispricing. The perfect information economy achieves higher welfare following an increase in the true underlying fundamentals.

In support of the proposed mechanism that links equity market and R&D out-

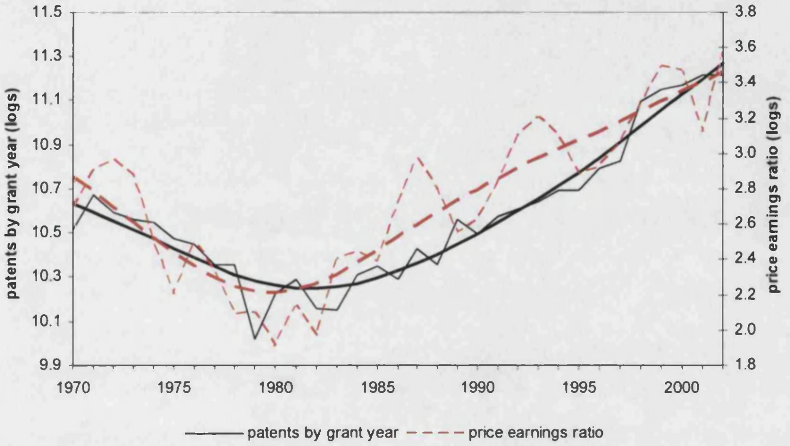


Figure 4.1: S&P500 price earning ratio and USPTO patents granted to non-government institutions

comes, Figure 4.1 presents data on the real price earnings ratio from the firms listed in S&P500 over the period 1970-2002, along with a proxy for R&D output, as given by the number of patents granted by USPTO to the United States non-government institutions (Griliches 1990)[1]. The two series commove along time, reflecting the pattern of productivity growth of the United States over the same period[2]. The same correlation pattern is supported when focusing on the performance of the Information and Communication Technologies sector (ICT-producing), which is highly intensive in R&D and patenting activity (Carlin and Mayer 2003)[3].

Rational expectations models that rely on the efficient markets hypothesis explain this correlation by the forward looking nature of the equity market and examine the effect of the research activity on the future productive ability of the

[1]Figure 4.1 presents the series in log levels and their respective trends (Hodrick-Prescott filter with $\lambda = 100$ for annual data). Data on price earnings ratio and patents are from Robert J. Shiller and Bronwyn H. Hall websites respectively.

[2]This correlation pattern is also in line with evidence that the equity market and corporate investment are positively correlated.

[3]See discussion in Chapter 1.

firms by using equity price as an indicator of final output performance. Within this framework, Pakes (1985) and Griliches, Hall, and Pakes (1991) found that the events that lead to changes in the equity market value of a firm are correlated with shocks in its innovative process. However, when the equity market efficiency assumption is relaxed, then there can also exist a direct feedback from the equity market on investment. Polk and Sapienza (2006) present evidence that a measure of equity market mispricing driven by market sentiment is positively correlated with abnormal investment. They also show that the higher is the R&D intensity of a firm or the share turnover, the more sensitive abnormal investment is to equity mispricing[4]. The positive correlation between market sentiment and real investment is also reported by Farhi and Panageas (2007). There is also evidence that the volatility of the investment of "equity-dependent" firms depends critically on the movements in the stock market (Baker, Stein, and Wurgler 2003). Allowing for equity prices to diverge from the underlying fundamentals distorts the effective cost of issuing equity compared to other sources of finance.

The mechanism proposed in this Chapter to explain the correlation of R&D and equity market output, is based on two important assumptions. First, R&D firms are "equity-dependent". This assumption is justified by the special features of the R&D-producing sector. In contrast to other economic sectors, this sector bears high uncertainty, investment and growth opportunities and dependence on intangible capital. As a result, it is more likely to depend on equity as it is not appealing for debt contracts, while internal finance is unlikely to provide sufficient funds. The literature on bankruptcy costs (e.g. Brealey and Myers 2003) emphasizes on that R&D-production activity lacks collateral and carries agency problems driven by the uncertainty about the success of innovations and the de-

[4]For such firms, the patterns in abnormal returns are found to be generally stronger.

mand for them. Therefore, debt financing may not be desirable or possible for the innovating firms. Control rights (e.g. Aghion and Bolton 1992), lack of consensus regarding new technologies' potential (e.g. Allen and Gale 1999)[5], renegotiation (e.g. Huang and Xu 1999) and corporate governance considerations are also listed in the corporate finance literature as reasons that favour equity issue over other sources of finance[6].

The empirical evidence in support of the assumption that R&D is equity-dependent comes from the analysis of Bradley, Jarrell, and Kim (1984), who show that R&D expenditures are negatively related to firm leverage (defined as the ratio of the long-term debt to the sum of debt and equity value). Using a sample of United Kingdom firms, Aghion, Bond, Klemm, and Marinescu (2004) show that firms that report R&D are more likely to raise equity than those that do not. Moreover, the probability of equity financing increases with R&D intensity. Carlin and Mayer (2003) investigate data for a set of OECD countries and find support for the hypothesis that the equity market is more relevant for raising funds for the R&D intensive firms, consistent with the renegotiation and information theories.

The second important assumption maintained in this Chapter is that equity prices can diverge systematically from the underlying fundamentals. Equity mispricing can arise due to irrationality (e.g Barberis, Shleifer, and Vishny 1998, De Long, Shleifer, Summers, and Waldmann 1990). However, equity mispricing can occur also in a purely rational setting, as shown by the work on higher order expectations by Allen, Morris, and Shin (2006) and Bacchetta and Wincoop (2007). The necessary condition for this is the existence of heterogeneous, noisy private information together with common, noisy public information[7]. Such a setting results

[5] This theory emphasizes that the banks would rather lend to firms for which they can economise on acquiring information. Therefore, innovative firms would not be attractive given the diversion of beliefs regarding new technologies' potential.

[6] For an extensive review of this literature see Allen and Gale (2000).

[7] The "public information" or "public signal" is distinct from the price signal in the theoretical

in a rational expectation equilibrium, where all investors end up taking both signals into account and asset prices are affected by the public signal. This Chapter has a similar approach regarding modeling of the information structure. Empirical studies support the existence of equity mispricing[8]. There is also evidence that equity market participants' expectations and prices are affected by market sentiment (e.g. Lee, Shleifer, and Thaler 1991, Swaminathan 1991, Menkhoff 1998).

This Chapter employs a general equilibrium setting and relates to the literature that examines the real effects of equity mispricing, when the latter is driven by market sentiment. In the analysis of Farhi and Panageas (2007), equity mispricing on the one hand alleviates financial constraints and on the other hand enables the realization of unproductive investment projects. Their empirical analysis suggests that the second negative effect dominates, i.e. there are efficiency losses due to equity mispricing[9]. However, they only perform a partial equilibrium analysis, which omits the link between R&D output and final consumption through higher output and wages.

In the present Chapter the R&D investment of an individual firm generates both a positive (knowledge spillover) and negative (congestion effect) technology externality. To the extent that the market fails to internalize these externalities, the equity contracts that are specific to individual firms would not reflect the social rate of returns of their assets. In particular, when the degree of R&D congestion is low, then equity price in a perfectly informed market does not account for the positive knowledge externalities that expand endogenously the productivity in the final good sector. As a result, there is a lower than optimum equilibrium invest-

analysis that follows. The public signal generates movements in the "market sentiment" that are not driven by historical prices.

[8]There is evidence that equity prices react slowly to changes in the variables that proxy the underlying fundamentals (e.g. Cutler, Poterba, and Summers 1991, Jegadeesh and Titman 1993, Chan, Jegadeesh, and Lakonishok 1996)

[9]This is the conclusion also in the empirical study of Polk and Sapienza (2006).

ment in R&D. The present Chapter shows that information imperfections in the equity market can alleviate the market failure in accounting for R&D externalities. This is because public information can lower the gap between the equity price that reflects the private return of an R&D firm, and its underlying social return. Aggregate economy bears net gains to the extent that the benefits from closing the gap between market and social returns of R&D are higher compared to the costs of R&D that result in capital losses due to the mispriced equity with respect to the realized market value of a firm.

The structure of the production side in this Chapter resembles closely the endogenous growth models (Romer 1990, Grossman and Helpman 1991b, Aghion and Howitt 1992, Comin and Gertler 2006), where R&D is the driver of growth. However, in all these studies equity market is assumed to be perfect. Allowing for equity market imperfections brings the analysis of this Chapter closer to that of Evans, Honkapohja, and Romer (1998). They built an endogenous growth model, where the complementarity among intermediate capital goods delivers multiple equilibria. Market sentiment coordinates self-fulfilling expectations and shifts the economy across different growth equilibria. In their setting, market sentiment is unrelated to fundamentals and therefore introduces an element of irrationality. On the contrary, in the model of the present Chapter, rational investors take market sentiment directly into account because it provides information regarding the underlying fundamentals. Closer to the information structure adopted in this Chapter, is the model by Lorenzoni (2005), although his model lacks explicit account for the equity market. In his model, individual producers have uncertainty about the aggregate productivity, which results in their over-reaction on news and under-reaction on shocks in actual productivity.

The Chapter relates broadly to the literature of overlapping-generation models that examines the existence and maintenance of bubbles in long-run equilibrium (Tirole 1985, Ventura 2006, Caballero, Farhi, and Hammour 2006). In such studies bubbles arise either in dynamically inefficient economies in order to serve as a means of store of value across the different generations, or in the presence of externalities that create a wedge between the private and social returns on investment. In the present Chapter, equity mispricing is caused by the imperfect information present in the equity market and can result in either closing or widening the wedge between the social and private returns to R&D dependent on the direction of the market sentiment. In all cases, the terminal conditions are satisfied.

This Chapter is organized as follows. Section 4.2 presents the baseline model. Section 4.3.2 discusses the analytical results that come from a three-period model economy. Section 4.3.3 presents the numerical results obtained for the solution of the infinite-horizon model. It confirms the conclusions of the three-period model and discusses the additional insights that become available within the long-horizon framework. Section 4.4 discusses the welfare properties of the model and the scope for growth promoting policy. Finally, Section 4.5 concludes.

4.2 The Model

4.2.1 Production side

Final good and intermediate-goods production

Competitive final good producers use labour, L, and the capital varieties, $x_t(j)$, available in the economy in period t ($j \in [0, A_t]$; $A_1 > 0$ given), in order to produce total output, Y_t:

$$Y_t = (\phi_t L)^{1-\alpha} \int_0^{A_t} x_t^{\alpha}(j) dj \tag{4.1}$$

, where ϕ_t is a labour augmenting productivity shock. At the beginning of period t, ϕ_t is known, but there is uncertainty for all future periods. The productivity shock is drawn from: $\phi_t \sim \mathcal{N}(\overline{\phi}, 1/\beta_\phi)$, which is the publicly known prior distribution of productivity[10].

Capital depreciates fully within a period[11]. The sector buys capital varieties from the intermediate-goods sector for a price $p_{x_t}(j)$ and pays wage w_t to each unit of labour. The final output is the numeraire and its price is normalized to one.

The intermediate-good producers engage into two distinct activities: R&D and intermediate-goods production. One period before they become active producers of intermediate goods, these firms invest in R&D to develop a blueprint for a new capital variety. The blueprint gives them infinitely-lived monopoly rights to produce the new intermediate good. Each monopolistic firm j has constant-returns-to-scale technology that requires that η units of final good are invested in order to produce one unit of capital good:

$$\pi_t(j) = \max_{p_{x_t}(j), x_t(j)} \left\{ p_{x_t}(j)x_t(j) - \eta x_t(j), \text{ s.t. } p_{x_t}(j) = \frac{\partial Y_t}{\partial x_t(j)} \right\}$$

Given the symmetry among the existent varieties of intermediate-goods in the final-good production, the demand for each variety is independent of j:

$$x_t = (\frac{\alpha^2}{\eta})^{\frac{1}{1-\alpha}} L\phi_t \tag{4.2}$$

[10]The normality assumption is used to simplify the analytical solution of the model. The main mechanism would remain valid with different distributional assumptions. Despite allowing for the possibility of a negative outcome, it is an assumption that is used widely in the finance literature about the liquidation value of assets. For reasonable assumptions about the parameters the dutribustion, the probability of negative output or asset prices is negligible.

[11]This assumption simplifies the analytical tractability of the model. In terms of interpretation, the capital varieties are not distinguishable from intermediates. Henceforth, the two terms are used interchangably.

Since the demand is linear in ϕ_t, the intermediate-goods firms operating in t face uncertain future demand. As a result, the operating profits are identical across firms and uncertain in the future:

$$\pi_t = \Gamma\phi_t;\ \Gamma = \eta\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\alpha^2}{\eta}\right)^{\frac{1}{1-\alpha}} L \tag{4.3}$$

Using (4.1), (4.2) and (4.3), the aggregate output and capital expenditures in equilibrium become proportional to the level of technology, A_t, and productivity, ϕ_t:

$$\begin{aligned} Y_t &= A_t\frac{1}{\alpha(1-\alpha)}\Gamma\phi_t && (4.4)\\ K_t &= A_t\eta x_t = A_t\frac{\alpha}{1-\alpha}\Gamma\phi_t && (4.5) \end{aligned}$$

R&D production and finance

Each entrepreneur e engaged into the development of new varieties is assumed to add incrementally to the set of available products by investing a finite amount of resources into R&D, $I_t(e)$. The output of an entrepreneur is $\overline{\lambda}_t I_t(e)$, where the arrival rate of the discovery of a new variety $\overline{\lambda}_t$ is taken as given by each entrepreneur and equals:

$$\overline{\lambda}_t = \lambda\left(\frac{I_t}{K_t}\right)^{\rho-1} K_t^{-1}A_t;\ \rho\in(0,1) \tag{4.6}$$

This specification follows the one in Comin and Gertler (2006). It allows for two spillover effects in the R&D production that affect its productivity in an opposite way: a positive knowledge and a negative congestion effect. The knowledge spillover effect is captured by A_t and suggests that increase in the number of known varieties increases R&D productivity permanently. The congestion effect is captured by the aggregate R&D investment, I_t, entering negatively this expression. Parameter ρ is the elasticity of R&D output with respect to R&D intensity and measures the extent of congestion. Higher value for ρ implies lower congestion and higher productivity for R&D in the given period. The current value of capital stock, K_t, acts as a proxy for the embodied knowledge stock. Parameter λ is the exogenous component of the arrival rate of innovations.

Entrepreneurs enter freely into R&D. It is assumed that the only way that each of them finances the up-front costs of its R&D activity is by issuing equity. Every entrepreneur issues one divisible share that bears price $P_t(e)$. His credit constraint implies that $I_t(e) \leq P_t(e)$. Assuming away agency problems between the entrepreneur and outside investors, each entrepreneur invests all the resources raised from equity issue in R&D production and shareholders obtain right for the entire stream of profits produced by the firm. Free-entry into R&D implies that each entrepreneur needs to break even, i.e. $P_t(e) = 1/\overline{\lambda}_t$[12]. Due to the symmetry across all assets, investors into the firms' equity (i.e. consumers) treat all equity in the economy as one asset and $P_t(e) = P_t$[13].

The evolution of aggregate knowledge stock is given by:

$$A_{t+1} - A_t = \lambda \left(\frac{I_t}{K_t} \right)^{\rho} A_t \tag{4.7}$$

Therefore, in equilibrium in every period there are $A_{t+1} - A_t$ new intermediate goods firms established (this is also the volume of equity issues). Aggregate R&D

[12]Note that the equity price, $P_t(e)$ corresponds to $V_{t+1}(e)$, which is the expected value of a claim to the infinite stream of profits that accrues to a typical intermediate-good producer that starts manufacturing at time $t + 1$.

[13]Symmetry across the assets is implied by two factors: First, the expected profits of all intermediate goods firms are identical. Second, the shocks in equity market are perfectly correlated across assets (see Section 4.2.2).

expenditures are given by: $I_t = \int_{A_t}^{A_{t+1}} I_t(e)de$. The implied credit constraint for aggregate R&D expenditures is:

$$I_t = P_t(A_{t+1} - A_t) \tag{4.8}$$

4.2.2 Consumption side

Consumption and investment allocation decision

The consumption side consists of overlapping generations of rational and non-rational consumers, who work and invest in assets in the first period of their lives, and consume and retire in the second period. The short-lived agents assumption emphasizes the behavior of investors, who care about the short-term price movements in addition to the fundamental value of firms.

There is a continuum of short-lived rational consumers normalized in the interval $[0, 1]$, who make their asset allocation decisions when young. A rational (indexed by r) consumer i, born in period t , invests his labour income ($w_t L$) in two types of assets: equity and risk-free asset. Equity is the shares of intermediate goods firms paying profits (4.3) as dividends every period. Investment M_t in risk-free technology gives a certain gross return $\tilde{R} \geq 1$ and its output, $\tilde{Y}_t$, is given by[14]:

$$\tilde{Y}_t = \tilde{R} M_{t-1} \tag{4.9}$$

Rational consumers maximize the CARA utility:

$$U_t = -e^{-\tau c_{r,t+1}(i)}$$

[14] The risk-free asset could be another final good technology, storage or foreign assets.

, where risk aversion is measured by τ. By the consumer's budget constraint, the consumption of a rational consumer i can be expressed as:

$$c_{r,t+1}(i) = (P_{t+1} + \pi_{t+1})h_{r,t}(i) + \tilde{R}M_{r,t}(i) = (P_{t+1} + \pi_{t+1} - \tilde{R}P_t)h_{r,t}(i) - \tilde{R}w_t L$$

, where $h_{r,t}(i)$ and $M_{r,t}(i)$ represent respectively consumer i's equity and risk-free asset demand. It is assumed that consumers face no short-selling or borrowing constraints.

Using (4.3), consumer i's optimal demand for equity can be expressed as:

$$h_{r,t}(i) = \frac{E[P_{t+1} + \Gamma\phi_{t+1}|\Omega_t(i)] - \tilde{R}P_t}{\tau \operatorname{Var}[P_{t+1} + \Gamma\phi_{t+1}|\Omega_t(i)]} \tag{4.10}$$

, where $\Omega_t(i)$ is the information set available for consumer i in period t, defined in Section 4.2.2.

Aggregate demand of rational consumers for equity and the risk-free asset are $H_{r,t} = \int_0^1 h_{r,t}(i)di$ and $M_{r,t} = w_t L - P_t H_{r,t}$ respectively. Aggregate consumption of rational consumers in period t is equal to: $C_{r,t} = (P_t + \pi_t)H_{r,t-1} + \tilde{R}M_{r,t-1}$.

The non-rational (indexed by n) consumers, born in period t, differ from the rational consumers only in two respects: they are not endowed with labour and they demand a random quantity of equity[15]. The existence of non-rational consumers with random equity demand is necessary to make the equity prices not fully revealing (a paradox first addressed by Grossman and Stiglitz 1980)[16]. Aggregate

[15]The wage income does not affect the demand for stocks with CARA utility maximization under no short-selling or borrowing constraints. Therefore, the split of wage income between rational and non-rational consumers does not affect the aggregate results.

[16]They showed that when the efficient market hypothesis is true and information is costly, then the competitive equilibrium does not exist. This is because in the absence of noise in the market, the prices become fully revealing of the underlysing fundamentals, as they aggregate over the heterogeneous initial beliefs of the investors.

equity demand of non-rational investors in period t is defined:

$$H_{n,t} = A_{t+1} - s_t, \tag{4.11}$$

where $s_t \sim \mathcal{N}\left(0, \frac{1}{\beta_s}\right)$ is the noise trading shock[17]. A negative trading shock, $s_t < 0$, suggests that there is "excess equity demand" in the equity market driven by the non-rational consumers.

The budget constraint for the non-rational consumers is similar to that of the rational consumers. Therefore, their aggregate demand for the risk-free asset in period t is $M_{n,t} = -P_t H_{n,t}$. The non-rational consumers born in $t-1$ consume $C_{n,t} = (P_t + \pi_t)H_{n,t-1} + \tilde{R}M_{n,t-1}$ in period t.

Aggregating over all consumers, both rational and non-rational, implies that the aggregate demand for equity in period t is:

$$H_t = H_{n,t} + H_{r,t} \tag{4.12}$$

Aggregate investment in the alternative technology and aggregate consumption are respectively:

$$M_t = M_{r,t} + M_{n,t} = w_t L - P_t A_{t+1} \tag{4.13}$$

and

$$C_t = C_{r,t} + C_{n,t} = (P_t + \pi_t)A_t + \tilde{R}M_{t-1} = (P_t + \pi_t - \tilde{R}P_{t-1})A_t + \tilde{R}w_{t-1}L \tag{4.14}$$

Expression (4.14) shows that aggregate consumption, C_t, equals the excess gains in equity market and returns from the saved labor income.

[17] The mean of the non-rational consumers' equity demand is equal to aggregate supply of assets in period t, i.e. A_{t+1}, in order to ensure that the equity market does not have excess or shortage of liquidity on average.

Information structure

Given the uncertainty about all future labour augmenting productivity shocks, expression (4.3) implies that the dividends paid in future periods are uncertain. The information set, $\Omega_t(i)$, available for a rational consumer i in period t, is gathered from three sources: First, public information that is common knowledge, second, private information that is the result of private research and is specific to each consumer, and lastly, the history of equity prices that is also publicly available. The information structure follows that of Allen, Morris, and Shin (2006) and Bacchetta and Wincoop (2007).

There are two types of public signals. The prior distribution of the labour-augmenting productivity shock is common knowledge and $\overline{\phi}$ is a public signal that coincides with the long-term productivity of the economy. Investors receive additional public signals every period t, regarding productivity T periods ahead: $\widetilde{\phi}_t = \phi_{t+T} + \varepsilon_{\widetilde{\phi},t}$, where $\varepsilon_{\widetilde{\phi},t} \sim \mathcal{N}(0, 1/\beta_{\widetilde{\phi}})$. Under these assumptions, the earliest public signal that is informative in period t is $\widetilde{\phi}_{t-T+1}$.

The private signal that every rational consumer i trading in period t, regards also productivity T periods ahead, $\nu_t(i) = \phi_{t+T} + \varepsilon_{\nu,t}(i)$, where $\varepsilon_{\nu,t}(i) \sim \mathcal{N}(0, 1/\beta_\nu)$. He also inherits the private signals from his ancestors (i.e. he gets a signal from a rational consumer i born in $t-1$ about ϕ_{t+T-1}, from one born in $t-2$ about ϕ_{t+T-2} etc.). The earliest private signal that remains informative in period t is $\nu_{t-T+1}(i)$.

Finally, the rational consumers obtain information about future productivity from current and historical prices. The earliest price that is useful for predicting future dividends is P_{t-T+1}.

All private and public signals, as well as the noise trading are assumed to be uncorrelated over time and with each other. Private signals are uncorrelated

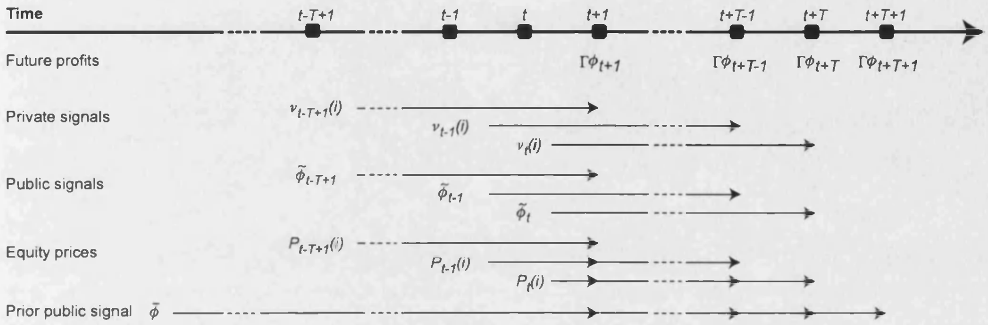


Figure 4.2: Information available in period t by the time of arrival.

across consumers.

The information set available for a rational consumer i in t is:

$$\Omega_t(i) = \{\nu_t(i), ..., \nu_{t-T+1}(i), P_t, ..., P_{t-T+1}, \widetilde{\phi}_t, ...\widetilde{\phi}_{t-T+1}, \overline{\phi}\}$$

and is illustrated in Figure 4.2.

4.2.3 Market clearing conditions

This Section concludes the presentation of the model by providing the clearing conditions in the two markets where the production side meets the consumption side: equity market and final output. The timing of production and investment decisions in the economy is summarized by Figure 4.3.

Equity market clearing and equilibrium equity price

In period t there are A_t old intermediate goods firms sold by consumers retiring in period t and $A_{t+1} - A_t$ new equity issues. Therefore, the aggregate supply of

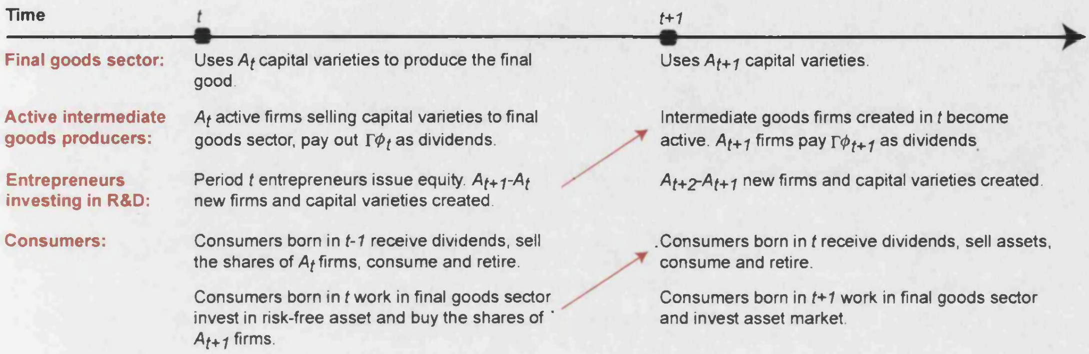


Figure 4.3: Timing of production and consumption decisions.

equity is A_{t+1}. Equity market clearing implies[18]:

$$H_t = A_{t+1} \Leftrightarrow s_t = H_{r,t} \tag{4.15}$$

Using (4.10) and (4.15) the equilibrium equity price is:

$$P_t = \frac{1}{\bar{R}}\overline{E}[P_{t+1} + \Gamma\phi_{t+1}|\Omega_t] - \tau\,\mathrm{Var}[P_{t+1} + \Gamma\phi_{t+1}|\Omega_t]s_t \tag{4.16}$$

where the conditional variance term is the same for all investors and over time, due to the homogeneous and time-invariant quality of information. Appendix C.4 shows that the equilibrium equity price is a linear function of the information contained in all signals that the rational investors receive:

$$P_t = \Gamma\left[Z_1'\Phi_t + \widehat{Z}'\widehat{\Phi}_t + \overline{z\phi}\right] \tag{4.17}$$

, where $\Phi_t = (\phi_{t+1}, .., \phi_{t+T}, \frac{s_{t-T+1}}{\Gamma}, .., \frac{s_t}{\Gamma})'$ includes the information received from private signals and prices. It is a vector of the unknowns that regard future pro-

[18]The equilibrium condition implies that given the volume of the equity market, equity price is determined to make the rational consumers willing to adjust their demand to meet the excess supply or demand from the non-rational traders in the market.

ductivity and historical net noise trading shocks. The vector $\widehat{\Phi}_t = (\widehat{\phi}_{t-T+1}, ..., \widehat{\phi}_t)'$ summarizes the information available from the two types of public signals. In particular, conditional on the public signals available in period t, $\widetilde{\phi}_t$ and $\overline{\phi}$, productivity T periods ahead is believed to follow the distribution : $\phi_{t+T}|\widetilde{\phi}_t, \overline{\phi} \sim \mathcal{N}(\widehat{\phi}_t, 1/\beta_{\widehat{\phi}})$, where $\beta_{\widehat{\phi}} = \beta_\phi + \beta_{\widetilde{\phi}}$ and $\widehat{\phi}_t = \frac{\beta_\phi}{\beta_{\widehat{\phi}}}\overline{\phi} + \frac{\beta_{\widetilde{\phi}}}{\beta_{\widehat{\phi}}}\widetilde{\phi}_t$. Finally, the vectors of coefficients, $Z_1 = (z_1, .., z_T, -z_{s,1}, .., -z_{s,T})'$ and $\widehat{Z} = (\widehat{z}_1, .., \widehat{z}_T)'$, depend on the parameters that govern the distributions of the various shocks and signals.

Goods market clearing

The goods market clearing condition in period t is:

$$\tilde{Y}_t + Y_t = C_t + K_t + I_t + M_t$$

Using equations (4.4), (4.5), (4.9), (4.13), (4.14) and $w_t L = (1-\alpha)Y_t$, this is simplified to:

$$(\Gamma\phi_t - \pi_t)A_t = I_t - P_t(A_{t+1} - A_t)$$

The left-hand side of this equals to zero, due to the equilibrium profits as given by (4.3). The right-hand side equals to zero, because all the funds raised from the equity market are used for R&D investment, (4.8). Therefore, the market clears out in all interim periods.

4.3 Results

4.3.1 R&D growth

By (4.7) and (4.8), equilibrium R&D growth in every period t is given by:

$$g_{A,t} \equiv \frac{A_{t+1} - A_t}{A_t} = \left(\lambda^{\frac{1}{\rho}} \frac{1-\alpha}{\alpha}\right)^{\frac{\rho}{1-\rho}} \left(\frac{P_t}{\pi_t}\right)^{\frac{\rho}{1-\rho}} \tag{4.18}$$

This expression shows that R&D growth during period t depends positively on the equity prices, given the profits paid as dividends in the same period and suggests the results to follow. As shown in (4.17), equity price in a market with information imperfections can deviate from the underlying expected value of the firm due to the presence of optimism (or pessimism) that is generated by the public signals and/ or transitory noise trading shocks. As a result, the evolution of R&D production over time itself deviates from the growth that would take place in an economy with perfect information[19].

4.3.2 Three-period example

Assume that there are only three periods. In the first period, the labour-augmenting productivity, ϕ_1, the initial number of known varieties, A_1, and investment in the risk-free technology, M_0, are given. The production of final good (4.1) takes place only in periods 1 and 2. As a result, the R&D and equity market operate only in period 1 (i.e. $A_3 - A_2 = 0$ and $P_2 = P_3 = 0$).

Entrepreneurs engage into R&D production (4.7) in period 1, in order to deliver the set of new blueprints, $A_2 - A_1$. Successful entrepreneurs manufacture the new intermediate-goods in period 2. Given that period 2 is the last productive period

[19]The same is true for output growth since it becomes positively dependent on the equity prices through the endogenous technological progress: $g_Y \equiv \frac{Y_{t+1}-Y_t}{Y_t} = (1+g_{A_t})\frac{\phi_{t+1}}{\phi_t} - 1$.

for all intermediate-goods producers, the dividend paid during this period equals the liquidation value of the firm.

As the only generation of equity market investors is the one born in period 1, its consumption in period 2 is given by (4.14), for $t = 2$. Consumption in period 1 is financed only by the returns on their endowments (i.e. their initial asset holdings, A_1 and M_0). Consumption in the terminal period equals the gross risk-free return on the labour income received during period 2[20].

In period 1, every rational consumer i born in that period decides upon its investment on equity given his information set (see Section (4.2.2)). When $T = 1$ and $t = 1$, every investor i trading in period 1 receives a private signal $\nu(i) = \nu_1(i) = \phi_2 + \varepsilon_{\nu,1}(i)$, where $\varepsilon_{\nu,1}(i) \sim N(1/\beta_\nu)$. All investors receive a public signal $\widetilde{\phi} = \widetilde{\phi}_1 = \phi_2 + \varepsilon_{\widetilde{\phi},1}$, where $\varepsilon_{\widetilde{\phi},1} \sim N(0, 1/\beta_{\widetilde{\phi}})$. The updated public signal is $\widehat{\phi} = \widehat{\phi}_1 = \frac{\beta_\phi}{\beta_{\widehat{\phi}}}\overline{\phi} + \frac{\beta_{\widetilde{\phi}}}{\beta_{\widehat{\phi}}}\widetilde{\phi}_1$. In the three-period setting, it is not important to distinguish the public signals about permanent and temporary productivity. Hence, in this Section, "the public signal" is given by: $\widehat{\phi} = \phi_2 + \varepsilon_{\widehat{\phi}}$, where $\varepsilon_{\widehat{\phi}} \sim N(0, 1/\beta_{\widehat{\phi}})$. To summarize, the information set is $\Omega_1(i) = \{\nu(i), \hat{\phi}, P_1\}$.

The equilibrium equity price equation in the three-period model is:

$$P_1 = \frac{\Gamma}{\tilde{R}}\phi_2 + \frac{\Gamma}{\tilde{R}}z_1\left(\hat{\phi} - \phi_2\right) - \frac{\Gamma}{\tilde{R}}z_{s,1}s_1 \tag{4.19}$$

, where:

$$z_1 = \frac{\beta_\phi}{\beta_{\widehat{\phi}} + (\frac{\beta_\nu}{\tau\Gamma})^2\beta_s + \beta_\nu}, \; z_{s,1} = \frac{\tau\Gamma + (\frac{\beta_\nu}{\tau\Gamma})\beta_s}{\beta_{\widehat{\phi}} + (\frac{\beta_\nu}{\tau\Gamma})^2\beta_s + \beta_\nu} \tag{4.20}$$

Details of the derivation are provided in Appendix C.1. The second term of the equilibrium price equation in (4.19) captures the extent of mispricing, due to the

[20]The market clearing condition in the first period is identical to Section 4.2.3. For the second period, $C_2 = \pi_2 A_2 + \tilde{R}M_1$ and $\tilde{Y}_2 + Y_2 = C_2 + K_2 + M_2$, which holds true by (4.1), (4.2), (4.5), (4.9) and (4.13). In period 3, $\tilde{Y}_3 = C_3 = \tilde{R}M_2$.

presence of the common and noisy public signal. When none of the signal is perfect, the rational consumers take all of them into account when forming their expectations about productivity in period 2. When aggregating over all rational consumers, while the noise in private signals averages to the true productivity, ϕ_2, the mean of the public signal does not average out to the true productivity. Equity mispricing can also result purely by a noise trading shock in period 1.

In the absence of a trading shock (i.e. $s_1 = 0$), the magnitude of equity mispricing depends on the weight on the public signal (z_1) in the equity pricing equation. This weight increases in the variance of private signal and noise trading shock and decreases in the variance of the public signal, as these variances reflect the relative quality of the different sources of information. Higher risk aversion implies lower demand and participation of rational-consumers in the equity market, which also worsens the quality of the price signals.

"Market optimism" is defined as the state where the updated information extracted from the public signal results in an expectation on the future productivity that exceeds its realization value, i.e. $\hat{\phi} > \phi_2$. Hence, in the absence of a noise trading shock, market optimism results in the equity price exceeding the underlying fundamental value of the firm.

Given the equilibrium equity price for the three-period model, (4.19), the remaining equilibrium allocations and growth rates may be solved for as described above and given in Section (4.2). The results of the model are contrasted to the ones delivered by an economy with the same production and consumption structure as the baseline model, but where there is perfect information in the equity market. Even though such an economy does not operate in a first-best environment (due to monopolistic and R&D production distortions), it is a useful benchmark as it uncovers the impact of the equity market imperfections on the long-run growth performance of the three-period economy.

Perfect information equilibrium price

If private information was perfect (i.e. $1/\beta_{\nu} \to 0$), or there was no public information (i.e. $1/\beta_{\widehat{\phi}} \to \infty$), then the wedge between the public signal and the actual productivity (i.e. $\hat{\phi} - \phi_2$) in (4.19) would disappear. In this case, consumers do not take into account the public signals. Define the economy with perfect private signals as the "Perfect Information" (PI) economy.

By (4.19) and (4.20), the equilibrium price in the PI economy is:

$$P_1^{PI} \equiv \lim_{1/\beta_{\nu} \to 0} (P_1) = \frac{\Gamma}{\bar{R}}\phi_2 \tag{4.21}$$

In the analysis that follows, equity is considered as "overpriced" ("underpriced"), if the equilibrium price in the model economy exceeds (is below) the one in the PI economy[21].

Consumption

The "initial path" of the model economy is such that the public signal is correct (i.e. $\widehat{\phi} = \phi_2 = \phi$) and the noise trading shock is at its mean (i.e. $s_1 = 0$). This implies that along this path the equilibrium outcomes of the model and PI economies would coincide. This Section compares the impact of changes in the true productivity, ϕ_2, market perception, $\widehat{\phi}$, and noise trading, s_1, on the two economies and discusses how these outcomes compare. The following Proposition summarizes the results. Details of the proof are in Appendix C.2.

[21] Note that $P_1 > P_1^{PI} \Longleftrightarrow \hat{\phi}_2 - \phi_2 > \frac{(\tau\Gamma)^2 + \beta_{\nu}\beta_s}{\beta_{\phi}\tau\Gamma} s_1$. Therefore, a sufficient condition for this is that there is market optimism and there is no excess supply of assets from the noise traders, i.e. $s_1 \leq 0$.

Proposition 1 *In the three-period model economy, an increase of the true productivity or public signal and a decrease of the noise trading lead to higher consumption in period 1 and period 3. In period 2, consumption increases due to a true productivity shock and decreases due to a positive public signal shock and a negative noise trading shock.*

The intuition for this result is the following. In response to such shocks, equity prices rise. This implies that consumption in period 1 is higher, because it is financed entirely by the returns on assets and the equity holdings may be sold for a higher price. Consumption in period 3 is also higher, because the higher equity prices lead to higher investment in technology and higher R&D production. The horizontal expansion of capital results in higher output and wages in period 2, which allow for higher consumption in the terminal period.

Consumers born in period 1 retire from the labour market before the newly developed technology is used in the production process. Therefore, they do not receive any benefits in terms of higher wages. The direction of change of their consumption depends on whether in period 2 they receive capital gains or losses on their equity holdings. On the one hand, when the actual productivity increases ceteris paribus, then equity price in period 1 effectively reflects market pessimism and equity is underpriced. Therefore, equity holders receive excess gains in the form of higher than expected dividends and can increase their consumption. On the other hand, if equity is overpriced (due to a positive public signal or negative noise trading shock), these consumers obtain excess losses in equity market and consume less in period 2[22]. The following Corollary summarizes how the model and PI economies compare in terms of aggregate consumption in every given period

[22]The magnitude of excess losses is affected by the weight investors put on the public signal (z_1). When this weight is high, then excess losses tend to be higher in the case of a positive public signal shock relative to a noise trading shock.

(for its proof see Appendix C.3)[23]:

Corollary 1 *When equity is overpriced ($P_1 > P_1^{PI}$), consumption in periods 1 and 3 is higher in the model economy than in the PI one. The opposite is true for consumption in period 2.*

There are two aspects of these results that are dependent on the current model set-up. First, given the three-period setting, where R&D production is a one-shot game, the intertemporal knowledge spillover effect is not fulfilled. This is because the expansion of technology frontier is not allowed to accommodate the R&D production in future periods. The congestion effect has a second-order role by decreasing the rate of returns to R&D investment. The infinite-horizon analysis that follows accounts for both of these effects. Second, due to the assumed OLG setting, R&D investment can increase along with aggregate consumption. This is because the generation that finances the R&D investment costs is different from the generation consuming in every period. The generation that allocates part of its final good resources (labour income) into equity redirects resources to the generation that retires from equity market and consumes within the same period. The effect of the investors' decisions on their own consumption comes only with one period lag.

4.3.3 Numerical results for the infinite-horizon

The results of the model of Section 4.2 are derived numerically in two stages: First, the equity price equation (4.17) is solved, by applying the method of undetermined coefficients to recover the vectors Z_1 and $\hat{Z}$. This provides the equilibrium price

[23] The results of this Section suggest that any comparison of the performance of the two economies in terms of aggregate consumption over time involves an important inter-generation welfare trade-off. Further discussion of the welfare properties of the model is postponed until Section 4.4.

equation. Second, the solution outcome of this first stage is used to solve for the remaining endogenous variables of the model. The PI price equation is found under the assumption of perfect private signals and is presented in Appendix C.4.

In the "initial path" of the model economy, noise trading is at its mean, the productivity is constant and all public signals are correct (i.e. $s_{t+k} = 0$, $\phi_{t+k} = 1$, $\overline{\phi} = 1$, $\widehat{\phi}_{t-T+k} = 1$, $\widetilde{\phi}_{t-T+k} = 1$ for all $k \in \mathbb{Z}$). Along this path the model and PI economy are along the same BGP, where R&D, output and consumption grow at the same rate and consumers do not obtain any excess gains or losses from the equity market. This Section presents the numerical results regarding the response of the model and the PI economy to different shocks, in terms of their equity prices, P_t, R&D growth, $g_{A,t}$, consumption, excess capital gains, $P_t + \pi_t - \tilde{R}P_{t-1}$, output growth, $g_{Y,t}$, and alternative asset holdings, M_t. In every period, consumption is measured in terms of consumption in the initial path, in order to capture its deviation from it[24]. Details on the choice of parameter values, are found in Appendix C.7[25].

A non-justified improvement of market perception about productivity in t. This case considers the impact of an increase in the public signal available in period $t - T$, $\tilde{\phi}_{t-T}$, regarding productivity in period t. This implies increase in $\widehat{\phi}_{t-T}$. Since public signal does not enter its equilibrium equity price, the PI economy is not affected and remains along the initial path. Figure 4.4 confirms the result of the three-period model that market optimism increases equity prices, R&D growth and output growth for the model economy in all periods from $t - T$ to $t - 1$. The long impact of the temporary public signal is due to the fact that

[24]In particular consumption deviation is measured as C_t/C_t^{intl} for the model and C_t^{PI}/C_t^{intl} for the PI economy, where C_t^{intl} is the consumption level corresponding to the initial scenario.

[25]The results presented here have rather a qualitative rather than qunatitative value provided that there are no direct measures of the quality of the different sources of information in the equity market.

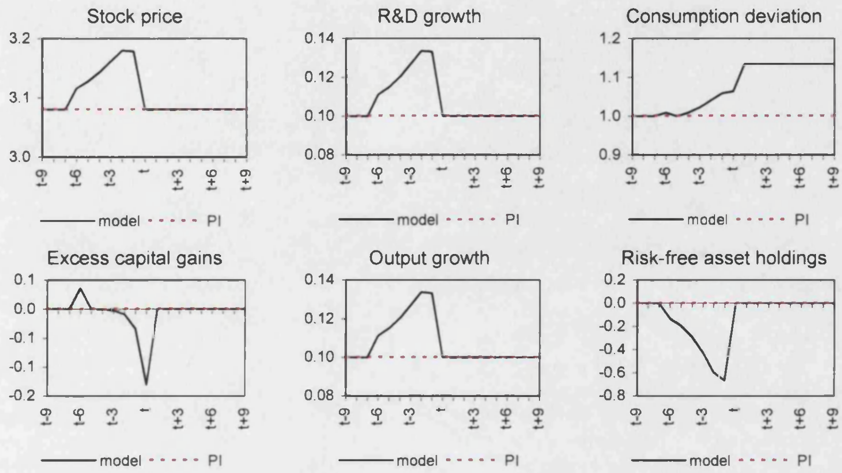


Figure 4.4: Impact of an unjustified improvement of the market sentiment in $t-T$.

since it is informative about future productivity, it enters the information set of all generations of investors during this time interval.

Regarding the effect of this shock on aggregate consumption, the results of the Section 4.3.2 are repeated: The effect on consumption in period 1 of the three-period setting corresponds to the one on consumption in period $t-T$ here. The impact on consumption in period 2 of the three-period setting corresponds to the one on consumption in period $t-T+1$ here, and finally the net gains of consumption in the terminal period correspond to the consumption gains of all consumers from period t onwards in the infinite-horizon setting. What the infinite-horizon setting highlights is that while all generations consuming between periods $t-T+1$ and t get excess losses in the equity market that increase over time, they can have higher consumption compared to the initial path ($C_{t-T+k} > C_{t-T+k}^{intl} = C_{t-T+k}^{PI}$ for $k \in [2, T]$), due to the increase of their wages that is due to the technology expansion.

Above mean demand from the noise traders This case considers a decrease of s_t. There is no impact for the PI economy. Equity price in the model economy increases in period t in response to the negative noise trading shock, and the effect of the shock is present until $t + T - 1$, because the noise trading shock is not fully revealed to the rational consumers until then. As a result, R&D and output growth increase during this period above their initial path levels.

The infinite-horizon setting highlights an important difference between the impact of a noise trading shock and a public signal. Figure 4.5 presents the impact of a temporary noise trading shock in period $t - T$ and an increase in the public signal in the same period[26]. In response to either shock, prices increase in period $t - T$ and remain above the initial path until $t - 1$.

A striking implication of this analysis is that while the effects of these two shocks are qualitatively similar, the persistence of the noise trading shock is very low[27]. The noise trading shock has a maximum impact in period $t - T$, when it has a direct effect on the equity prices. Following the first period, as a historical noise trading shock, it has only a limited impact on the equity prices, as it affects them only indirectly through the noisy historical price signals. As a result, equity mispricing almost disappears after the noise trading shock period. In contrast, an optimistic public signal retains its direct impact on the equity prices over time and thus its positive effect on equity prices resembles high persistence. Since the impact of any shocks is transmitted to the other economic variables through the equity price, it follows that the increase in future consumption levels due to a noise trading shock is smaller compared to the one resulting from market optimism.

[26] Recall that this captures optimism regarding productivity in period t.

[27] This is the reason that the persistence of the noise trasing shock is not clearly visible in Figure 4.5.

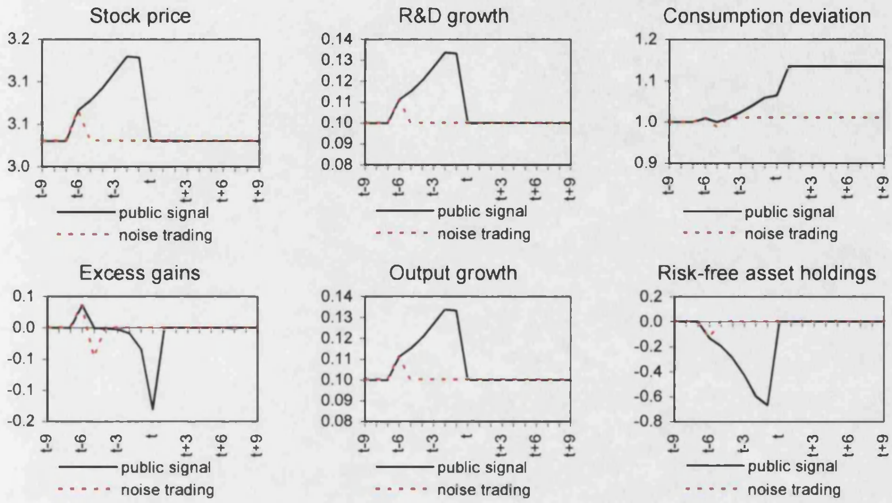


Figure 4.5: Comparison of the impact of a public signal shock about productivity in t and a noise trading shock in $t - T$.

A temporary productivity shock that is not accompanied with a change in the public signal

This case considers the impact of temporary increase of productivity in ϕ_t. The effect absent in the three-period model economy is that in period t, equity price returns to the initial level, while profits of the intermediate-goods firms increase (Figure 4.6). As a result, R&D growth falls below its initial path level for one period. While the acceleration of R&D growth is lower in the model economy during periods $t - T$ to $t - 1$, in t it falls to the same level as in the PI economy. The economy with information imperfections and effectively pessimistic public signal does not take the full advantage of the positive productivity shock, which could result in lower consumption levels compared to the initial scenario for the model economy.

In contrast to a temporary productivity shock, a permanent improvement of productivity is not accompanied by a fall in R&D growth below its pre-shock level.

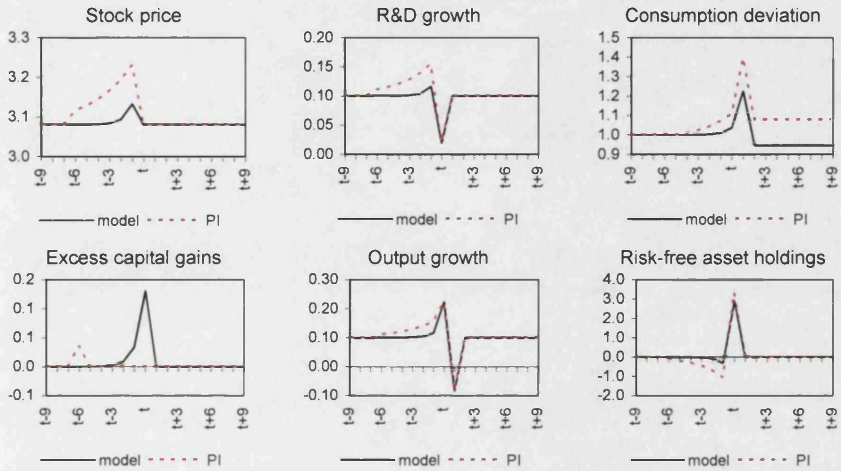


Figure 4.6: Impact of a temporary productivity shock in t, not anticipated in the public signals

The results in Figure 4.7 show the impact of a permanent productivity shock that is fully anticipated in public signals. In view of the previous results, it follows that in the presence of some degree of optimism (pessimism) in the equity market due to the public signals, the implied gains (losses) for the consumption of the future generations would be higher.

4.4 Discussion on the welfare properties of the model

The model economy analyzed in this paper bears three sources of distortions. The first two are common in the R&D-based endogenous growth model and regard the monopolistic structure of the intermediate-goods market and the spillover effects present in the R&D process. The presence of monopoly prices imply that there is underinvestment in R&D as its private returns (i.e. expected profit flow) does not account fully for its social returns (i.e. final output productivity due to the

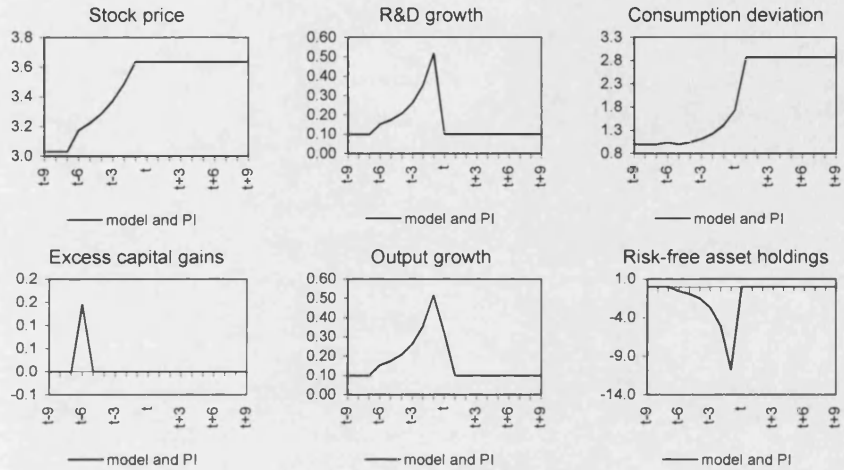


Figure 4.7: Impact of a permanent and fully anticipated increase of productivity in t

capital's horizontal expansion). The spillover effects in the R&D process can also result in underinvestment in R&D to the extent that the positive spillover effect dominates the negative congestion effect. This is the case when the degree of congestion is low in the R&D process. Both of these spillover effects are purely external and as a result, the value of the firm cannot internalize them.

The third source of distortion comes from the equity market, where the presence of information imperfections implies that equity price can deviate systematically from the underlying fundamental value of the firm. While the equity contract cannot account explicitly for the external effects that the R&D activity of the firm generates, the equity market's distortion may act towards alleviating the distortion in the production side of the economy. In the presence of optimism, equity price rises above the underlying fundamentals, which implies that equity investors offer "free funds" to the R&D producers. Even though this is the outcome of factors unrelated to the external effects of the intermediate-goods development and production, it results in bringing R&D investment closer to its socially desirable level, when social returns to R&D are higher than the private ones.

To summarize, the above discussion suggests that market optimism facilitates the coordination among the equity market participants to determine equity prices closer to the social value of assets. In contrast, in perfect financial markets such coordination would fail due to free-riding. Given the aggregate path of technology, there are no incentives to invest in equity if equity prices are above the present discounted value of dividends.

The analysis of the model's results in Section 4.3 highlights that the impact of the information imperfections on aggregate economy involves an important intergenerational welfare trade-off. This is because R&D production is not free, given that it competes for the limited final good resources available every period. Market optimism causes a misallocation of investors' finite resources (labour income) away from the risk-free asset and into the intermediate-goods equity. Therefore, the first generation that experiences a purely temporary positive public information shock, receives net losses in asset market without any compensation from the higher final good production that is enabled through the expansion of the known intermediate-goods' varieties. Moreover, this generation, when investing in the equity market, directs its labour income resources not only to R&D innovators, but also to the investors that offer the "old" assets in the market. This accrues to a transfer of consumption ability across generations that has a dramatic effect at the time that market optimism is generated.

On the other hand, any subsequent generations of investors sharing market optimism effectively bear a lower cost in investing their labour income into equity, since these resources already reflect the benefits from R&D driven output expansion. Once the actual productivity is realized and market optimism dissolves, all future generations experience a pure gain in consumption terms driven by the intertemporal knowledge spillover effect and the expansion of the output possibility frontier.

When market optimism is not only due to a one-period observation of a positive public signal regarding future productivity, but is instead fed with subsequent releases of positive public information, it is possible that no generation of investors in the model economy experiences a reduction of its consumption compared to the case of absence of market optimism. Proposition 2 shows that persistent market optimism can overwhelm the inter-generational consumption trade-off described above and in this sense market optimism can cause a Pareto improvement in terms of consumption across generations[28]. Without loss of generality, the result is proved for the simplest case of an infinite-horizon model, where investors get public signals about productivity two periods ahead, $T = 2$.

Proposition 2 *Assume that actual productivity stays constant and equal to its long-term value, $\phi_t = \overline{\phi} = \phi$, and noise trading is at it mean value each period, $s_t = 0$, for any t. When there are positive public signal shocks in two consecutive periods, $\hat{\phi}_t = \phi + \Delta\hat{\phi}_t$ and $\hat{\phi}_{t+1} = \phi + \Delta\hat{\phi}_{t+1}$, while $\Delta\hat{\phi}_{t+1-k} = \Delta\hat{\phi}_{t+k} = 0$ for any $k \geq 2$, then there exist $\Delta\hat{\phi}_t > 0$ and $\Delta\hat{\phi}_{t+1} > 0$ such that consumption in the model economy is at least as high as in the one with perfect information in every period, i.e. $C_t \geq C_t^{PI}$ for any t.*

The intuition behind the result is the following. Proposition 1 and Corollary 1 imply that the release of the public signals raises equity prices above fundamentals from period t until $t+2$, and, as a result, consumption in t and for any period from $t+4$ onwards is strictly higher in the model economy compared to the PI one. In contrast to the case of a unique positive public signal shock (i.e. when $\Delta\hat{\phi}_{t+1} = 0$), equity prices do not need to fall between t and $t+1$ when there is a subsequent

[28] Such Pareto improvement does not rely on inter-generational transfers that violate the transversality conditions.

positive public signal. If the second public signal is sufficiently high, consumers in period $t+1$ can have at least as high consumption as in the PI. In periods $t+2$ and $t+3$, consumers get excess losses in the equity market. If the public signals are not too high, the benefits from higher wages due to the endogenous output expansion can offset the losses in the equity market. This result depends on the degree of congestion in the R&D production, since it regulates the strength of the diminishing returns to R&D investment[29].

In view of this discussion of the welfare properties of the model economy, this paper has some policy implications to the extent that some policy making institutions have the ability to affect the public signal (e.g., the central bank's comments about economic conditions and outlook). The results reveal the existence of a dilemma for such policy makers. If the public signal coincides with the true productivity, then there is no room for equity mispricing. Hence, potential negative effects of such mispricing would be eliminated. However, given the possible aggregate consumption gains (losses) driven by market optimism (pessimism), there is a role for discretionary policy. In particular, the policy maker has incentives to preserve an asymmetric behavior over periods that the equity market sentiment is optimistic or pessimistic. This is because, unless the wedge between the public signal and the underlying fundamentals is extremely high, it is unlikely that issuing a low public signal is welfare improving (in terms of aggregate consumption over time). Quite to the contrary, in a pessimistic market the policy maker has clear incentives to intervene by injecting optimism to the market. The downside of adopting such asymmetric policy is that it is likely to reduce the credibility of policy maker's optimistic statements among the market participants (i.e. the

[29]Consider the extreme case of congestion, i.e. $\rho \to 0$. Then R&D growth is no longer endogenous, $g_{A_t} \to \lambda$, as any additional funds have zero additional effect on the underlysing productivity. Therefore, market optimism does not transmit to R&D growth.

policy action affect the whole distribution of the public signal). That would imply that the policy instrument becomes weaker. At the same time, there is the trade-off regarding the welfare across different generations of the equity market participants.

An implication of the information structure is that the extent of the equity market mispricing depends on the relative quality of the different sources of information. The better is the private information and the more informative are the price signals compared to the public ones, the smaller is the bias caused by mispricing[30]. In order to lower the quality of information of the public signal, a policy maker could reduce the frequency of statements about economic outlook and equity prices. However, the dilemma and trade-off of welfare among different generations as discussed above remains.

4.5 Conclusions

This Chapter analyzes a model economy, where the equity market's information imperfections affect long-run aggregate economic performance. The proposed transmission mechanism is the reliance of R&D activities' funding on equity, that is potentially priced away from the underlying fundamentals. The results from such setting are contrasted to ones from the economy where R&D is funded in an equity market with perfect private information. The comparison between the two economies leads to the following conclusions.

First, the model economy tends to perform worse than the one with perfect information in the event of true productivity shocks that increase the equity prices. This is a result of the market pessimism and equity underpricing that is generated

[30]This is purely due to the fact that investors assign lower weight on public signal in their expectation.

to the extent that the market sentiment does not match these changes. Second, the model economy tends to perform better than the perfect information one in the presence of market optimism. This occurs because overpricing of assets results in more R&D being produced. Even if demand in the future does not justify the initial equity prices, more R&D has a positive impact on future generations consumption levels through higher output. As a result, in the model economy there are gains in consumption of all future generations at the expense of possible losses of the earliest generation(s). However, when market optimism is fed with subsequent positive public information release, there is scope for the early periods' losses to be eliminated. The positive effect of some optimism is present, when the R&D-production market is not already highly congested. Third, the model economy can also have consumption gains in response to a noise trading shock that rises equity prices above the underlying fundamentals. However, the persistence of this shock is much smaller compared to the shock related to market optimism.

Related to the original motivation of the paper, this paper suggests that there could be welfare gains for the United States from the 1990s "dot-com" experience in terms of innovations that expanded the United States production possibility frontier. This is because, the ICT innovating sector was arguably not highly congested and market optimism was present regarding the future prospects of the ICT-producing sector productivity.

Chapter 5

Conclusion

In Chapters 2-4, this thesis examines aggregate economic performance in an economy, where the different production sectors are linked through the production and use of R&D products, like Information and Communication Technologies (ICT), and intermediates. The price of these goods is determined by the interaction of the different sectors in their production. Their use delivers benefits for the aggregate economy to the extent that sectors that differ in terms of their production structure respond to the economic incentives provided by their prices. The analysis is used to account for recent growth episodes in the United States and the United Kingdom.

Chapter 2 examines growth of the United States economy over the past thirty years. It focuses on the use of ICT and the production of intermediates. It shows that despite the fact that advances in ICT benefit directly only the sector that uses ICT-capital, there are also indirect growth benefits for the sector that uses only non-ICT-capital. This is because the ICT-using and non-ICT-using sectors are linked through the production of intermediates, where the evolving over time productivity embodied in the ICT-capital, results in falling intermediates and capital prices. In the long-run equilibrium, the non-ICT-using sector experiences capital accumulation driven growth, which is lower than that of the ICT-using sector. The uneven sector-level growth delivers a constant growth path for the aggregate economy, where growth is endogenously driven by the ICT progress.

Chapter 3 focuses on the use and production of goods and services-intermediates. An empirical study applied for the United States and the United Kingdom over the past thirty years, reveals that there is a substitution of the goods-intermediates with the services ones. It shows that this substitution is explained by the falling relative prices of the goods-intermediates, when the latter complement the services-intermediates in the production of an average industry. It uses the empirical results to highlight the patterns of additional technological and policy factors that affect an industry's choice of secondary inputs.

Chapter 4 is motivated by the output growth and the equity market experience of the United States economy during the 1990s, which is related to the ICT-production. It highlights the importance of the equity market in providing funding for the technology producing sector, and investigates the long-run aggregate economic impact of information imperfections that cause equity mispricing. It shows that in the presence of optimism in the market regarding future productivity, equity prices rise above the underlying fundamentals, increasing the funding for R&D activities and therefore expanding the production possibility frontier of the economy. Despite the realized losses in the equity market, there are potential welfare gains in terms of aggregate consumption.

The results of this thesis emphasize that policies that are meant to enhance long-run growth need to take into account the multi-sector setup of aggregate production. Chapter 2 demonstrates the importance of policy directed to the use of the new large-scale technologies (like ICT). In particular, the results show that the linkage of the intensive and non-intensive technology-using sectors in the economy have a positive growth effect for the non-intensive technology-using sector and a negative one for the intensive technology-using sector. Hence, any sector-level productivity policy (e.g. regulations, subsidies for technology-use, subsidies/ taxes scheme affecting prices of intermediates) need to be designed in a way to achieve the following goals. First, increase the adoption of the technology throughout the economy. Second, eliminate any policies distorting the relative prices between the intensive and non-intensive technology-using sectors. Third, foster the role of the intensive technology-using sector in providing intermediates services at relatively low prices, by creating policies that foster its productivity (e.g. incentives for more intensive and efficient use of the technology, lower the adjustment costs in relation to technology adoption and business transactions).

Chapter 3 complements the policy implications of Chapter 2. It indicates that industry-level productivity policy cannot be designed without taking into account the way this industry is linked to the other industries in the economy in terms of intermediates transactions. Its results suggest that policy may have a long-lasting effect on the industries' choices of productive factors and thereby final output performance.

Chapter 4 has policy implications regarding the role of policy with respect to the equity market performance. It shows that given the conditions in the equity market and the R&D-producing sector, there might not be incentives to interfere in the presence of optimism in the equity market that increase the funds available for R&D intensive firms. This is because equity mispricing in this case, functions as a means to internalize the technology spillover present in the R&D-production. The decision regarding such policy depends critically on how the policy makers sets objectives and values the utility of different generations. In addition, the results show that should the policy maker be willing to issue any signals, these would be biased to be positive. Such bias in policy announcement would weaken (and in the limit eliminate) this policy instrument. A detailed theoretical and empirical investigation of such policy-related issues provides scope for further research.

Extensions of the analytical frameworks of Chapters 2-4 provide additional avenues for future research. Chapter 2 may be extended to account for more specific features of the ICT, such as the network aspect of these technologies. The current theoretical framework applies more generally to an economy with partial adoption of a General Purpose Technology and does not examine any technology adoption decisions. Within this, network externalities would appear as an additional productivity gain for the ICT-using sector that is not embodied in the ICT-capital. This productivity gain would be increasing in the number of ICT applications. However, in a more complete setting, network externalities need to be analyzed together with the adoption decisions. Within this, industries decide whether to adopt ICT, depending on the price of ICT-capital and their expectation regarding the size of the network of the ICT-using industries. The firms that supply ICT-capital would take the network externalities present in the demand-side into account. The ICT-producing sector would respond to these developments in the downstream sectors.

In terms of its application, Chapter 2 may be extended to analyze the dynamic behavior of the economy, when the Constant Growth Path restrictions are not imposed on the set of equilibrium conditions. Such extension would reveal how much the economy's CGP differs from out of CGP behavior. It could also provide a more suitable setup to analyze the acceleration of the United States productivity growth in the mid-1990s through a potentially improved calibration of the transition dynamics.

Regarding the empirical analysis of Chapter 2, an important extension would be a comparative study of the United States with major European economies. This would shed more light regarding the performance of the model in accounting for the growth experience in the ICT era. In addition, such analysis would highlight differences across these economies with respect to the features of the production and consumption side that are important within the theoretical setting that Chapter 2 develops. This would indicate how the current framework needs to be extended, in order to accommodate the special features of the major European countries and explain the United States-Europe productivity gap.

Accounting for the United States-United Kingdom productivity gap poses additional challenge, given that the two economies are broadly similar in terms of their institutional characteristics. The productivity analysis framework employed in Chapter 3 can be used for an in-depth analysis of this issue. Its empirical investigation indicates the importance of technology and/ or policy related factors in determining the industries' secondary inputs choice. One control for such factors would be to allow for a more general production framework and/ or use measures of technology or policy-related instruments that can impact an industry's efficiency in using the different types of intermediates. The extension of the current framework into a more general production framework that will jointly account for all inputs in the production function, both primary and secondary would strengthen the present results of Chapter 3. Furthermore, in order to account for the effect of a policy or a technology breakthrough on industry productivity, one may use directly the I-O tables and apply existent methodologies (such as "Input-Output multipliers") in order to recover the impact of such factors for the final industry performance.

Another direction for future research is an empirical analysis that would account for the quantitative importance of the mechanism proposed in Chapter 4.

The theoretical framework of Chapter 4 also gives way for extensions by relaxing its stylized assumptions regarding the source of funding for R&D activities, the exogenous choice of timing for equity issue and the lack of uncertainty in the R&D process. Doing so, would not alter the main mechanics, but it would have an impact on the magnitude of the different forces and potentially introduce new ones. Moreover, it would increase the complexity of the policy decisions. The use of alternative welfare measures would be also an interesting application, as it would point out to the importance of the selected policy objectives in terms of the policy action related to the equity market developments.

To conclude, this thesis aims to account for drivers of economic growth in the recent history. It examines the behavior of the economy at the disaggregate sector and/ or industry-level through theoretical and empirical frameworks developed in Chapters 2-4. It shows that the revealed dynamics at the disaggregate level are critically dependent on the criteria used to group different industries of the economy. Within the spirit of the recent developments in the productivity analysis, it emphasizes the role of ICT and other intermediates in terms of the production and transmission of growth throughout the economy. It highlights the importance of the equity market for the long-run economic performance, when growth is driven R&D. A more thorough investigation of these issues is left for future research.

Appendix A

Appendix for Chapter 2

A.1 Proof of Proposition 1

Production side: The final good producers take prices as given in input and output markets. Therefore, their demand for capital comes by equating the value of marginal product of every capital variety to its price:

$$\begin{aligned} \frac{\partial Y_0}{\partial x_0(i)} &= \alpha(u_0 L)^{1-\alpha} x_0^{\alpha-1}(i) = \hat{p}_0(i), \forall i && \text{(A.1)} \\ p_1 \frac{\partial Y_1}{\partial x_1(j)} &= p_1 \alpha(u_1 L)^{1-\alpha} x_1^{\alpha-1}(i) = \hat{p}_1(j), \forall j && \text{(A.2)} \end{aligned}$$

The intermediate output producer also takes prices as given in input and output markets. The demand for the intermediates produced by the two final-good sectors is:

$$\begin{aligned} p_H \frac{\partial H}{\partial h_0} &= \beta p_H h_0^{\beta-1} h_1^{1-\beta} = 1 && \text{(A.3)} \\ p_H \frac{\partial H}{\partial h_1} &= (1-\beta) p_H h_0^{\beta} h_1^{-\beta} = p_1 && \text{(A.4)} \end{aligned}$$

The implied relative demands and price for the intermediate goods:

$$\frac{\beta}{1-\beta}\frac{h_1}{h_0} = \frac{1}{p_1} \tag{A.5}$$

$$p_H = Bp_1^{1-\beta} \tag{A.6}$$

,where $B = \left[\beta^{\beta}(1-\beta)^{1-\beta}\right]^{-1}$.

The producers of the capital varieties function under monopolistic competition. In the absence of dynamic decision variables, they maximize their profits by choosing their price and production in every period:

$$\pi_0(i) = \max_{\hat{p}_0(i),x_0(i)} \{\hat{p}_0(i)x_0(i) - p_H x_0(i); s.t.(\text{A.1})\}$$
$$\pi_1(j) = \max_{\hat{p}_1(i),x_1(i)} \{\hat{p}_1(i)x_1(j) - p_H x_1(j); s.t.(\text{A.2})\}$$

The solution to these programs gives:

$$x_0 = \alpha^{\frac{2}{1-\alpha}}\left(\frac{1}{p_H}\right)^{\frac{1}{1-\alpha}}(u_0 L) \tag{A.7}$$

$$x_1 = \alpha^{\frac{2}{1-\alpha}}\left(\frac{p_1}{p_H}\right)^{\frac{1}{1-\alpha}}(u_1 L) \tag{A.8}$$

$$\hat{p}_0 = \hat{p}_1 = \frac{p_H}{\alpha} \tag{A.9}$$

The model delivers symmetry across the varieties of each type of capital goods. The implied profit flows for every period is:

$$\pi_0 = \frac{1-\alpha}{\alpha}\alpha^{\frac{2}{1-\alpha}}\left(\frac{1}{p_H}\right)^{\frac{\alpha}{1-\alpha}}(u_0 L) \tag{A.10}$$

$$\pi_1 = \frac{1-\alpha}{\alpha}\alpha^{\frac{2}{1-\alpha}}p_1^{\frac{1}{1-\alpha}}\left(\frac{1}{p_H}\right)^{\frac{\alpha}{1-\alpha}}(u_1 L) \tag{A.11}$$

Aggregate per-period profits are defined as $\Pi = A\pi_0 + N\pi_1$.

The producers of capital varieties enter the market upon getting a "blueprint" that allows them to produce the new varieties that are available at every point in time, $\dot{N}$. The old varieties are fixed in number, hence no new firms enter the market producing non-ICT-capital varieties. With well defined property rights, the cost that each ICT-capital variety producer needs to assume in order to acquire a blueprint is equal to the present discounted value of his entire stream of future profits, $V_1(t)$. The firm considers the real interest rate and the price index of the composite good as given:

$$\frac{V_1(t)}{p_c(t)} = \int_t^{\infty} e^{-\int_t^{\tau} r(s)ds} \frac{\pi_1(j)(\tau)}{p_c(\tau)} d\tau \tag{A.12}$$

Since the labour market is perfectly competitive, there exists a wage, w_L, that clears out the market. This wage is equal to the value of marginal product of labour in all three sectors, where p_N is the value of a patent paid for a new variety:

$$\frac{\partial Y_0}{\partial(u_0 L)} = (1-\alpha)\left(\frac{1}{p_H}\right)^{\frac{\alpha}{1-\alpha}} A\alpha^{\frac{2\alpha}{1-\alpha}} = w_L \tag{A.13}$$

$$p_1 \frac{\partial Y_1}{\partial(u_1 L)} = (1-\alpha) N \alpha^{\frac{2\alpha}{1-\alpha}} p_1^{\frac{1}{1-\alpha}} \left(\frac{1}{p_H}\right)^{\frac{\alpha}{1-\alpha}} = w_L \tag{A.14}$$

$$p_N \frac{\partial \dot{N}}{\partial(u_N L)} = V_1 \lambda N = w_L \tag{A.15}$$

Equating (A.13) and (A.14):

$$p_1 = \left(\frac{A}{N}\right)^{1-\alpha} \tag{A.16}$$

Equating (A.14) and (A.15):

$$V_1 \lambda = (1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}} p_1^{\frac{1}{1-\alpha}} \left(\frac{1}{p_H}\right)^{\frac{\alpha}{1-\alpha}} \tag{A.17}$$

Consumer side: The households solve the following dynamic problem by choosing

$\{c_0, c_1\}$ taking all prices as given:

$$H = e^{-\rho t}\frac{\left\{\left[\theta c_0^{\epsilon}+(1-\theta)c_1^{\epsilon}\right]^{\frac{1}{\epsilon}}\right\}^{1-\sigma}-1}{1-\sigma} + q\left[rS + \frac{w_L L+\Pi-c_0-p_1c_1}{p_c}\right]$$

The solution to this problem gives the standard conditions:

$$\frac{c_1}{c_0} = \left(\frac{1-\theta}{\theta}\frac{1}{p_1}\right)^{\frac{1}{1-\epsilon}} \tag{A.18}$$

$$-\frac{\dot{q}}{q} = r \tag{A.19}$$

The price index of the composite consumption good is given by the inverse of the shadow price to the per-period consumption expenditures allocation problem: $\max\limits_{c_0,c_1}\{[\theta c_0^{\epsilon} + (1-\theta)c_1^{\epsilon}]^{\frac{1}{\epsilon}}\ ;\ s.t.\ E = c_0 + p_1c_1\}$[1]:

$$p_c = \left[\theta^{\frac{1}{1-\epsilon}} + (1-\theta)^{\frac{1}{1-\epsilon}}p_1^{\frac{-\epsilon}{1-\epsilon}}\right]^{-\frac{1-\epsilon}{\epsilon}} \tag{A.20}$$

The above imply:

$$\frac{\dot{C}}{C} = \frac{1}{\sigma}\left[r + \sigma(1-\gamma(t))\frac{\dot{p}_1}{p_1} - \rho\right] \tag{A.21}$$

, where $\gamma(t) = \frac{c_0}{c_0+p_1c_1} = \frac{\theta c_0^{\epsilon}}{\theta c_0^{\epsilon}+(1-\theta)\theta c_1^{\epsilon}} = \frac{1}{1+\left(\frac{1-\theta}{\theta}\right)^{\frac{1}{1-\epsilon}}p_1^{\frac{-\epsilon}{1-\epsilon}}}$ from the equilibrium conditions above.

In order to complete the static equilibrium results, note that the production side requires: $\frac{p_1Y_1}{Y_0} = \frac{u_1}{u_0}$. Given the demand for capital varieties, it follows, $p_HK_0 = \alpha^2Y_0$ and $p_HK_1 = \alpha^2p_1Y_1$ and therefore: $\frac{K_1}{K_0} = \frac{u_1}{u_0}$. Combining these with the market clearing condition for intermediate goods, $H = h_0^{\beta}h_1^{1-\beta} = K_0 + K_1$, (A.3),

[1] See details also in Chapter 3 of Grossman and Helpman (1991a).

and the market clearing for non-ICT-using good, $Y_0 = c_0 + h_0$ it follows:

$$\alpha^2\beta\left(1 + \frac{u_1}{u_0}\right) = \frac{h_0}{h_0+c_0} \tag{A.22}$$

Also, combining the static equilibrium conditions for intermediates and consumption goods: $\frac{h_1}{h_0}\frac{\beta}{1-\beta} = \frac{c_1}{c_0}\frac{\theta}{1-\theta}$. Therefore, combining the results above together with the market clearing conditions for the non-ICT-using and the ICT-using good, $Y_1 = c_1 + h_1$ that:

$$\frac{u_1}{u_0}\left(1 + \frac{c_1}{c_0}\right) = \frac{1-\theta}{\theta}\frac{c_0}{h_0} + \frac{1-\beta}{\beta} \tag{A.23}$$

Using (A.22) and (A.23) allows to solve for the consumption to intermediates shares in the two final goods sectors and relative labour allocations:

$$\frac{c_0}{h_0} = \frac{\gamma(t)(1-\alpha^2)}{\alpha^2\beta} \tag{A.24}$$

$$\frac{c_1}{h_1} = \frac{(1-\gamma(t))(1-\alpha^2)}{\alpha^2(1-\beta)} \tag{A.25}$$

$$\frac{u_1}{u_0} = \frac{1-\alpha^2\beta-\gamma(t)(1-\alpha^2)}{\alpha^2\beta+\gamma(t)(1-\alpha^2)} \tag{A.26}$$

The shares to be positive if: $\frac{1-\alpha^2\beta}{1-\alpha^2} > \gamma(t)$.

Along the CGP, for constant growth rate for the varieties stock, $\frac{\dot{N}}{N}$, the labour allocation in the ICT-producing sector needs to be constant, $\dot{u}_N = 0$. This in turn implies constant growth for the relative prices of capital varieties, $\frac{\dot{\hat{p}}_1}{\hat{p}_1} = \frac{\dot{\hat{p}}_0}{\hat{p}_0} = \frac{\dot{p}_1}{p_1}$, intermediates $\frac{\dot{p}_H}{p_H} = (1-\beta)\frac{\dot{p}_1}{p_1}$, composite consumption good, $\frac{\dot{p}_c}{p_c} = (1-\gamma(t))\frac{\dot{p}_1}{p_1}$, and ICT-using final good, $\frac{\dot{p}_1}{p_1} = -(1-\alpha)\frac{\dot{N}}{N}$, given (A.9), (A.6), (A.20) and (A.16). Note that the condition for constant $\frac{\dot{N}}{N}$, permits for time-varying employment shares in the two final good sectors, with rates of change that satisfy: $\dot{u}_1 = -\dot{u}_0$.

Regarding the dynamic equilibrium results, given the demand for capital varieties (A.7), (A.8) and the growth rates of relative prices, the implied growth rates for the two final-good sectors are constant as well. The growth of aggregate output is constant as well and equal to the growth of the non-ICT-using good. Note that, for the growth of the aggregate output to be constant, it is sufficient that $\dot{u}_N = 0$, because the output growth differences are cancelled out by the relative price differences of the two final-good sectors and any labour reallocations between the two sectors aggregate to zero:

$$\frac{\dot{Y}_0}{Y_0} = \alpha(1-\beta)\frac{\dot{N}}{N} + \frac{\dot{u}_0}{u_0} \tag{A.27}$$

$$\frac{\dot{Y}_1}{Y_1} = (1-\alpha\beta)\frac{\dot{N}}{N} + \frac{\dot{u}_1}{u_1} \tag{A.28}$$

$$\frac{\dot{Y}}{Y} = \alpha(1-\beta)\frac{\dot{N}}{N} \tag{A.29}$$

Given the demand for capital varieties, it follows, $p_H K_0 = \alpha^2 Y_0$ and $p_H K_1 = \alpha^2 p_1 Y_1$. For capital as for output, it is sufficient for constant growth that $\dot{u}_N = 0$. It follows that along the CGP:

$$\frac{\dot{K}_1}{K_1} = \frac{\dot{K}_0}{K_0} = (1-\beta)\frac{\dot{N}}{N} \tag{A.30}$$

$$\frac{\dot{K}}{K} = \alpha(1-\beta)\frac{\dot{N}}{N} \tag{A.31}$$

The market clearing condition for intermediate goods, $H = h_0^{\beta} h_1^{1-\beta} = K_0 + K_1$, (A.5) and the relative prices' growth on CGP, imply:

$$\frac{\dot{h}_0}{h_0} = \alpha(1-\beta)\frac{\dot{N}}{N} \tag{A.32}$$

$$\frac{\dot{h}_1}{h_1} = (1-\alpha\beta)\frac{\dot{N}}{N} \tag{A.33}$$

Finally, the market clearing conditions for the two final-good products together with (A.27), (A.28) and (A.30) :

$$\frac{\dot{c}_0}{c_0} = \alpha(1-\beta)\frac{\dot{N}}{N} \quad \text{(A.34)}$$

$$\frac{\dot{c}_1}{c_1} = (1-\alpha\beta)\frac{\dot{N}}{N} \quad \text{(A.35)}$$

From (A.12), it follows that: $\frac{\dot{V}_1}{V_1} = \left[r(t) + (1-\gamma(t))\frac{\dot{p}_1}{p_1}\right] - \frac{\pi_1}{V_1}$, and from (A.17): $\frac{\dot{V}_1}{V_1} = \frac{1-\alpha(1-\beta)}{1-\alpha}\frac{\dot{p}_1}{p_1}$. Hence, the implied real interest rate from the production side is:

$$r(t) = \left[\frac{1-\alpha(1-\beta)}{1-\alpha} - (1-\gamma(t))\right]\frac{\dot{p}_1}{p_1} + \frac{\pi_1}{V_1}$$

, where again (A.17) implies that: $\frac{\pi_1}{V_1} = \lambda\alpha u_1 L$.

Finally, the market clearing conditions imply that $\frac{\dot{C}}{C} = \frac{\dot{Y}}{Y} = \alpha(1-\beta)g_N$, where $g_N \equiv \frac{\dot{N}}{N} = \lambda L\left(1 - \frac{u_1}{1-\gamma(t)(1-\alpha^2)-\alpha^2\beta}\right)$. Using this condition, substituting for the real interest rate and rearranging terms:

$$\rho + [1-\alpha(1-\beta)+\sigma\alpha(1-\beta)]\,g_N = \lambda\alpha u_1 L + (1-\sigma)(1-\alpha)(1-\gamma(t))g_N$$

Along the CGP, the LHS of this expression is constant. Hence, this relation will hold only if the RHS is constant as well. The requirement for this is: $\frac{\dot{u}_1}{\dot{\gamma}} = \frac{(1-\alpha)(1-\sigma)g_N}{\lambda\alpha L}$. This condition though has to comply with $\frac{\dot{u}_1}{\dot{\gamma}} = -(1-\alpha^2)\frac{g_N}{\lambda L}$, that comes from (A.26) under the CGP requirements. These two conditions are satisfied when the intertemporal elasticity of substitution is: $\sigma = 1+\alpha(1+\alpha)$.

For $\sigma = 1+\alpha(1+\alpha)$, and the steady-state labour allocation into the ICT-producing sector is given by the following expression:

$$u_N = \frac{\alpha\left[1-\gamma(t)(1-\alpha^2)-\alpha^2\beta\right]-\frac{\rho}{\lambda L}}{\alpha[1-\gamma(t)(1-\alpha^2)-\alpha^2\beta]+1+\alpha(1+\alpha)[\alpha(1-\beta)+(1-\alpha)(1-\gamma(t))]}$$

This shows however that the equilibrium allocation is a function of time. The necessary condition for the steady-state requirement $\dot{u}_N = 0$, is either $\dot{\gamma} = 0$, which implies that $\epsilon = 0$, or $\rho = -\frac{\lambda L\left[1+\alpha^2(1-\beta)\right]}{2} < 0$. The latter cannot be the case for a well defined problem. Therefore, this implies that restriction on the intertemporal elasticity of substitution is not a sufficient condition for the existence of a CGP. The necessary condition for this is that there is unit intratemporal elasticity of substitution, i.e. $\epsilon = 0$. The argument for this proof is completed in Proposition 2, where it is shown that the condition on $\epsilon = 0$, is not only necessary, but also sufficient condition for a CGP, since one can solve for the constant allocations of labour and constant growth rates along the CGP, without any further requirements on the intertemporal elasticity of substitution.

A.2 Proof of Proposition 2

For unit intratemporal elasticity of substitution: $u(c_0, c_1) = \frac{\left(c_0^{\theta} c_1^{1-\theta}\right)^{1-\sigma} - 1}{1-\sigma}$, which implies:

$$\frac{c_1}{c_0} = \frac{1-\theta}{\theta}\frac{1}{p_1} \tag{A.36}$$

$$-\frac{\dot{\lambda}}{\lambda} = r \tag{A.37}$$

The price index of the composite consumption good is:

$$p_c = \Theta p_1^{1-\theta} \tag{A.38}$$

,where $\Theta = \left[\theta^{\theta}(1-\theta)^{1-\theta}\right]^{-1}$. The above imply:

$$\frac{\dot{C}}{C} = \frac{\dot{c}_0}{c_0} = \frac{1}{\sigma}\left[r + \sigma(1-\theta)\frac{\dot{p}_1}{p_1} - \rho\right] \tag{A.39}$$

Production side: The solution of the dynamic programs of the final good producers, composite intermediate good and the capital varieties firms remains as described in Proposition 1, and described by (A.1) through (A.17).

Along the CGP, for constant growth rate for the varieties stock, $\frac{\dot{N}}{N}$, the labour allocation in the ICT-producing sector needs to be constant, $\dot{u}_N = 0$. Given (A.9), (A.6), (A.38) and (A.16), this implies constant growth for the relative prices of capital varieties, $\frac{\dot{\hat{p}}_1}{\hat{p}_1} = \frac{\dot{\hat{p}}_0}{\hat{p}_0} = \frac{\dot{p}_H}{p_H}$, intermediates $\frac{\dot{p}_H}{p_H} = (1-\beta)\frac{\dot{p}_1}{p_1}$, composite consumption good, $\frac{\dot{p}_c}{p_c} = (1-\theta)\frac{\dot{p}_1}{p_1}$, and ICT-using final good, $\frac{\dot{p}_1}{p_1} = -(1-\alpha)\frac{\dot{N}}{N}$.

The "guess", to be verified later, is that along the CGP real interest rate, r, and the labour allocations in the two final good sectors are constant. Under these assumptions and together with the constant growth of relative prices, it follows from equating (A.14) and (A.15) that there is a negative relationship between the real interest rate and the ICT-production growth:

$$\alpha\lambda u_1 L = r + \frac{\dot{N}}{N}\left[\theta(1-\alpha) + \alpha\beta\right] \tag{A.40}$$

Completing the static equilibrium results, the consumption to intermediates shares in the two final goods sectors and relative labour allocations are now modified as follows:

$$\frac{c_0}{h_0} = \frac{\theta(1-\alpha^2)}{\alpha^2\beta} \tag{A.41}$$

$$\frac{c_1}{h_1} = \frac{(1-\theta)(1-\alpha^2)}{\alpha^2(1-\beta)} \tag{A.42}$$

$$\frac{u_1}{u_0} = \frac{1-\alpha^2\beta-\theta(1-\alpha^2)}{\alpha^2\beta+\theta(1-\alpha^2)} \tag{A.43}$$

The condition on parameter values that ensures positive labour allocations is: $\frac{1-\theta(1-\alpha^2)}{\alpha^2} > \beta$.

Regarding the dynamic equilibrium results, given the demand for capital varieties (A.7), (A.8) and the growth rates of relative prices, the implied growth rates for the two final-good sectors are constant as well. The growth of aggregate output is constant as well and equal to the growth of the non-ICT-using good. Constant labour allocation in the ICT-producing sector, $\dot{u}_N = 0$, is sufficient for constant aggregate output growth, since the relative output growth differences are cancelled out by the relative price differences of the two final-good sectors and any labour reallocations between the two sectors should aggregate to zero:

$$\frac{\dot{Y}}{Y} = \frac{\dot{Y_0}}{Y_0} = \alpha(1-\beta)\frac{\dot{N}}{N} \quad (A.44)$$

$$\frac{\dot{Y_1}}{Y_1} = (1-\alpha\beta)\frac{\dot{N}}{N} \quad (A.45)$$

Given the demand for capital varieties, it follows, $p_H K_0 = \alpha^2 Y_0$ and $p_H K_1 = \alpha^2 p_1 Y_1$. For capital as for output, it is sufficient for constant growth that $\dot{u}_N = 0$. It follows that along the CGP:

$$\frac{\dot{K_1}}{K_1} = \frac{\dot{K_0}}{K_0} = (1-\beta)\frac{\dot{N}}{N} \quad (A.46)$$

$$\frac{\dot{K}}{K} = \alpha(1-\beta)\frac{\dot{N}}{N} \quad (A.47)$$

The market clearing condition for intermediate goods, $H = h_0^{\beta} h_1^{1-\beta} = K_0 + K_1$, (A.5) and the relative prices' growth on CGP, imply:

$$\frac{\dot{h_0}}{h_0} = \alpha(1-\beta)\frac{\dot{N}}{N} \quad (A.48)$$

$$\frac{\dot{h_1}}{h_1} = (1-\alpha\beta)\frac{\dot{N}}{N} \quad (A.49)$$

Finally, the market clearing conditions for the two final-good products together with (A.44), (A.45) and (A.46):

$$\frac{\dot{c}_0}{c_0} = \alpha(1-\beta)\frac{\dot{N}}{N} \tag{A.50}$$

$$\frac{\dot{c}_1}{c_1} = (1-\alpha\beta)\frac{\dot{N}}{N} \tag{A.51}$$

In order to solve for the constant interest rate, allocations and growth of ICT-production, (A.39) is used together with (A.50), (A.40), (A.43) and $\frac{\dot{N}}{N} = \lambda L\,(1-u_1-u_0)$:

$$u_1^d = \frac{\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]\left(\frac{\rho}{\lambda L}+\Phi\right)}{\alpha[1-\theta(1-\alpha^2)-\alpha^2\beta]+\Phi} \tag{A.52}$$

$$u_0^d = \frac{\left[\theta(1-\alpha^2)+\alpha^2\beta\right]\left(\frac{\rho}{\lambda L}+\Phi\right)}{\alpha[1-\theta(1-\alpha^2)-\alpha^2\beta]+\Phi} \tag{A.53}$$

$$g_N^d \equiv \frac{\dot{N}}{N}^d = \lambda L\frac{\alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]-\frac{\rho}{\lambda L}}{\alpha[1-\theta(1-\alpha^2)-\alpha^2\beta]+\Phi} \tag{A.54}$$

, where $\Phi = \sigma + (1-\sigma)\left[\alpha\beta+\theta(1-\alpha)\right]$.

In order to check the conditions for an interior solution, it is sufficient to check that $u_1^d > 0$ and $g_N^d > 0$. Note that for $\frac{1-\theta(1-\alpha^2)}{\alpha^2} > \beta$ it is sufficient to search conditions for $\Phi \geq 0$. If $\sigma \leq 1$, it follows that $\Phi \geq 0$ and $u_1^d > 0$. If instead $\sigma > 1$, then the condition for $\Phi \geq 0$ is that either $\frac{1-\theta(1-\alpha)}{\alpha} > \beta$, or $\frac{1-\theta(1-\alpha)}{\alpha} < \beta < \frac{1-\theta(1-\alpha^2)}{\alpha^2}$ with $\sigma \leq \frac{\alpha\beta+\theta(1-\alpha)}{\alpha\beta+\theta(1-\alpha)-1}$. Therefore, a sufficient condition for interior solution is that $\frac{1-\theta(1-\alpha)}{\alpha} > \beta$. This imposes no further requirement on the intertemporal elasticity of substitution. However, that restriction is always satisfied itself always given that $\theta, \beta \in (0,1)$. Hence the only condition required on the parameters is that $L > \frac{\rho}{\lambda\alpha[1-\theta(1-\alpha^2)-\alpha^2\beta]}$.

A.3 Proof of Proposition 3

Let $\Delta = \alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]+\Phi$. The comparative statics are for parameters that satisfy $\frac{1-\theta(1-\alpha)}{\alpha} > \beta$ and $L > \frac{\rho}{\lambda\alpha[1-\theta(1-\alpha^2)-\alpha^2\beta]}$. The effect of a change in λ is:

$$\begin{aligned}
\frac{\partial g_N^d}{\partial \lambda} &= \frac{\alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]L}{\Delta} > 0 \\
\frac{\partial\left(u_1^d/u_0^d\right)}{\partial \lambda} &= 0
\end{aligned}$$

A change in ρ implies:

$$\begin{aligned}
\frac{\partial g_N^d}{\partial \rho} &= -\frac{1}{\Delta} < 0 \\
\frac{\partial\left(u_1^d/u_0^d\right)}{\partial \lambda} &= 0
\end{aligned}$$

A change in σ implies:

$$\begin{aligned}
\frac{\partial g_N^d}{\partial \sigma} &= -\frac{1}{\Delta^2}\left[1-\theta(1-\alpha)-\alpha\beta\right]\left(\lambda L\alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]-\rho\right) < 0 \\
\frac{\partial\left(u_1^d/u_0^d\right)}{\partial \lambda} &= 0
\end{aligned}$$

A change in θ implies:

$$\begin{aligned}
\frac{\partial g_N^d}{\partial \theta} &= \frac{1}{\Delta^2}\left\{-\alpha(1-\alpha^2)\left(\lambda L\Phi+\rho\right)\right. \\
&\quad \left.-(1-\sigma)(1-\alpha)\left(\lambda L\alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]-\rho\right)\right\} \\
\frac{\partial\left(u_1^d/u_0^d\right)}{\partial \theta} &= \frac{-(1-\alpha^2)}{[\theta(1-\alpha^2)+\alpha^2\beta]^2} < 0
\end{aligned}$$

For $\sigma \leq 1$, the effect on the growth rate is definitely negative.

A change in α implies:

$$\begin{aligned}
\frac{\partial g_N^d}{\partial \alpha} &= \frac{1}{\Delta^2}\left\{\left[1-\theta(1-\alpha^2)-\alpha^2\beta+2\alpha^2(\theta-\beta)\right](\lambda L\Phi+\rho)\right. \\
&\quad \left. -(1-\sigma)(\theta-\beta)\left(\lambda L\alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]-\rho\right)\right\} \\
\frac{\partial\left(u_1^d/u_0^d\right)}{\partial \alpha} &= \frac{2\alpha(\theta-\beta)}{\left[\theta(1-\alpha^2)+\alpha^2\beta\right]^2}
\end{aligned}$$

The results depend critically on θ, β and σ. For $\theta > \beta$ the effect on the growth rate and the relative labour allocations is positive if $\sigma \geq 1$.

A change in β implies:

$$\begin{aligned}
\frac{\partial g_N^d}{\partial \beta} &= \frac{1}{\Delta^2}\left\{-\alpha^3(\lambda L\Phi+\rho)\right. \\
&\quad \left. -(1-\sigma)\alpha\left(\lambda L\alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]-\rho\right)\right\} \\
\frac{\partial\left(u_1^d/u_0^d\right)}{\partial \beta} &= \frac{-2\alpha^2}{\left[\theta(1-\alpha^2)+\alpha^2\beta\right]^2} < 0
\end{aligned}$$

The effect on growth would be negative for $\sigma \leq 1$.

A.4 Proof of Lemma 1

The social planner's economy optimization problem is summarized below:

$$\begin{aligned}
\mathcal{H} &= e^{-\rho t}\frac{\left(c_0^\theta c_1^{1-\theta}\right)^{1-\sigma}-1}{1-\sigma} + \kappa\left[(u_0L)^{1-\alpha}\textstyle\int_0^A x_0^\alpha(j)dj - c_0 - h_0\right] \\
&\quad +\mu\left[(u_1L)^{1-\alpha}\textstyle\int_0^N x_1^\alpha(i)di - c_1 - h_1\right] \\
&\quad +\xi\left[h_0^\beta h_1^{1-\beta} - \textstyle\int_0^A x_0(j)dj - \int_0^N x_1(i)di\right] + \nu\left[\lambda L(1-u_0-u_1)N\right]
\end{aligned}$$

, where the FOCs are:

$$\begin{aligned}
\tfrac{\partial H}{\partial c_0} &= e^{-\rho t}\left(c_0^{\theta}c_1^{1-\theta}\right)^{-\sigma}\theta c_0^{\theta-1}c_1^{1-\theta}-\kappa=0 \\
\tfrac{\partial H}{\partial c_1} &= e^{-\rho t}\left(c_0^{\theta}c_1^{1-\theta}\right)^{-\sigma}(1-\theta)c_0^{\theta}c_1^{-\theta}-\mu=0 \\
\tfrac{\partial H}{\partial h_0} &= \xi\left(\beta h_0^{\beta-1}h_1^{1-\beta}\right)-\kappa=0 \\
\tfrac{\partial H}{\partial h_1} &= \xi\left[(1-\beta)\,h_0^{\beta}h_1^{-\beta}\right]-\mu=0 \\
\tfrac{\partial H}{\partial u_0} &= \kappa\left[(1-\alpha)\frac{Y_0}{u_0}\right]-\nu\lambda LN=0 \\
\tfrac{\partial H}{\partial u_1} &= \mu\left[(1-\alpha)\frac{Y_1}{u_1}\right]-\nu\lambda LN=0 \\
\tfrac{\partial H}{\partial x_0(j)} &= \kappa\left[\alpha(u_0L)^{1-\alpha}x_0^{\alpha-1}(j)\right]-\xi=0\ ;\ \forall j \\
\tfrac{\partial H}{\partial x_1(i)} &= \mu\left[\alpha(u_1L)^{1-\alpha}x_1^{\alpha-1}(i)\right]-\xi=0\ ;\ \forall i \\
-\dot{\nu} &= \tfrac{\partial H}{\partial N}=-\xi x_1(N)+\mu(u_1L)^{1-\alpha}x_1^{\alpha}(N) \\
&\quad +\nu(1-u_0-u_1)L
\end{aligned}$$

The standard TVC applies: $\lim_{T\to\infty}\left[\nu(T)N(T)\right]=0$.

The solution to the social planner economy closely resembles that of the market economy. In summary, the main equations that drive the dynamics and specify the steady-state are:

$$
\begin{aligned}
\frac{c_0}{c_1}\frac{1-\theta}{\theta} &= \frac{1-\beta}{\beta}\frac{h_0}{h_1} = \frac{Y_0/u_0}{Y_1/u_1} \\
x_0 &= \left(\frac{\kappa}{\xi}\right)^{\frac{1}{1-\alpha}} \alpha^{\frac{1}{1-\alpha}}(u_0 L) \\
x_1 &= \left(\frac{\mu}{\xi}\right)^{\frac{1}{1-\alpha}} \alpha^{\frac{1}{1-\alpha}}(u_1 L) \\
\frac{\mu}{\kappa} &= \left(\frac{A}{N}\right)^{1-\alpha} \\
\frac{\kappa}{\nu} &= \frac{\lambda}{(1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}}\frac{N}{A}\left(\frac{\kappa}{\xi}\right)^{\frac{-\alpha}{1-\alpha}} \\
\frac{\mu}{\nu} &= \frac{\lambda}{(1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}}\left(\frac{\mu}{\xi}\right)^{\frac{\alpha}{1-\alpha}} \\
\frac{\xi}{\nu} &= \frac{\lambda}{(1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}}\frac{N}{A}\left(\frac{\kappa}{\xi}\right)^{\frac{-1}{1-\alpha}} \\
-\frac{\dot{\nu}}{\nu} &= \lambda L(1-u_0)
\end{aligned}
$$

The main difference to the decentralized equilibrium is the absence of an auction process in the valuation of the patents and the monopolistic competition in the market for intermediate capital varieties. A higher share of output is allocated to capital and as a result, the capital-deepening effect on growth is stronger.

Following the same steps as in Appendix A.2., which solves the decentralized equilibrium, the resulting equilibrium labour allocations in the two final good sectors and the equilibrium growth rate of the ICT-producing sector are the following:

$$
\begin{aligned}
u_1^* &= \frac{[\alpha\beta+\theta(1-\alpha)]\left[\frac{\rho}{\lambda L}-(1-\sigma)(1-\alpha\beta-\theta(1-\alpha))\right]}{\sigma} \\
u_0^* &= \frac{[\alpha\beta+\theta(1-\alpha)]\left[\frac{\rho}{\lambda L}-(1-\sigma)(1-\alpha\beta-\theta(1-\alpha))\right]}{\sigma[1-\alpha\beta-\theta(1-\alpha)]} \\
g_N^* &= \lambda L\frac{1-\alpha\beta-\theta(1-\alpha)-\frac{\rho}{\lambda L}}{\sigma[1-\alpha\beta-\theta(1-\alpha)]}
\end{aligned}
$$

The growth rates for the sector and aggregate consumption, capital and output are as in Proposition 2, with the difference that the endogenous growth rate is the one described above. The growth of the ICT-producing sector is strictly decreasing function of the composite intermediates' output elasticity with respect to the intermediate input provided by the non-ICT-using sector. This is because in the social planner's economy, the effect of the participation of the non-ICT-using sector to the production of capital has solely a negative impact of growth, by requiring the production of capital at a higher cost.

$$\frac{\partial g_N^*}{\partial \beta} = -\alpha\sigma\frac{\rho}{\lambda L} < 0$$

For $\sigma = 1$, then $u_N^* = \frac{1-\alpha\beta-\theta(1-\alpha)-\frac{\rho}{\lambda L}}{\sigma[1-\alpha\beta-\theta(1-\alpha)]} = u_N^d = \frac{\alpha\left[1-\theta(1-\alpha^2)-\alpha^2\beta\right]-\frac{\rho}{\lambda L}}{\alpha[1-\theta(1-\alpha^2)-\alpha^2\beta]+1}$ for a value of $\beta = \tilde{\beta}(\theta, \alpha, \rho, \lambda, L)$:

$$\tilde{\beta} = \frac{1-\alpha}{\alpha}\frac{1-\theta(1-\alpha)-\frac{\rho}{\lambda L}\theta(1-\alpha^2)}{1+\frac{\rho}{\lambda L}(1-\alpha^2)}$$

For $\tilde{\beta} \in (0, 1)$, this suggests the following parameter restrictions:

$$\frac{(1-\alpha)[1-\theta(1-\alpha)]-\alpha}{\theta(1-\alpha^2)} < \frac{\rho}{\lambda L} < \frac{1-\theta(1-\alpha)}{\theta(1-\alpha^2)}$$

For the calibrated parameters employed in the numerical exercises (calibration and transition dynamics) discussed in Chapter 2 ($\theta = 0.78$, $\alpha = 0.61$, $\rho = 0.028$ and $\lambda L = 7.17$), this condition is satisfied and the value of $\tilde{\beta}$ suggested by this solution is 0.57. As a comparison, the calibrated value for β is 0.63. When allowing for intertemporal elasticity of substitution different than one, then the solution for $\tilde{\beta}$ requires the solution of a non-linear function in β. To get some intuition though, for high intertemporal elasticity of substitution, i.e. $\sigma \leq 1$, then the results from comparative statics analysis suggests that the allocations would be brought closer to the social planner's ones, i.e. higher long-run growth, when the parameters of the model suggest a relatively low value for $\tilde{\beta}$. For $\sigma > 1$ the result could be the opposite and is highly dependent on all parameters' configuration.

A.5 Aggregate output measure: model vs. data

The multi-sector models of growth have a potential problem when there is attempt to match the aggregate data[2]. This Section explores whether under the conditions for CGP for the final output of the theoretical model, there is constant growth in the empirically observed series of aggregate output.

In the theoretical model, the volume of the aggregate final output is measured in terms of the non-ICT-using good[3]. In a multi-sector environment, the choice that is irrelevant in terms of the properties of the CGP, but one may pay attention to the difference between the aggregation in the model and the one in National Accounts. In practice, the final output growth in NIPA accounts is calculated using a chain-weight scheme that implies that the final output growth is the Divisia index that aggregates over the growth rates of both final good sectors, using their nominal output shares as weights. Define the NIPA measure of output as $\tilde{Y}$. Then its growth rate is given as:

$$\frac{\dot{\tilde{Y}}}{\tilde{Y}} = \frac{p_{Y_1} Y_1}{\tilde{Y}} \frac{\dot{Y}_1}{Y_1} + \frac{p_{Y_0} Y_0}{\tilde{Y}} \frac{\dot{Y}_0}{Y_0}$$

, where p_{Y_1} and p_{Y_0} are the NIPA prices of the ICT-using and non-ICT-using goods respectively. First, it is straightforward to see that under the conditions that ensure CGP for the aggregate output of the model, $Y = Y_0 + p_1 Y_1$, then there is a constant growth steady-state for $g_{\tilde{Y}}$. This is because the condition for a CGP ensures that there is constant sector-level output growth and constant output shares. The question then is whether there can be other conditions that ensure constant $g_{\tilde{Y}}$, i.e. one would like to examine whether the theoretical model's

[2]See discussion in Whelan (2003) and Greenwood, Hercowitz, and Krusell (1997).

[3]Since the relative prices reflect the relative productivity of the final good sectors, the "nominal" growth of the two sectors, i.e. in terms of a particular good reflects volume growth of the corresponding sector.

conditions are simply a sufficient or also a necessary condition for CGP as matched by the aggregate data.

As in the theoretical model, the condition for constant g_N implies $\dot{u}_N = 0$. Then, given (A.27) and (A.28) from Appendix A.1 above, it follows that:

$$\begin{aligned}
\frac{\dot{\tilde{Y}}}{\tilde{Y}} &= \frac{p_{Y_1}Y_1}{\tilde{Y}}\left[(1-\alpha\beta)g_N + \frac{\dot{u}_1}{u_1}\right] + \frac{p_{Y_0}Y_0}{\tilde{Y}}\left[\alpha(1-\beta)g_N + \frac{\dot{u}_0}{u_0}\right] \\
&= \frac{g_N}{1-u_N}\left[(1-\alpha\beta)u_1 + \alpha(1-\beta)u_0\right] + \frac{1}{1-u_N}\left[u_1\frac{\dot{u}_1}{u_1} + u_0\frac{\dot{u}_0}{u_0}\right]
\end{aligned}$$

The second term equals identically zero. Therefore, the condition for constant growth for the aggregate output is that $(1-\alpha\beta)u_1 + \alpha(1-\beta)u_0$ is constant, or else: $(1-\alpha\beta)\dot{u}_1 + \alpha(1-\beta)\dot{u}_0 = 0$. Given that the condition for constant labour allocation in the ICT-producing sector requires that , $\dot{u}_1 = -\dot{u}_0$, the last two equations can be reconciled either for $\dot{u}_1 = \dot{u}_0 = 0$, or for $\frac{\alpha(1-\beta)}{1-\alpha\beta} = 1$. The latter requires $\alpha = 1$; a contradiction. Hence, for constant growth of the empirical analogue of output, labour allocations need to be constant in the two final good sectors.

As a final note in this Appendix, in the absence of an aggregate production function for the final output in the theoretical model, there is a large set of options with respect to the choice of the numeraire for the aggregate final good output. This choice should not be important for the derived properties of the steady-state CGP. Consider the alternative aggregate output, $\hat{Y}$, which is measured in units of the composite consumption good, i.e. $\hat{Y} = \frac{p_1}{p_c}Y_1 + \frac{1}{p_c}Y_0$. Then:

$$\frac{\dot{\hat{Y}}}{\hat{Y}} = \frac{p_1Y_1}{p_c\hat{Y}}\left(\frac{\dot{p}_1}{p_1} - \frac{\dot{p}_c}{p_c} + \frac{\dot{Y}_1}{Y_1}\right) + \left(1 - \frac{p_1Y_1}{p_c\hat{Y}}\right)\left(-\frac{\dot{p}_c}{p_c} + \frac{\dot{Y}_0}{Y_0}\right)$$

From Appendices A.1 and A.2, using conditions (A.16), (A.38), (A.44), (A.45) and the constancy of the output shares that are supported by the CGP for Y:

$$\begin{aligned}\frac{\dot{\hat{Y}}}{\hat{Y}} &= \frac{p_1 Y_1}{p_c \hat{Y}}\left[-\theta(1-\alpha)g_N + (1-\alpha\beta)g_N\right] \\ &+ \left(1-\frac{p_1 Y_1}{p_c \hat{Y}}\right)\left[(1-\theta)(1-\alpha)g_N + \alpha(1-\beta)g_N\right] \\ &= g_N\left[1-\alpha\beta-\theta(1-\alpha)\right]\end{aligned}$$

Note that this implies that $\frac{\dot{\hat{Y}}}{\hat{Y}}$ is also constant along the CGP. This growth rate is ensured to be positive by the restrictions for interior solution (see discussion in the end of Appendix A.2). Furthermore, a similar argument as above shows that using $\hat{Y}$ as the measure for final output would not change the restrictions for CGP.

A.6 Transition dynamics: detailed derivations and methodology

The social planner's optimization problem solves for the control variables $\{c_0, c_1, K_0, u_0, u_1\}$, given the state-variables $\{K_1, N\}$[4]:

$$\begin{aligned}\mathcal{H} &= e^{-\rho t}\frac{\left(c_0^{\theta} c_1^{1-\theta}\right)^{1-\sigma}-1}{1-\sigma} + \kappa\left[(u_0 H)^{1-\alpha} A^{1-\alpha} K_0^{\alpha} - c_0\right] \\ &+\mu\left[(u_1 H)^{1-\alpha} N^{1-\alpha} K_1^{\alpha} - c_1 - K_0 - \delta K_1\right] + \nu\left[\lambda(1-u_0-u_1)HN\right]\end{aligned}$$

The standard FOCs provide the main equilibrium conditions that summarize the solution path. The marginal rate of substitution in the consumption equals relative

[4]The advantage of solving for the social planner's equilibrium is that it preserves the features of the implied dynamics of the competitive equilibrium, while being more straightforward to handle analytically (and check that the TVCs are satisfied).

prices of the consumption goods:

$$\frac{c_1}{c_0} = \frac{1-\theta}{\theta}\frac{\kappa}{\mu} \tag{A.55}$$

The marginal product of the non-ICT-capital equals its cost:

$$\frac{\kappa}{\mu} = \frac{K_0}{\alpha Y_0} \tag{A.56}$$

Returns to human capital are equal across sectors:

$$\frac{\kappa}{\mu} = \frac{Y_1}{Y_0}\frac{u_0}{u_1} \tag{A.57}$$

The implied growth rates of the shadow prices for the capital and the ICT stock:

$$-\frac{\dot{\mu}}{\mu} = \alpha\frac{Y_1}{K_1} - \delta \tag{A.58}$$

$$-\frac{\dot{\nu}}{\nu} = \lambda H(1-u_0) \tag{A.59}$$

The first step to analyze transition dynamics is to understand the properties of the solution along the CGP, when the two state variables, as well as the aggregate output, consumption and capital grow at constant rates. Along such path, the TVCs are satisfied, when the shadow prices and the state variables grow at constant rates. The condition for constant growth in N is: $\dot{u}_N = 0$. The condition for constant growth in the ICT-production shadow price, ν, is that: $\dot{u}_0 = 0$. Therefore, the TVC on the value of ICT-production in the limit implies that there is no reallocation along the steady-state: $\dot{u}_0 = \dot{u}_1 = \dot{u}_N = 0$. The condition for constant growth rate of the shadow price of the ICT-capital, μ, is: $\frac{\dot{Y}_1}{Y_1} = \frac{\dot{K}_1}{K_1}$. The production function of the ICT-using sector together with the requirement of

$\dot{u}_1 = 0$, implies: $\frac{\dot{Y}_1}{Y_1} = \frac{\dot{N}}{N}$. Furthermore, by (A.56) and (A.57): $K_0 = Y_1\frac{u_1}{u_0}$. This condition together with the one on constant allocations imply: $\frac{\dot{K}_0}{K_0} = \frac{\dot{Y}_1}{Y_1}$. From the law of motion for the ICT-capital, $\frac{\dot{K}_1}{K_1} = \frac{Y_1}{K_1} - \frac{c_1}{K_1} - \delta - \frac{K_0}{K_1}$, it follows that $\frac{\dot{K}_1}{K_1}$ is constant only if $\frac{\dot{c}_1}{c_1} = \frac{\dot{K}_1}{K_1}$. Finally, the non-ICT-using sector production function together with the resource constraint of this sector imply that along the steady-state: $\frac{\dot{c}_0}{c_0} = \frac{\dot{Y}_0}{Y_0} = \alpha\frac{\dot{N}}{N}$. To summarize, the following are true along the steady-state time path:

$$
\begin{aligned}
\frac{\dot{u}_0}{u_0} &= \frac{\dot{u}_1}{u_1} = \frac{\dot{u}_N}{u_N} = 0 \\
\frac{\dot{c}_1}{c_1} &= \frac{\dot{K}_1}{K_1} = \frac{\dot{K}_0}{K_0} = \frac{\dot{Y}_1}{Y_1} = \frac{\dot{N}}{N} \\
\frac{\dot{c}_0}{c_0} &= \frac{\dot{Y}_0}{Y_0} = \alpha\frac{\dot{N}}{N}
\end{aligned}
$$

The system of FOCs is redefined in terms of one "state-like" variable, $\{k_1 \equiv \frac{K_1}{N}\}$, and five "control-like" variables, $\{k_0 \equiv \frac{K_0}{N}, \omega_0 \equiv \frac{c_0}{N^\alpha}, \omega_1 \equiv \frac{c_1}{N}, u_0, u_1\}$. However, given that the dynamics of the control variables of of the two final good sectors are linearly dependent, it follows that it is sufficient to follow the dynamic behavior of only one of the two final good sectors (here the ICT-using is chosen). In particular, the resource constraint of the non-ICT-using good, ω_0 can be expressed as a function of (k_0, u_0):

$$\omega_0 = (u_0 H)^{1-\alpha} A^{1-\alpha} k_0^\alpha \tag{A.60}$$

Using the resource constraint for the non-ICT-using sector and equating (A.55) to (A.56) and (A.55) to (A.57) gives k_0 and u_0 as a function of (k_1, u_1, ω_1):

$$k_0 = \frac{\alpha\theta}{1-\alpha}\omega_1 \tag{A.61}$$

$$u_0 = \frac{\theta}{1-\theta}\omega_1 L^{\alpha-1} u_1^\alpha k_1^{-\alpha} \tag{A.62}$$

Therefore, the differential equations that completely summarize the dynamics are the following:

$$\frac{\dot{k}_1}{k_1} = (u_1 L)^{1-\alpha} k_1^{\alpha-1} - \left(1 + \frac{\alpha\theta}{1-\theta}\right) \frac{\omega_1}{k_1} - \delta - \lambda L \left(1 - \frac{\theta}{1-\theta} \omega_1 L^{\alpha-1} u_1^{\alpha} k_1^{-\alpha} - u_1\right) \quad \text{(A.63)}$$

$$\frac{\dot{u}_1}{u_1} = \frac{1-\alpha}{\alpha} \left[\delta + \lambda L \left(1 - \frac{\theta}{1-\theta} \omega_1 L^{\alpha-1} u_1^{\alpha} k_1^{-\alpha}\right)\right] + \lambda L u_1 - \left(1 + \frac{\alpha\theta}{1-\theta}\right) \frac{\omega_1}{k_1} \quad \text{(A.64)}$$

$$\begin{aligned} \frac{\dot{\omega}_1}{\omega_1} &= \frac{1}{\sigma} \left\{-\rho + \alpha \left[\alpha (u_1 L)^{1-\alpha} k_1^{\alpha-1} - \delta\right] + (1-\alpha)\lambda L u_1 + \right. \\ &\quad \left. + (1-\sigma)(1-\theta)(1-\alpha) \left[\alpha (u_1 L)^{1-\alpha} k_1^{\alpha-1} - \delta - \lambda L u_1\right]\right\} + \\ &\quad + (1-\alpha) \left[\alpha (u_1 L)^{1-\alpha} k_1^{\alpha-1} - \delta - \lambda L u_1\right] - \lambda L \left(1 - \frac{\theta}{1-\theta} \omega_1 L^{\alpha-1} u_1^{\alpha} k_1^{-\alpha} - u_1\right) \end{aligned} \quad \text{(A.65)}$$

Equation (A.63) is derived by using that $\frac{\dot{k}_1}{k_1} = \frac{\dot{K}_1}{K_1} - \frac{\dot{N}}{N}$. The law of motion for the ICT-capital and the ICT-production growth rate are expressed in terms of the variables of the model for the state and control-like variables while substituting for u_0 and k_0 by (A.62) and (A.61) respectively. Equation (A.64) is derived by differentiating with respect to time the condition that equates the return to labour in the ICT-using and ICT-producing sector and substituting for the shadow prices growth rate. Again, the variables need to be transformed into the state and control-like variables and u_0 and k_0 expressed by (A.62) and (A.61). Finally, equation (A.65) is derived by using that $\frac{\dot{\omega}_1}{\omega_1} = \frac{\dot{c}_1}{c_1} - \frac{\dot{N}}{N}$. The equation that characterizes the time path of the ICT-using consumption good is derived with the use of the FOC for the consumption goods as a function of the growth in the shadow price of the non-ICT-using good, $\frac{\dot{\kappa}}{\kappa}$, and ICT-using capital, $\frac{\dot{\mu}}{\mu}$. The latter are themselves functions of the state and control-like variables.

Given the high non-linearity of the system of (A.63), (A.64) and (A.65), the steady state and comparative statics are derived numerically in MATLAB following the steps required by the "time elimination" algorithm. These steps involve the following:

- solving for the steady-state $\{k_1^*,\ u_1^*,\ \omega_1^*\}$ by solving for the homogeneous system: $\frac{\dot{k}_1}{k_1} = \frac{\dot{u}_1}{u_1} = \frac{\dot{\omega}_1}{\omega_1} = 0$. The steady-state values of $\{k_0^*,\ u_0^*,\ \omega_0^*\}$ are derived by using (A.60)-(A.62).
- finding the policy functions $u_1 = u_1(k_1)$ and $\omega_1 = \omega_1(k_1)$ by using the time elimination method. This requires two separate steps:
  - calculation of the steady-state slope of the policy functions. This is found by the spectral decomposition of the Jacobian of the linear approximation of the system around the steady-state[5].
  - calculation of the out of steady-state slopes by using the chain rule of calculus: $u'(k_1) = \frac{\dot{u}_1}{\dot{k}_1}$ and $\omega'(k_1) = \frac{\dot{\omega}_1}{\dot{k}_1}$.

The parameter values are picked to match properties of the data for the United States economy for the 1995-2001 period. In order to normalize the units of the model, the non-ICT-using variety index, A, and the labour stock, L, are set equal to one. The output elasticity of capital, α, is the one used for the calibration exercise of Section 2.4.1. The time preference parameter, ρ, and the intertemporal elasticity of substitution, $1/\sigma$, are taken from the micro-data based estimates of Attanasio and Weber (1989) and Attanasio, Banks, and Tanner (2002)

[5]It is given by the eigenvector that corresponds to the negative eigenvalue.

respectively[6]. There is no estimate for the productivity of the ICT-producing sector. One way to indirectly infer it is using the TFP growth for the 1995-2000 period for the ICT-producing sector ((Jorgenson, Ho, and Stiroh 2005b), report average annual growth equal to 17.15%) and divide it by the average employment share of this sector during the same period (the GGDC data show an average of 2.4%)[7]. The parameter that weights the preference towards the non-ICT-using good, θ, matches the average expenditure share for the non-ICT-using goods, as calculated by the Personal Consumption Expenditures by Type of Expenditure NIPA Table, available from BEA. Finally, the annual depreciation rate for the ICT-capital stock, δ, is taken from data that BEA has published in "The Survey of Current Business", 1997, on depreciation rates of various assets. The calibrated depreciation rate is the average depreciation rate of the ICT-capital assets[8]. Table A.1 summarizes these baseline parameters.

Table A.1: Parameters used for transition dynamics calibration

parameters	A	L	α	ρ	σ	λ	θ	δ
values	1	1	0.61	0.028	2.5	7.17	0.78	0.21

A.7 Data Summary

A.7.1 Data sources

The data on average value added and Domar shares, value added and TFP growth for the 1977-2000 period for 44 industries, are taken from Table 8.6 in Jorgenson,

[6]The parameter values for ρ and σ, are also consistent with empirical findings based on macro data and a representative agent framework, as found in Epstein and Zin (1991).

[7]ICT-producing sector reported TFP growth for the 1970-1995 period, equals 11.8%, while its employment share is 1.9% for the 1979-1995 period.

[8]These include: "Office, computing and accounting machinery", "Communications equipment", "Electronic components and accessories", "Computers and peripheral equipment", "Instruments", "Photocopy and related equipment".

Ho, and Stiroh (2005b). Table 7.1 provides with the decomposition of the output growth for these 44 industries into the contribution of capital, labor, intermediate materials and TFP for the 1977-2000 period. ICT-capital intensity in 1995 for each of the 44 industries is coming from Table 4.2. All data are based the three-digit SIC 1987 industry classification. Details on the sources and methodology for the detailed industry growth accounting are found in Chapter 4 of Jorgenson, Ho, and Stiroh (2005b).

The data on employment, value added and value added deflators for 57 industries of the United States economy are taken from the "60-Industry Database", which is constructed by the Groningen Growth and Development Centre (GGDC). The data cover the period 1979-2001 (version Oct. 2003) and are based on the three-digit ISIC Rev.3 industry classification. The dataset is constructed based on the information available in the OECD STructural ANalysis Database (STAN) and official United States Statistical Offices: the Bureau of Economic Analysis (BEA) and Bureau of Labour Statistics (BLS).

The data on the use shares of the commodities are from the "Use Table" of the "Benchmark 1997 Input-Output Table" (after redefinitions) available from BEA. The 1997 benchmark I-O accounts use the classification system that is based on the North American Industry Classification System (NAICS).

The data on "Personal Consumption Expenditures by Type of Product" are taken from NIPA Table 2.4.5. available from BEA, in accordance with NIPA Table 2.5.5 on "Personal Consumption Expenditures by Type of Expenditures". NIPA Tables from BEA are consistent with the NAICS basis used in their I-O Tables.

Since different data sources rely on different systems of industry classification, the mapping of every industry is only approximate across the different databases. The original classification tables for NAICS 1997, NAICS 2002, SIC 1987, ISIC

Rev. 3.1 and ISIC Rev. 3 were checked together with the correspondence tables provided by the United Nations (ISIC Rev. 3-ISIC Rev. 3.1, ISIC Rev. 3.1-NAICS 2002 (US)) and U.S. Census Bureau (NAICS 1997-SIC 1987, NAICS 1997-NAICS 2002).

In order to illustrate the consistency across the different data sources, Table A.2 summarizes the main variables' values across the different sources. Table A.3 provides descriptive statistics of the main variables used.

A.7.2 Variables definitions

Value added is current gross value added measured at producer prices or at basic prices, depending on the valuation used in the national accounts. It represents the contribution of each industry to total GDP.

Value added deflator is the change in the value added deflator. It can be combined with current value added to derive quantity indices of real value added at industry level[9].

Hours refers to average annual hours worked per employee or per person engaged.

Personal consumption expenditures are the goods and services purchased by persons[10].

[9]The official data were readily adjusted into using a hedonic deflator system, so as to account better for the benefits arising from the ICT production and use. The deflators provided in the GGDC database come from official BEA data (harmonising of the deflators for other countries in the dataset does not affect USA data) and are based on the double deflation procedure for the ICT related industries. For an overview of the literature regarding hedonic deflators, see Triplett (2004).

[10]In the national income and product accounts (NIPAs), persons consist of individuals, nonprofit institutions that primarily serve individuals, private noninsured welfare funds, and private trust funds.

A.7.3 Aggregation method

In each dataset, the industries are grouped into three aggregate sectors: ICT-producing, ICT-using and non-ICT-using. Any transactions with abroad are not taken into consideration.

The Information and Communication Technology sector (ICT) producing sector is defined as in Jorgenson, Ho, and Stiroh (2005b) to include (SIC 1987 codes in parentheses) Computers and Office equipment (357), Electronic Components (367), Communications equipment (36 x 366-367) and Computer Services (737)[11]. Following Jorgenson, Ho, and Stiroh (2005b), the criterion for classifying an industry as ICT using is its degree of ICT-capital intensity in 1995. In particular, the share of the ICT-capital out of total capital compensation for an industry in 1995 needs to exceed the 15%[12]. Details on the mapping of the GGDC data industries in each aggregate sector are provided below.

The aggregation is straightforward for the hours and consumption expenditures, intermediates and value added at current prices data. The direct aggregation across industries follows the "Aggregate Production Possibility Frontier" approach, which was first developed by Jorgenson (1966) and is now used as the benchmark framework in growth accounting studies. A Törnqvist index was applied to obtain value added deflators and value added growth rates for each of the three sectors[13]. The Domar weights were used for the aggregation of the

[11] Compared to the OECD definition of the ICT sector that is followed in other studies (e.g. (van Ark and O'Mahony 2003)), Jorgenson's ICT-producing definition excludes the manufacturing industries ISIC Rev. 3. 1, (3312) and (3313), while it only includes the services industry ISIC rev. 3.1, (72).

[12] Alternative definitions for both the ICT-producing and ICT-using sectors were used, as well as the exclusion of the government sectors. The results presented in the paper are relatively robust to these alternative measures. The particular application was preferred because of its implied TFP data availability and its straightforward comparison to already found results.

[13] The Törnqvist aggregation method is based on weighting each industry's exponential annual growth rate with a two-period average of its share in aggregate value added. After computing the growth rate, the implied quantity index was derived, with the normalization that it is equal to 100 in 1995.

contributions of capital, labor and TFP growth in aggregate value added.

A.7.4 Aggregate sectors in GGDC database

ICT-producing sector[14]*:*

Office machinery (30), Insulated wire (313), Electronic valves and tubes (321), Telecommunication equipment (322), Radio and television receivers (323), Computer and related activities (72)

ICT-using sector:

Printing & publishing (22), Mechanical engineering (29), Other electrical machinery and apparatus nec (31-313), Scientific instruments (331), Other instruments (33-331), Building and repairing of ships and boats (351), Aircraft and spacecraft (353), Railroad equipment and transport equipment nec (352+359), Furniture, miscellaneous manufacturing; recycling (36-37), Wholesale trade and commission trade, except of motor vehicles and motorcycles (51), Communications (64), Financial intermediation, except insurance and pension funding (65), Insurance and pension funding, except compulsory social security (66), Activities auxiliary to financial intermediation (67), Renting of machinery and equipment (71), Research and development (73), Legal, technical and advertising (741-3), Other business activities, nec (749).

non-ICT-using:

Agriculture (01), Forestry (02), Fishing (05), Mining and quarrying (10-14), Food, drink & tobacco (15-16), Textiles (17), Clothing (18), Leather and footwear (19), Wood & products of wood and cork (20), Pulp, Chapter & Chapter products (21), Mineral oil refining, coke & nuclear fuel (23), Chemicals (24), Rubber & plastics (25), Non-metallic mineral products (26), Basic metals (27), Fabricated metal products (28), Motor vehicles (34), Electricity, gas and water supply (40-41), Construction (45), Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel (50), Retail

[14]ISIC codes, Rev.3, in parentheses.

trade, except of motor vehicles and motorcycles;repair of personal and household goods (52), Hotels & catering (55), Inland transport (60), Water transport (61), Air transport (62), Supporting and auxiliary transport activities; activities of travel agencies (63), Real estate activities (70), Public administration and defence; compulsory social security (75), Education (80), Health and social work (85), Other community, social and personal services (90-93), Private households with employed persons (95).

Table A.2: Comparison across the different sources of information used for the United States

Source:		Jorgenson (2005)	GGDC		BEA, I-O	BEA, NIPA
variable/ period of comparison:		1977-2000	1979-2000	1997	1997	1997
value added growth	Total Economy	3.08	3.03			
(in percent)	ICT-producing	20.09	20.48			
	ICT-using	3.89	2.98			
	non-ICT-using	2.31	2.11			
shares in value added	ICT-producing	2.1	2.9	3.7	3.5	
(in percent)	ICT-using	26.1	28.0	30.0	31.6	
	non-ICT-using	71.8	69.1	66.4	64.9	
expenditure shares	ICT-using				22.5	22.3
(in percent)	non-ICT-using				77.5	77.7

Table A.3: Descriptive statistics of main United States sector-level variables

		Average			St. Deviation		
	sector/ period	1979-01	1979-95	1995-01	1979-01	1979-95	1995-01
share of total hours worked	ICT-producing	2.0	1.9	2.4	0.29	0.13	0.25
(in percent)	ICT-using	25.7	25.5	26.4	0.73	0.63	0.40
	non-ICT-using	72.2	72.6	71.2	0.97	0.71	0.60
share of value added	ICT-producing	3.0	2.7	3.7	0.59	0.38	0.24
(in percent)	ICT-using	28.1	27.2	30.2	1.72	0.96	1.04
	non-ICT-using	69.0	70.1	66.1	2.29	1.30	1.27
real value added growth rate	ICT-producing	19.81	19.68	21.08	6.78	7.01	6.63
(in percent)	ICT-using	3.11	2.35	4.77	2.76	2.49	2.54
	non-ICT-using	2.09	2.06	2.16	1.84	2.06	1.13
value added deflator growth rate	ICT-producing	-10.22	-9.44	-12.72	3.63	3.60	2.96
(in percent)	ICT-using	4.02	4.88	2.10	2.24	1.98	1.28
	non-ICT-using	3.79	4.23	2.58	2.15	2.38	0.45
expenditure shares	ICT-using	20.7	20.0	22.4	1.61	1.32	0.50
(in percent)	non-ICT-using	79.3	80.0	77.6	1.61	1.32	0.50

Sources: GGDC "60 Industry Database", 2003. Expenditure shares from the BEA NIPA Table on "Personal Consumption

Appendix B

Appendix for Chapter 3

B.1 Decomposition of the goods-intermediates use share

The trend in the expenditure share of goods-intermediates at the aggregate economy level can be driven by two distinct forces. One of them relates to the trends in the expenditure shares of the individual sectors (goods and services). This is called the *substitution effect.* The other force relates to the trends in the shares of the individual sectors in the total expenditure on intermediates. This is called the *size effect.*

Consider the aggregate economy's goods-intermediates expenditure share, γ_G. The economy consists of two sectors, goods and services (indexed G and S respectively). Denote $\tilde{I}$ the total expenditures/ production of intermediates in the economy. By market clearing conditions, $\tilde{I} = p_{I_G} I_G + p_{I_S} I_S$, where $p_{I_G} I_G$ is the total intermediates production of the goods-sector and $p_{I_S} I_S$ the total intermediates production of the services-sector. Each sector uses both types of intermediates. Denote $\tilde{I}^j$ the total expenditure of sector j and $p_{I_i} I_i^j$ the expenditure of sector j on intermediates produced by sector i, $j, i \in \{G, S\}$. It holds that $\tilde{I}^G = p_{I_G} I_G^G + p_{I_S} I_S^G$ and $\tilde{I}^S = p_{I_G} I_G^S + p_{I_S} I_S^S$. Hence, it follows:

$$\begin{aligned}
\gamma_G &= \frac{p_{I_G} I_G^G + p_{I_G} I_G^S}{\tilde{I}} \\
&= \frac{p_{I_G} I_G^G}{\tilde{I}^G}\frac{\tilde{I}^G}{\tilde{I}} + \frac{p_{I_G} I_G^S}{\tilde{I}^S}\frac{\tilde{I}^S}{\tilde{I}} \\
&= \gamma_G^G s_G + \gamma_G^S s_S
\end{aligned}$$

, where γ_G^j is the goods-intermediates expenditure share of sector j and s_j is the share of sector j in the total expenditures on intermediates, $s_G + s_S = 1$. Therefore:

$$g_{\gamma_G} = \underbrace{\sum_{j \in \{G,S\}} \frac{\gamma_G^j s^j}{\gamma_G} g_{\gamma_G^j}}_{\text{"substitution effect"}} + \underbrace{\sum_{j \in \{G,S\}} \frac{\gamma_G^j s^j}{\gamma_G} g_{s^j}}_{\text{"size effect"}}$$

The weights in either of these two effects equal $\frac{\gamma_G^j s^j}{\gamma_G} = \frac{p_{I_G} I_G^j}{I_G}$, i.e. the share of the sector in total expenditures/ production of goods-intermediates.

The composition effect is driven by changes in the intermediates expenditure share of the individual sectors. Note that s_j may be written as follows: $\frac{\tilde{I}^j}{\tilde{I}} = \frac{\tilde{I}^j}{p_V V_j}\frac{p_V V_j}{p_V V}\frac{p_V V}{\tilde{I}}$. Therefore, the composition effect comes from a *size effect* that is measured by the value added share of the sector, $\frac{p_V V_j}{p_V V}$, and a *production technology effect* that is measured by the intensity of the sector in using intermediates for its final output production in comparison to the average/ aggregate economy, $\frac{\tilde{I}^j}{p_V V_j} / \frac{\tilde{I}}{p_V V}$. The data in Section 3.2.3 indicate that there are no trends in the latter, which implies that $s_j \propto \frac{p_V V_j}{p_V V}$.

The size effect alone can drive a negative trend in the goods-intermediates expenditure share at the aggregate level. In order to illustrate such an example, consider the case that both of the sectors do not change their intensity in using goods-intermediates, i.e. $g_{\gamma^G_G} = g_{\gamma^S_G} = 0$. Since $\sum\limits_{j\in\{G,S\}} s_j = 1$, then $g_{s_j} = -\frac{s_i}{s_j} g_{s_i}$, $i \neq j$, and $g_{\gamma_G} = -g_{s_i}\frac{s_i}{\gamma_G}\left(\gamma^j_G - \gamma^i_G\right)$. As a result, $g_{\gamma_G} < 0$ if $sgn\left[g_{s_i}\left(\gamma^j_G - \gamma^i_G\right)\right] > 0$, i.e. sectors that decline in their share in total expenditures of intermediates are the sectors that have the highest intensity in using goods-intermediates.

The aggregation issue is important also at the sector-level, since each sector j is an aggregate over K_j distinct industries. With an analogous argument, $\gamma^j_G = \sum_{k=1}^{K} \gamma_k s_k$; $\sum_{k=1}^{K} s_k = 1$ and the growth of the goods-intermediates expenditure share of sector j equals:

$$g_{\gamma^j_G} = \underbrace{\sum_{k=1}^{K_j} \frac{\gamma_k s_k}{\gamma_j} g_{\gamma_k}}_{\text{"within-industry effect"}} + \underbrace{\sum_{k=1}^{K_j} \frac{\gamma_k s_k}{\gamma_j} g_{s_k}}_{\text{"between-industry effect"}}$$

, where the *within-industry effect* effectively captures the substitution effect and the between-industry effect the size effect.

To conclude, once the shares are taken out of an aggregate measure (total gross output, value added or intermediates expenditures) then the composition effect of the individual sectors/ industries and their time patterns over time, become important determinants of the underlying trends.

As an illustration, consider the potential drivers of the share of total goods-intermediates expenditures/ production in total gross output.

$$\begin{aligned} \frac{I_G}{Y} &= \frac{p_{I_G} I^G_G + p_{I_G} I^S_G}{Y} \\ &= \gamma^G_G \frac{\tilde{I}^G}{Y_G}\frac{Y_G}{Y} + \gamma^S_G \frac{\tilde{I}^S}{Y_S}\frac{Y_S}{Y} \end{aligned}$$

It is apparent that trends in this share are not only driven by the actual substitution taking place in the goods and services-sector, captured by γ^G_G and γ^S_G. It is also affected by the production technology of each sector, $\frac{\tilde{I}^G}{Y_G}$ and $\frac{\tilde{I}^S}{Y_S}$, as well as from the evolution of the size of each sector, $\frac{Y_G}{Y}$ and $\frac{Y_S}{Y}$.

A different way to consider the driving forces behind this aggregate measure is the following. Let $\delta_G \equiv \frac{p_{I_G} I_G}{Y}$. Since $\frac{p_{I_G} I_G}{Y} = \gamma_G \delta$, where $\delta \equiv \frac{\tilde{I}}{p_Y Y}$ is the aggregate production/ expenditure on intermediates in the economy's gross output production. Then $g_{\delta_G} = g_{\gamma_G} + g_\delta$. The forces driving the first component were analyzed above. Changes in δ_G can be driven by the factors that drive changes in δ alone, given that $g_\delta = \frac{p_V V}{p_Y Y}(g_{\tilde{I}} - g_{p_V V})$.

In the case that there is growth of the value added of both sectors in the economy ceteris paribus, i.e. $g_{V_G}, g_{V_S} > 0$, while $g_{\tilde{I}^j} = g_{p_{I_j} I_j} = g_{\gamma_G^j} = g_{s_j} = 0$, $\forall j$. It follows that $g_{\tilde{I}} = 0 < g_{p_V V} = \sum_j \frac{p_V V_j}{p_V V} g_{p_V V j}$ and as a result, $g_\delta, g_{\delta_G} < 0$. Hence, in the event that there is growth in the sectors, such that they use altogether fewer intermediate resources to produce output, then the share of the goods-intermediates expenditures out of gross-output would be declining, yet not revealing any undergoing substitution between the two types of intermediates in the economy.

Another case that the aggregate data would be misleading regarding the existence of a substitution among the different types of intermediates, is the one that while $g_{\gamma_G^j} = 0$, the two sectors experience a balanced growth for their value added and intermediates expenditures, i.e. $\frac{\tilde{I}^j}{p_V V_j}$ is constant , $\forall j$. In such case, since $\delta = \sum_j \frac{p_V V_j}{p_V V} \frac{\tilde{I}^j}{p_V V_j}$ it follows that $g_\delta = \sum_j \frac{\tilde{I}^j}{p_V V_j} g_{\frac{p_V V_j}{p_V V}} = -g_{\frac{p_V V_j}{p_V V}} \left(\frac{\tilde{I}^i}{p_V V_i} - \frac{\tilde{I}^j}{p_V V_j} \right)$, for $j \neq i$. Hence, in such case δ_G would be falling at the aggregate level, as long as the growing sector is the sector with the lower expenditure on intermediates compared to its value added.

To conclude, in order to isolate the substitution effect, one needs to examine expenditures out of the sector'/ industry's own measure of output/ intermediates[1].

[1] This is the approach followed in Sections 3.2.4 and 3.2.5.

B.2 Aggregate-level econometric analysis

In the analysis that follows, the econometric specification suggested by (3.2) is employed at the aggregate-level data, both for the time-series and the cross-section dimension. Details for the information used to receive a measure of the relative price data required is found in Appendix B.3. Despite the very limited observations along either dimension, the exercise that follows may be regarded as an attempt to identify bounds regarding the information contained in the U.S. data[2]. The analysis that follows tries to circumvent to extent feasible the problems of identification, following the analysis in Diamond, McFadden, and Rodriguez (1978) and as discussed in Section 3.2.4. All results regarding the estimated degree of substitution between the two types of intermediates need be treated with caution.

Time-series regression

At the sector-level (i.e. when $i = j$), condition (3.2) allows the two sectors to face the same relative prices in goods and services-intermediates, but substitute them at a different degree in their intermediates production function. Therefore, it suggests the following regression specification for the two sectors:

$$\left(\frac{g_{\gamma}}{1-\gamma}\right)_{jt} = b_1 g_{\frac{p_G}{p_S}t} + b_2 \left(g_{\frac{p_G}{p_S}t} * D_j\right) + x'_{jt} b_3 + \varepsilon_{jt};\ j \in \{G, S\},\ t = 1...T \qquad \text{(B.1)}$$

, where $D_j = \{1, \text{ iff } j = G\}$ is the sector-specific dummy. That implies that $b_1 = 1 - \sigma_S$ and $b_2 = \sigma_S - \sigma_G$. The specification allows for other potential control(s), x'_{jt} that are meant to proxy for $g_{\frac{A^i_S}{A^i_G}}$.

Under the assumption that $g_{\frac{A^i_S}{A^i_G}}$ is constant over time and across sectors, then the required control is simply a constant. The inclusion of a linear trend allows to

[2] The empirical literature regarding the substitution between capital and labour has shown that the cross-sectional data imply elasticities of substitution close to one, while the time-series ones imply lower than one (see discussion in Antràs (2004)).

check whether there is any left autocorrelation in the data that may be captured by $g_{\frac{A^i_S}{A^i_G}}$. The inclusion of sector fixed-effect (D_j) allows for differences across the two sectors with respect to both technology and elasticity of substitution.

Table B.1 presents the regression results for the sector-level data. In specification (1), the data for the two sectors are pooled together. The coefficient in front of the growth of relative prices of the goods-intermediates is statistically significant, suggesting that the elasticity of substitution is below one. The constant comes out insignificant. The implied magnitude of the elasticity of substitution between goods and services-intermediates is 0.15, though insignificantly different than zero. This estimate hints to the limit case of complementarity between the two types of intermediates. This elasticity reconciles the decreasing expenditure share of the goods-intermediates in the presence of increasing relative prices of the services-intermediates. Specification (2) groups the data by sector and specification (3) allows for linear trend. Inference remains unaffected. The inclusion of additional controls does not accommodate the identification of elasticity of substitution statistically different than zero for either sector. On the contrary, given the limited information they make the estimate more imprecise.

Cross-section regression

Figure B.1 presents the use share of goods relative to the services-intermediates for either sector. It summarizes the information analyzed in Section 3.2.4 and highlights the first increasing and then decreasing trend in the use share. The increasing trend in the series is initiated at the beginning of the sample that coincides with the first oil-shock in 1971. In response to the second oil-shock in 1979, there is no such equivalent increasing trend. In contrast, there is very limited upward correction.

The elasticity of substitution implied by the cross-section variation is estimated

Table B.1: United States goods and services sector-level regressions

Dependent variable: $\left(\frac{g_\gamma}{1-\gamma}\right)_{jt}$			
Controls:	(1)	(2)	(3)
constant	-0.006 (0.004)	-0.007 (0.005)	-0.007 (0.011)
$g_{\frac{PG}{PS}t}$	0.846 (0.119)***	0.775 (0.170)***	0.780 (0.179)***
D_j		0.001 (0.007)	-0.009 (0.015)
$g_{\frac{PG}{PS}t} * D_j$		0.144 (0.241)	0.205 (0.254)
trend			0.000 (0.000)
$trend * D_j$			0.000 (0.000)
obs	68	68	68
$\bar{R}^2$	0.43	0.41	0.40
F-test	50.78	16.63	10.20
implied σ_S	0.15 (0.119)	0.23 (0.170)	0.22 (0.179)
implied σ_G	0.15 (0.119)	0.08 (0.170)	0.02 (0.179)

Notes: s.e. in parentheses

(***) indicates significance at 1%

for the year 1978, as well as for the period 1975-1978[3]. This is done in an attempt to figure out periods in time that suggest virtually constant relative shares, so as to maximize likelihood of identifying separately the role of prices and technological progress (see Diamond, McFadden, and Rodriguez (1978)). The data for this period are coming from the same sub-sample, hence following the same SIC classification, while data for 1977 correspond to the Benchmark I-O Table, while the oil-shock that borders this period is reasonably regarded as a purely exogenous across industry shock. The 38 observations suggest a estimate of $\sigma = 0.58$ (s.e. 0.04) for the 1978 regression and $\sigma = 0.78$ (s.e. 0.12) for the 1975-1978 period[4].

Figure B.2 uses the estimated elasticities from the aggregate cross-section and

[3]This corresponds to the sample correlation between growth in goods-intermediates use share and growth in their relative prices.

[4]The constant term from the latter regression suggests: $g_{\frac{A^i_S}{A^i_G}} = 0.67\%$.

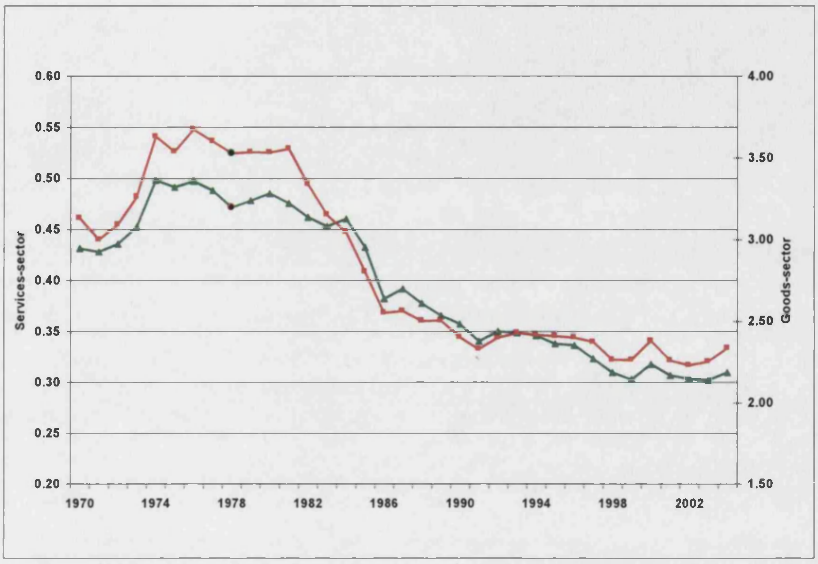


Figure B.1: United States goods and services-sector's relative use share of goods-intermediates.

time-series data to present how the changes in the relative prices alone capture the trends in the data[5]. This graph is only suggestive regarding the extent to which one expects the prices' changes to affect the intermediates' use patterns over a wide range of elasticity of substitution estimates[6]. Lower degree of substitution, implying an immediate adjustment to relative prices' changes increases the fit.

B.3 Data for intermediates' prices

Information on the relative prices of the two types of intermediates is not readily available (see Section 3.2.3).

For the aggregate-level regressions of Appendix B.2, two alternative measures were considered for the growth in the relative prices of goods-intermediates. The

[5]The initial value was set at the 1970-2004 average.

[6]Nevertheless, estimates are for $\sigma < 1$.

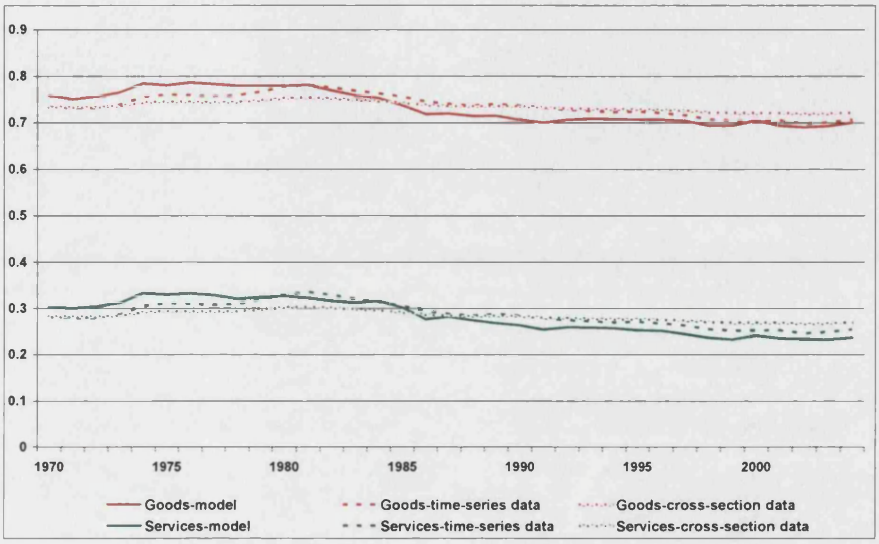


Figure B.2: Actual and predicted use shares of goods-intermediates for the United States' aggregate data.

first measure is given by the growth in the relative prices of the goods-sector gross output. This is sufficient to capture the underlying trend in the intermediates' relative prices, under the assumption that the goods and services-sector deliver the intermediates they produce at the basic price of their gross output production. The second measure is based directly on the information available for the intermediates. Given the available data on the value and volume growth of the goods and services-intermediates, one can calculate the implied price growth of these two types of intermediates at the aggregate economy level[7]. Figure B.3 presents the price index for these two measures and shows that they are almost identical. In either case, the relative price of the goods-intermediates falls over time.

For the baseline regressions at the industry-level of Section 3.2.4, two alternative measures of the relative prices of intermediates are considered. The first set of regressions (results in Table 3.7) uses the same source of information for

[7]Note that for the goods-intermediates, one needs to use a Törnqvist aggregation over materials and enegy intermediate-goods.

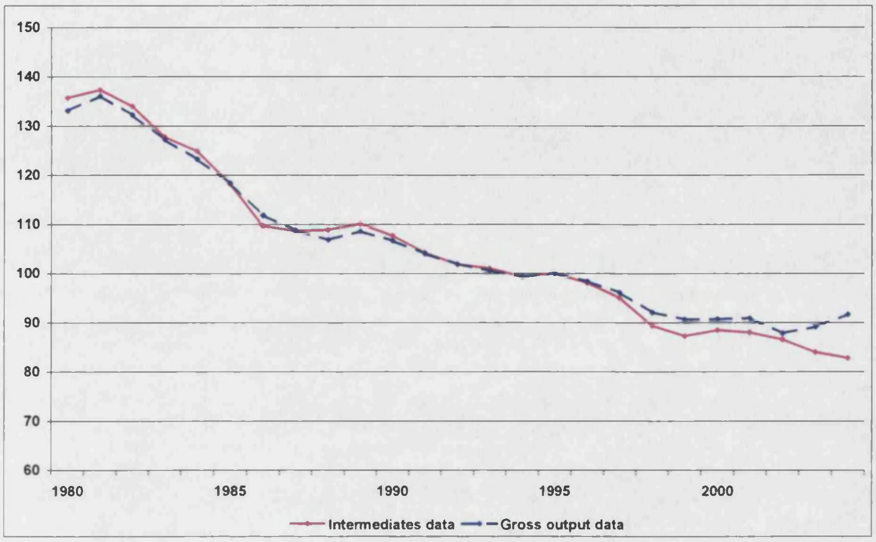
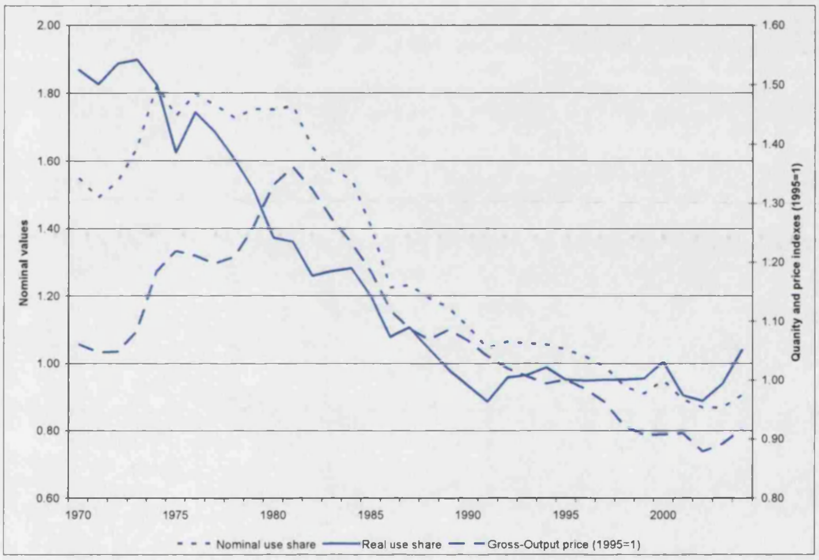


Figure B.3: Relative prices of the goods-intermediates

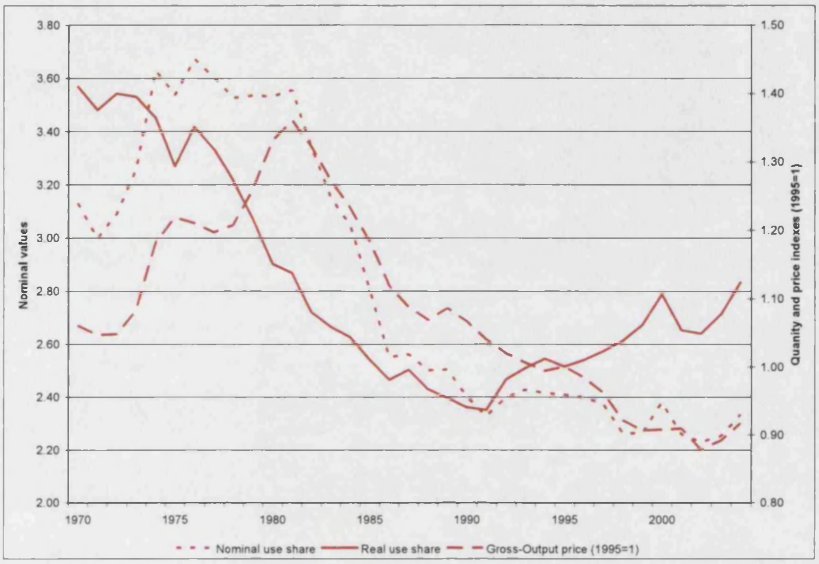
the relative prices for goods and services as in the sector-level regressions, i.e. the gross output growth of the relative prices of the gross sector. In the second set of regressions (results in Table 3.8) the information for the intermediates value and volume growth at the industry level is used to infer the industry-specific growth in the relative prices of goods and services-intermediates. It is possible that there is industry-specific variation at the relative prices due to the fact that there are many types of intermediates within the set of goods and the services-intermediates. Given that every industry uses a different composition of these goods, the implied price of the "basket" of goods or services-intermediates that they use is different across industries.

B.4 Additional figures

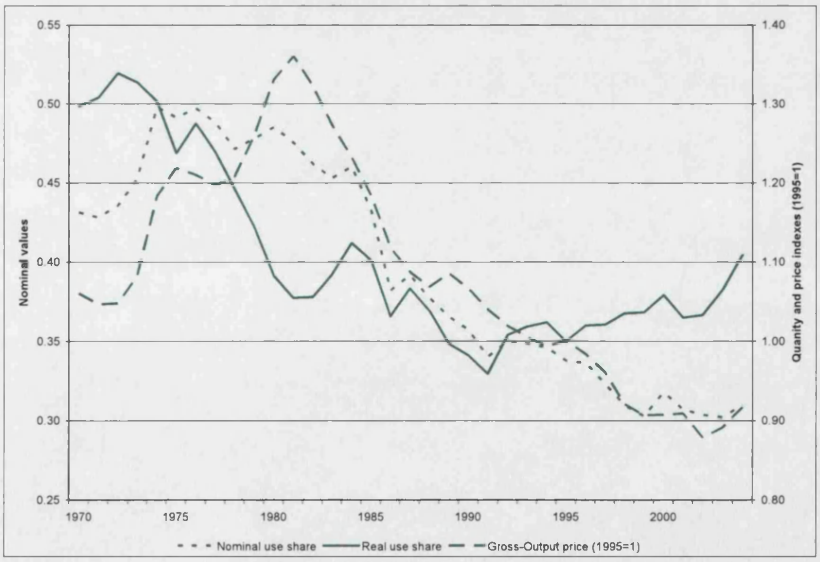
The following figures show the following for the United States and the United Kingdom. First, the relative "nominal use share" of goods-intermediates, $\frac{p_G I_G^j}{p_S I_S^j}$, relative "real use share" of goods-intermediates (i.e. relative volume), $\frac{I_G^j}{I_S^j}$, and relative prices of goods-intermediates (from gross-output prices), $\frac{p_G}{p_S}$. The figures for the United Kingdom omit the datapoint for the breakpoint year 1991.



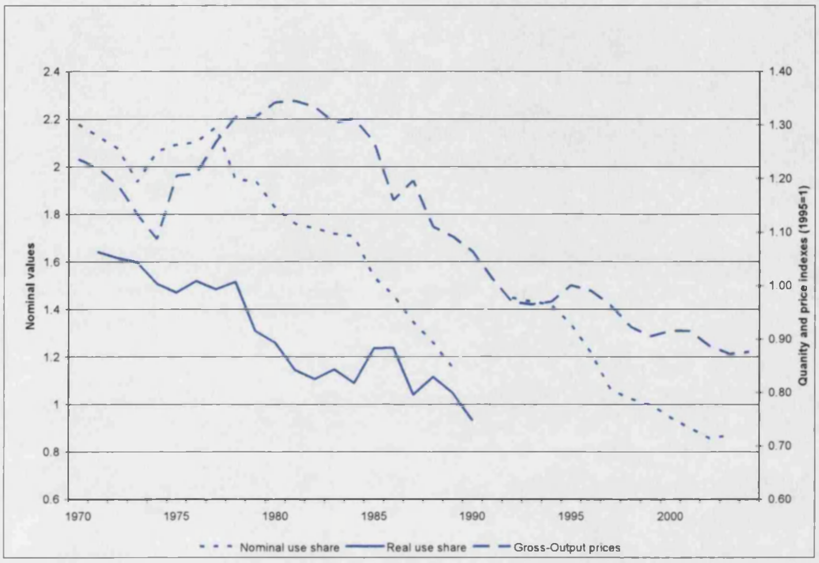
United States goods-intermediates relative expenditure shares, volumes and prices.



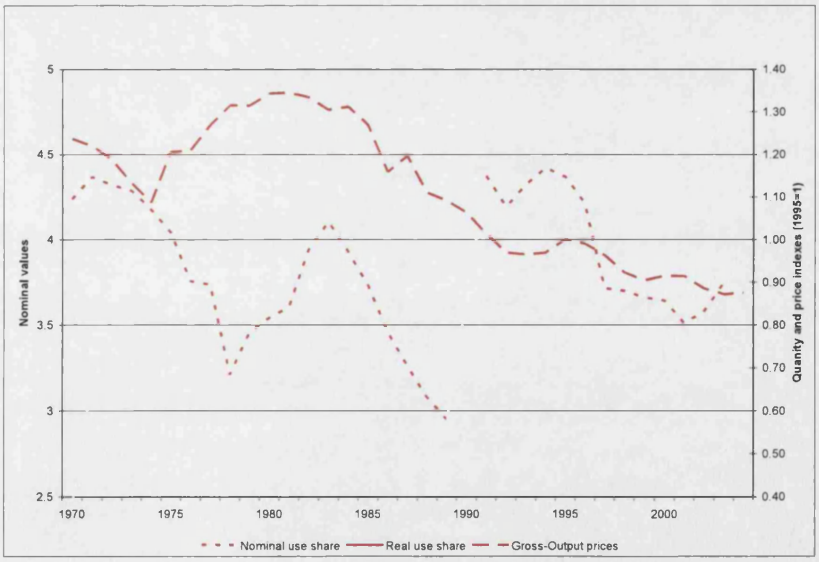
United States goods-sector's goods-intermediates relative expenditure shares, volumes and prices.



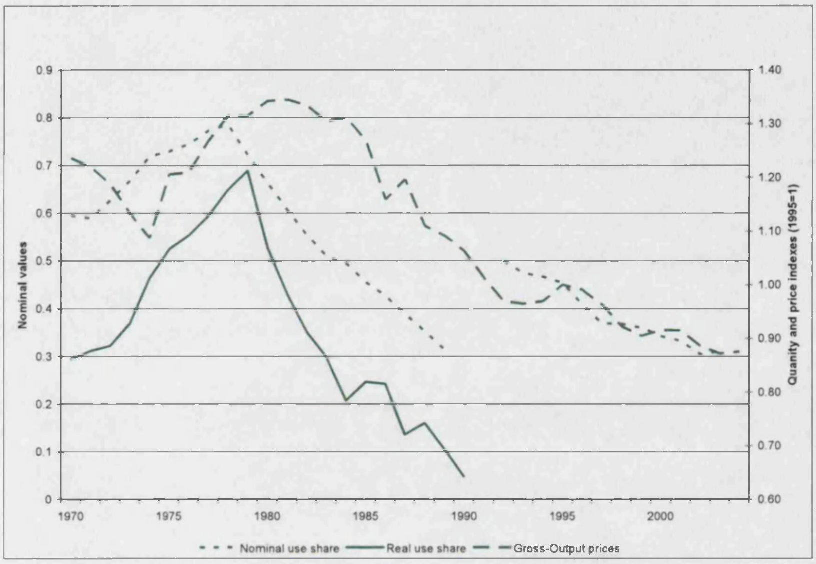
United States services-sector's goods-intermediates relative expenditure shares, volumes and prices.



United Kingdom goods-intermediates relative expenditure shares, volumes and prices.



United Kingdom goods-sector's goods-intermediates relative expenditure shares, volumes and prices.



United Kingdom services-sector's goods-intermediates relative expenditure shares, volumes and prices.

Appendix C

Appendix for Chapter 4

C.1 Equilibrium equity price for the three-period model economy

Starting from the equilibrium price function (4.16) for $t = 1$, in order to solve for the average conditional expectations and variance of ϕ_2, assume that the equilibrium price follows the linear rule:

$$P_1 = \mu_1(\mu_2\widehat{\phi} + \mu_3\phi_2 - s_1) \tag{C.1}$$

Given that prices reveal information, the implied price signal $\tilde{P}_1$ from (C.1 is defined as follows:

$$\tilde{P}_1 \equiv \frac{P_1/\mu_1 - \mu_2\widehat{\phi}}{\mu_3} = \phi_2 - \frac{s_1}{\mu_3}$$

To summarize, the signals that rational consumer i has are:

$$\begin{aligned} \text{Public signal:} &\quad \widehat{\phi}|\phi_2 \sim \mathcal{N}(\phi_2, 1/\beta_{\widehat{\phi}}) \\ \text{Private signal:} &\quad \nu(i)|\phi_2 \sim \mathcal{N}(\phi_2, 1/\beta_\nu) \\ \text{Price signal:} &\quad \tilde{P}_1|\phi_2 \sim \mathcal{N}(\phi_2, 1/\mu_3^2\beta_s) \end{aligned}$$

Using Bayesian updating, the distribution of ϕ_2 based on all the information investor i has is:

$$\phi_2|\Omega_1(i) \sim \mathcal{N}\left(\frac{\beta_{\widehat{\phi}}\widehat{\phi}+\mu_3^2\beta_s B_1+\beta_\nu\nu(i)}{\beta_{\widehat{\phi}}+\mu_3^2\beta_s+\beta_\nu}, \frac{1}{\beta_{\widehat{\phi}}+\mu_3^2\beta_s+\beta_\nu}\right)$$

This implies that the variance is the same from the point of view of every investor. The average conditional expectation is:

$$\overline{E}[\phi_2|\Omega_1] = \frac{\beta_{\widehat{\phi}}\widehat{\phi}+\mu_3^2\beta_s(\phi_2-s_1/\mu_3)+\beta_\nu\phi_2}{\beta_{\widehat{\phi}}+\mu_3^2\beta_s+\beta_\nu}$$

Replacing this into (4.16) for $t=1$, the coefficients μ_1, μ_2 and μ_3 are derived by equating the coefficients from the latter to the ones in (C.1):

$$\begin{aligned} \mu_1 &= \frac{\tau\Gamma^2+\frac{\beta_s\beta_\nu}{\tau}}{R(\beta_{\widehat{\phi}}+(\frac{\beta_\nu}{\tau\Gamma})^2\beta_s+\beta_\nu)} \\ \mu_2 &= \frac{\beta_{\widehat{\phi}}}{\tau\Gamma+\frac{\beta_s\beta_\nu}{\tau\Gamma}} \\ \mu_3 &= \frac{\beta_\nu}{\tau\Gamma} \end{aligned}$$

These give the equilibrium equity price equation in (4.19).

C.2 Proof of Proposition 1

Using (4.14), (4.18), (4.4), (4.21), $w_t = (1-\alpha)Y_t$, then given that equity market exists only in period 1, aggregate consumption in every period is:

$$\begin{aligned} C_1 &= (P_1 + \Gamma\phi_1)A_1 + \tilde{R}M_0 \\ C_2 &= (\Gamma\phi_2 - \tilde{R}P_1)A_1(1+g_A) + \tilde{R}A_1\phi_1\frac{\Gamma}{\alpha} \\ C_3 &= \tilde{R}A_1\phi_2(1+g_A)\frac{\Gamma}{\alpha}. \end{aligned} \tag{C.2}$$

Increase of true productivity by $\Delta\phi_2 = \phi_2 - \phi \geq 0$

Increase of true productivity affects equity prices, P_1, and therefore the technology growth rate. By (4.19) $\frac{\partial P_1}{\partial \phi_2} = \frac{\Gamma}{\tilde{R}}(1-z_1) \geq 0$, with strict equality holds if $z_1 < 1$, i.e. by (4.20) this true when the private and price signals are informative ($\beta_s, \beta_\nu > 0$). Given this, the impact of a productivity shock on excess gains in the equity market is $\frac{\partial(\Gamma\phi_2 - \tilde{R}P_1)}{\partial\phi_2} = z_1\Gamma \geq 0$. The strict equality holds if $z_1 > 0$, i.e. public signal is informative ($\beta_\phi > 0$) and other signals are not perfect ($1/\beta_s, 1/\beta_\nu > 0$).

Note that if public signal does not take into the increase of productivity, i.e. $\hat{\phi}_2 = \phi$, and noise trading is at its mean, $s_1 = 0$, then investors get excess gains $\Gamma\phi_2 - \tilde{R}P_1 = \Gamma z_1 \Delta\phi_2$, as long as $z_1 > 0$.

From (4.18), growth of technology increases in equity prices:

$$\frac{\partial g_A}{\partial P_1} = \left(\lambda^{\frac{1}{\rho}} \frac{1-\alpha}{\alpha} \frac{1}{\pi_1}\right)^{\frac{\rho}{1-\rho}} \frac{\rho}{1-\rho} (P_1)^{\frac{2\rho-1}{1-\rho}} > 0 \tag{C.3}$$

This implies $\frac{\partial g_A}{\partial \phi_2} = \frac{\partial g_A}{\partial P_1}\frac{\partial P_1}{\partial \phi_2} \geq 0$. As a result, the impact of productivity shock on consumption levels is:

$$
\begin{aligned}
\frac{\partial C_1}{\partial \phi_2} &= A_1 \frac{\partial P_1}{\partial \phi_2} \geq 0 \\
\frac{\partial C_2}{\partial \phi_2} &= A_1(1+g_A)\frac{\partial\left(\Gamma\phi_2 - \tilde{R}P_1\right)}{\partial \phi_2} + (\Gamma\phi_2 - \tilde{R}P_1)A_1\frac{\partial g_A}{\partial \phi_2} \geq 0 \\
\frac{\partial C_3}{\partial \phi_2} &= \tilde{R}A_1(1+g_A)\frac{\Gamma}{\alpha} + \tilde{R}A_1\phi_2\frac{\Gamma}{\alpha}\frac{\partial g_A}{\partial \phi_2} \geq 0
\end{aligned}
$$

Increase of public signal $\hat{\phi}_2 = \phi + \Delta\hat{\phi}_2$

From (4.19) $\frac{\partial P_1}{\partial \hat{\phi}_2} = \frac{\Gamma}{\tilde{R}}z_1 \geq 0$. Using (C.3), this also implies that $\frac{\partial g_A}{\partial \hat{\phi}_2} = \frac{\partial g_A}{\partial P_1}\frac{\partial P_1}{\partial \hat{\phi}_2} \geq 0$. Investors obtain excess losses in equity market $\Gamma\phi_2 - \tilde{R}P_1 = -\Gamma z_1 \Delta\hat{\phi}_2$, if $z_1 > 0$. Therefore:

$$
\begin{aligned}
\frac{\partial C_1}{\partial \hat{\phi}_2} &= A_1 \frac{\partial P_1}{\partial \hat{\phi}_2} \geq 0 \\
\frac{\partial C_2}{\partial \hat{\phi}_2} &= -\tilde{R}A_1(1+g_A)\frac{\partial P_1}{\partial \hat{\phi}_2} + (\Gamma\phi_2 - \tilde{R}P_1)A_1\frac{\partial g_A}{\partial \hat{\phi}_2} \leq 0 \\
\frac{\partial C_3}{\partial \hat{\phi}_2} &= \tilde{R}A_1\phi_2\frac{\Gamma}{\alpha}\frac{\partial g_A}{\partial \hat{\phi}_2} \geq 0
\end{aligned}
$$

Decrease of noise trading, $s_1 < 0$

A negative noise trading shock has a similar impact to a positive public signal shock: i.e. $-\frac{\partial P_1}{\partial s_1} = \frac{\Gamma^2(1-z_1)\tau}{\tilde{R}\beta_\nu} \geq 0$, $-\frac{\partial g_A}{\partial s_1} = -\frac{\partial g_A}{\partial P_1}\frac{\partial P_1}{\partial \partial s_1} \geq 0$ and investors obtain excess losses $\Gamma\phi_2 - \tilde{R}P_1 = \frac{\Gamma^2(1-z_1)\tau}{\beta_\nu}s_1 < 0$. Therefore,

$$
\begin{aligned}
-\frac{\partial C_1}{\partial s_1} &= A_1\left(-\frac{\partial P_1}{\partial s_1}\right) \geq 0 \\
-\frac{\partial C_2}{\partial s_1} &= -\tilde{R}A_1(1+g_A)\left(-\frac{\partial P_1}{\partial s_1}\right) + (\Gamma\phi_2 - \tilde{R}P_1)A_1\left(-\frac{\partial g_A}{\partial s_1}\right) \leq 0 \\
-\frac{\partial C_3}{\partial s_1} &= \tilde{R}A_1\phi_2\frac{\Gamma}{\alpha}\left(-\frac{\partial g_A}{\partial s_1}\right) \geq 0
\end{aligned}
$$

C.3 Proof of Corollary 1

The initial risk-free asset holdings (M_0), productivity in period 1 (ϕ_1) and the initial level of technology (A_1) are the same in the model and the PI economy. Given that $P_1^{PI} = \frac{\Gamma\phi_1}{\tilde{R}}$, by (4.21), it follows that consumers in period 2 in the PI economy receive no gains or losses in the equity market, i.e. $\Gamma\phi_2 - \tilde{R}P_1$. The consumption levels in the PI economy are:

$$\begin{aligned} C_1^{PI} &= (P_1^{PI} + \Gamma\phi_1)A_1 + \tilde{R}M_0 \\ C_2^{PI} &= \tilde{R}A_1\phi_1\frac{\Gamma}{\alpha} \\ C_3^{PI} &= \tilde{R}A_1\phi_2(1+g_A^{PI})\frac{\Gamma}{\alpha} \end{aligned} \tag{C.4}$$

Using (C.2), (C.4) and (4.18) the following is true:

$$\begin{aligned} C_1 &> C_1^{PI} \iff P_1 > P_1^{PI} \\ C_2 &> C_2^{PI} \iff \Gamma\phi_2 - \tilde{R}P_1 > 0 \iff P_1 < P_1^{PI} \\ C_3 &> C_3^{PI} \iff g_A > g_A^{PI} \iff P_1 > P_1^{PI} \end{aligned}$$

C.4 Infinite-horizon model equilibrium equity price

As for the three-period model, the solution method starts from (4.16) and assuming that the price equation is in the form of (4.17).

Conditional only on the public signals, the "prior" distribution of Φ_t ($2T \times 1$)

is:

$$
\begin{aligned}
\Phi_t &\sim \mathcal{N}(\widehat{\Phi}_{0,t}, \Sigma_\Phi); \\
\widehat{\Phi}_{0,t} &= (\widehat{\phi}_{t-T+1}, .., \widehat{\phi}_t, 0, .., 0)' \\
\Sigma_\Phi &= \begin{pmatrix} \frac{1}{\beta_{\widehat{\phi}}} & 0 & & & \cdots & 0 \\ 0 & \ddots & & & & \vdots \\ & & \frac{1}{\beta_{\widehat{\phi}}} & & & \\ & & & \frac{1}{\Gamma^2 \beta_s} & & \\ \vdots & & & & \ddots & \vdots \\ 0 & & & & \cdots & \frac{1}{\Gamma^2 \beta_s} \end{pmatrix}
\end{aligned}
$$

For the price signals, for $k = [0, T-1]$ the adjusted prices (that can be interpreted as price signals) are defined as:

$$
\tilde{P}_{t-k} = P_{t-k} - \Gamma \overline{z} \overline{\phi} - \Gamma \widehat{Z}' \widehat{\Phi}_t - \Gamma \sum_{l=1}^{k} \left(z_l \phi_{t-k+l} - z_{s,l} \frac{s_{t-T-k+l}}{\Gamma} \right)
$$

The vector of observables for investor i trading in period t is defined as $\Lambda_t(i) =$

$(\widetilde{P}_t, ..., \widetilde{P}_{t-T+1}, v_{t-T+1}(i), ..., v_t(i))'$, $\Lambda_t(i)$ is $(2T \times 1)$. Then:

$$
\begin{aligned}
\Lambda_t(i) &= \Gamma Z \Phi_t + \boldsymbol{\varepsilon}_t; \\
\boldsymbol{\varepsilon}_t &= (0, ..., 0, \varepsilon_t(i), ..., \varepsilon_{t-T+1}(i))' \\
Z &= \begin{pmatrix}
z_1 & \cdots & z_{T-1} & z_T & -z_{s,1} & \cdots & -z_{s,T-1} & -z_{s,T} \\
z_2 & \cdots & z_T & 0 & -z_{s,2} & \cdots & -z_{s,T} & 0 \\
\vdots & \ddots & 0 & 0 & \vdots & \ddots & 0 & 0 \\
z_T & \cdots & 0 & 0 & -z_{s,T} & \cdots & 0 & 0 \\
1/\Gamma & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 \\
\vdots & \ddots & 0 & 0 & \vdots & \ddots & 0 & 0 \\
0 & 0 & 1/\Gamma & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1/\Gamma & 0 & 0 & 0 & 0
\end{pmatrix}
\end{aligned}
$$

This implies:

$$
\begin{aligned}
\Lambda_t(i)|\Phi_t &\sim \mathcal{N}(\Gamma Z \Phi_t, \Sigma_\Lambda); \\
\Sigma_\Lambda &= \begin{pmatrix}
0 & \cdots & 0 & 0 & \cdots & 0 \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
0 & \cdots & 0 & 0 & \cdots & 0 \\
0 & \cdots & 0 & \frac{1}{\beta_v} & \cdots & 0 \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
0 & \cdots & 0 & 0 & \cdots & \frac{1}{\beta_v}
\end{pmatrix}
\end{aligned}
$$

The updated distribution of the unobservables, conditional on the observables for each of the consumer i, is found with the use of the projection theorem:

$$
\begin{aligned}
E[\Phi_t|\Lambda_t(i)] &= \widehat{\Phi}_{0,t} + \Gamma \Sigma_\Phi Z'(\Gamma^2 Z \Sigma_\Phi Z' + \Sigma_\Lambda)^{-1}(\Lambda_t(i) - \Gamma Z \widehat{\Phi}_{0,t}) \\
\mathrm{Var}[\Phi_t|\Lambda_t(i)] &= \Sigma_\Phi - \Gamma^2 \Sigma_\Phi Z'(\Gamma^2 Z \Sigma_\Phi Z' + \Sigma_\Lambda)^{-1} Z \Sigma_\Phi \equiv V_\Phi
\end{aligned}
$$

, where V_Φ indicates that the conditional variance of unobservables, which is constant over time and the same from the point of view of every consumer. Aggregating over all rational investors, provides with the average expectations of the unobservables:

$$\overline{E}[\Phi_t|\Lambda_t] = (I - QZ)\widehat{\Phi}_{0,t} + QZ\Phi_t$$

, where $Q \equiv \Gamma^2\Sigma_\Phi Z'(\Gamma^2 Z\Sigma_\Phi Z' + \Sigma_\Lambda)^{-1}$ and I is the $(2T \times 2T)$ identity matrix. Using this:

$$\begin{aligned} \overline{E}[P_{t+1} + \Gamma\phi_{t+1}|\Omega_t] &= \Gamma((z_T + \widehat{z}_T + \overline{z})\overline{\phi} + (Z_2'(I - QZ) + \widehat{Z}_2')\widehat{\Phi}_{0,t} + Z_2'QZ\Phi_t) \qquad (C.5) \\ \mathrm{Var}[P_{t+1} + \Gamma\phi_{t+1}|\Omega_t] &= \Gamma^2\left[Z_2'V_\Phi Z_2 + z_T^2\frac{1}{\beta_\phi} + \widehat{z}_T^2\frac{\beta_{\hat{\phi}} - \beta_\phi}{\beta_{\hat{\phi}}\beta_\phi} + \frac{z_{s,T}^2}{\Gamma^2}\frac{1}{\beta_s}\right] \end{aligned}$$

, where $Z_2' = (1, z_1, .., z_{T-1}, 0, -z_{s,1}, ..., -z_{s,T-1})$ and $\widehat{Z}_2' = (0, \widehat{z}_1, .., \widehat{z}_{T-1}, 0, 0, ..., 0)$.

The variance is verified to be constant over time, and homogeneous across consumers. It depends on the coefficients and precision of shocks. The average expectation is linear in future productivity, historical noise trading and public signals, while s_t enters into price equation from (4.16) directly. Therefore, the prices take the form of the conjectured price equation and the vectors of coefficients Z_1 and $\widehat{Z}$ can be recovered numerically by replacing the above results into (4.16) and equating coefficients with (4.17).

C.5 Infinite-horizon perfect information equilibrium price

For the infinite-horizon PI economy, investors are assumed to receive a perfect private signal about ϕ_{t+T} in t and are aware also of the private signals about ϕ_{t+1} to ϕ_{t+T-1}. This means that the public signal $(\overline{\phi})$ is informative only from period $t + T + 1$ onwards, because there are no agents with better about this than the information than the public signal (i.e. the prior distribution $\phi_{t+T+k} \sim \mathcal{N}(\overline{\phi}, 1/\beta_{\phi})$, for $k > 1$). Thus, the information set available in t is $\Omega_t^{PI} = \Omega_t^{PI}(i) = \{\phi_{t+1}, ..., \phi_{t+T}\}$. The uncertainty about prices comes also from the noise trading in every period, $s_{t+k} \sim \mathcal{N}(0, 1/\beta_s)$.

All rational consumers have the same expectations, $E[..|\Omega_t^{PI}(i)] = \overline{E}[..|\Omega_t^{PI}] = E[..|\Omega_t^{PI}]$ and $\text{Var}\left[..|\Omega_t^{PI}(i)\right] = \text{Var}\left[..|\Omega_t^{PI}\right]$, and the law of iterated expectations holds in this case. Therefore:

$$E[P_{t+1} + \Gamma\phi_{t+1}|\Omega_t^{PI}] = \Gamma\sum_{k=1}^{T} \tfrac{1}{\tilde{R}^{k-1}}\phi_{t+k} + \Gamma\tfrac{1}{\tilde{R}^{T-1}(\tilde{R}-1)}\overline{\phi}$$

, which is the present discounted value of the expected future profits. The variance is:

$$\text{Var}\left(P_{t+1} + \Gamma\phi_{t+1}|\Omega_t^{PI}\right) = \text{Var}\left[\tfrac{1}{\tilde{R}^{T-1}}\Gamma\phi_{t+T+1} + s_{t+1}\tau\,\text{Var}\left(P_{t+2} + \Gamma\phi_{t+2}|\Omega_t^{PI}\right)\right]$$

There are two important observations. First, prices in $t + 1$ are a function of ϕ_{t+T+1}, which is not known in t. Therefore, its variance needs to be taken into account as well (investors know that the price moves due to additional perfect signal being issued). Second, the quality of information is the same over time. Hence, $\text{Var}\left(P_{t+1} + \Gamma\phi_{t+1}|\Omega_t^{PI}\right) = \text{Var}\left(P_{t+2} + \Gamma\phi_{t+2}|\Omega_t^{PI}\right) \equiv V^{PI}$, where:

$$V^{PI} = \frac{1 \pm \sqrt{1 - 4\frac{\Gamma^2\tau^2}{R^{2(T-1)}\beta_{\phi}\beta_s}}}{2\frac{\tau^2}{\beta_s}}$$

Rational agents opt to minimize the variance, and therefore only the lower root is considered here. This term is very small and therefore the PI pricing equation is given by:

$$P_t^{PI} = \sum_{k=1}^{T} \frac{1}{\tilde{R}^k}\Gamma\phi_{t+k} + \frac{1}{\tilde{R}^T(\tilde{R}-1)}\Gamma\overline{\phi} \tag{C.6}$$

Only the period t noise trading affects the equity price. The term $\frac{1}{\tilde{R}^T(\tilde{R}-1)}\Gamma\overline{\phi}$ reflects the lack of knowledge about the long term productivity.

C.6 Proof of Proposition 2

Assume that $\Delta\hat{\phi}_t = \kappa_t\phi$ and $\Delta\hat{\phi}_{t+1} = \kappa_t\kappa_{t+1}\phi$. For the proof of the result, its is sufficient that there exist $\kappa_t > 0$ and $\kappa_{t+1} > 0$ such that $C_t \geq C_t^{PI}$.

Given the assumptions (as in Proposition 2) and (C.6) the PI equity prices are constant $P^{PI} \equiv P_t^{PI} = \frac{\Gamma\phi}{\tilde{R}-1}$ in every t. From (4.18), this implies constant growth rate of technology $g_A^{PI} \equiv g_{A,t}^{PI} = \left(\lambda^{\frac{1}{\rho}}\frac{1-\alpha}{\alpha}\right)^{\frac{\rho}{1-\rho}}\left(\frac{1}{\tilde{R}-1}\right)^{\frac{\rho}{1-\rho}}$. Using (4.4), (4.14) and $w_tL = (1-\alpha)Y_t$ consumption is always proportional to the level of technology $C_t^{PI} = A_{t-1}^{PI}\frac{\tilde{R}}{\alpha}\Gamma\phi$.

As public signal does not affect the model before period t, $P_{t-l} = P^{PI}$ and $g_{A,t-l} = g_A^{PI}$ for every $l \geq 1$. Consumption is given by $C_{t-l} = A_{t-l-1}\frac{\tilde{R}}{\alpha}\Gamma\phi$. Given that the model and PI economy start from the same initial level of technology, $A_{t-l-1} = A_{t-l-1}^{PI}$ and $C_{t-l} = C_{t-l}^{PI}$ if $l \geq 1$.

Equity prices will be higher for three consecutive periods and from (4.17) are given by:

$$\begin{aligned}
P_t &= \frac{\Gamma\phi}{\tilde{R}-1} + \hat{z}_2\Gamma\kappa_t\phi > P^{PI} \\
P_{t+1} &= \frac{\Gamma\phi}{\tilde{R}-1} + \hat{z}_1\Gamma\kappa_t\phi + \hat{z}_2\Gamma\kappa_t\kappa_{t+1}\phi > P^{PI} \\
P_{t+2} &= \frac{\Gamma\phi}{\tilde{R}-1} + \hat{z}_1\Gamma\kappa_t\kappa_{t+1}\phi > P^{PI}
\end{aligned}$$

Using (4.18), the growth rate of technology will also be higher for three consecutive periods and can be expressed as:

$$\begin{aligned} g_{A,t} &= g_A^{PI}\left(1+\hat{z}_2\left(\tilde{R}-1\right)\kappa_t\right)^{\frac{\rho}{1-\rho}} > g_A^{PI} \\ g_{A,t+1} &= g_A^{PI}\left(1+\left(\tilde{R}-1\right)\kappa_t\left(\hat{z}_1+\hat{z}_2\kappa_{t+1}\right)\right)^{\frac{\rho}{1-\rho}} > g_A^{PI} \\ g_{A,t+2} &= g_A^{PI}\left(1+\left(\tilde{R}-1\right)\hat{z}_1\kappa_t\kappa_{t+1}\right)^{\frac{\rho}{1-\rho}} > g_A^{PI} \end{aligned}$$

In $t+3$, κ_t and κ_{t+1} cease to affect equity prices and $P_{t+2+k} = P^{PI}$ and $g_{A,t+2+k} = g_A^{PI}$ for $k \geq 1$. This implies that the level of technology in PI economy and the model is the same until period t and will be permanently higher afterwards, i.e. $A_{t-1} = A_{t-1}^{PI}$, $A_t = A_t^{PI}$, $A_{t+1} = A_t^{PI}(1+g_{A,t}) > A_{t+1}^{PI}$, $A_{t+2} = A_t^{PI}(1+g_{A,t})(1+g_{A,t+1}) > A_{t+2}^{PI}$, $A_{t+2} = A_t^{PI}(1+g_{A,t})(1+g_{A,t+1})(1+g_{A,t+1}) > A_{t+2}^{PI}$ and $A_{t+1+k} = (1+g_{A,t})(1+g_{A,t+1})(1+g_{A,t+1})(1+g_A^{PI})^{k-3}A_t^{PI} > A_{t+1+k}^{PI}$ for every $k \geq 3$. From $t+1+k$ onwards, consumers do not get excess gains and losses in equity market and $C_{t+1+k} = A_{t+k}\frac{\tilde{R}}{\alpha}\Gamma\phi > C_{t+1+k}^{PI}$ for $k \geq 1$.

Consumption in period t is given by $C_t = \Gamma A_t^{PI}\hat{z}_2\kappa_t\phi + A_{t-1}^{PI}\frac{\tilde{R}}{\alpha}\Gamma\phi > C_t^{PI}$, whenever $\kappa_t > 0$ because of higher equity prices they receive. So we need to find conditions that make the remaining three generations (consumers in $t+1$, $t+2$ and $t+3$) at least as well off as the PI economy.

Consumption in $t+1$:

$$C_{t+1} = \kappa_t\phi(\hat{z}_1+\hat{z}_2\kappa_{t+1}-\tilde{R}\hat{z}_2)\Gamma A_t^{PI}(1+g_{A,t}) + A_t^{PI}\frac{\tilde{R}}{\alpha}\Gamma\phi$$

From (C.5) and (4.16) the coefficient in front of $\hat{\phi}_t$ is given by $\frac{\Gamma}{\tilde{R}}(q_2+\hat{z}_1)$, where $q_2 > 0$ is the second element of 1×4 matrix $Z_2'(I-QZ)^1$. From (4.17) the coefficient

[1]Notice that conditional variance of unobservables $V_\Phi = (I-QZ)\Sigma_\Phi$. This implies $Z_2'(I-QZ) = Z_2'V_\Phi\Sigma_\Phi^{-1}$. Second element of this is given by $q_2 = \beta_\phi \operatorname{Cov}\left(\phi_{t+1+k}, \phi_{t+2+k}|\Omega_{t+k}\right) + z_1\beta_\phi \operatorname{Var}\left(\phi_{t+1+k}, \phi_{t+2+k}|\Omega_{t+k}\right) - \beta_\phi\frac{z_{s,1}}{\Gamma}\operatorname{Cov}\left(\phi_{t+2+k}, s_{t+k}|\Omega_{t+k}\right)$ for any k. As private signals are independent, ϕ_{t+1+k}, ϕ_{t+2+k}, s_{t+k} are connected trough price signals. Looking at (4.17), higher price signal indicates either higher ϕ_{t+1+k}, ϕ_{t+2+k} or lower s_{t+k}.

in from of $\hat{\phi}_t$ is $\Gamma\hat{z}_2$. In equilibrium $\Gamma\hat{z}_2 = \frac{\Gamma}{\tilde{R}}(q_2 + \hat{z}_1) \Rightarrow \tilde{R}\hat{z}_2 - \hat{z}_1 = q_2 > 0$. This implies that $C_{t+1} \geq C_{t+1}^{PI}$ iff $\kappa_{t+1} \geq \frac{\tilde{R}\hat{z}_2 - \hat{z}_1}{\hat{z}_2} > 0$. As it is sufficient, if this condition is binding, assume in what follows that:

$$\kappa_{t+1} = \frac{\tilde{R}\hat{z}_2 - \hat{z}_1}{\hat{z}_2}$$

Consumption in period $t+2$ is given by:

$$\begin{aligned} C_{t+2} &= -\left[\tilde{R}z_1\kappa_t\phi + \left(\tilde{R}z_2 - z_1\right)\kappa_t\kappa_{t+1}\phi\right]\Gamma A^{PI}(1+g_{A,t})(1+g_{A,t+1}) \\ &\quad + A_t^{PI}(1+g_{A,t})\frac{\tilde{R}}{\alpha}\Gamma\phi \end{aligned}$$

and $C_{t+2} \geq C_{t+2}^{PI}$ if there is $\kappa_t > 0$, such that $F(\kappa_t) \geq 0$, where:

$$F(\kappa_t) \equiv \left(g_{A,t} - g_A^{PI}\right) - \frac{\alpha\left[\tilde{R}z_1z_2 + \left(\tilde{R}z_2 - z_1\right)^2\right]}{\tilde{R}z_2}\kappa_t(1+g_{A,t})(1+g_{A,t+1})$$

Note that $F(0) = 0$. It is sufficient for this purpose that one examines the conditions for this in the neighborhood of $\kappa_t = 0$, i.e. from a first-order Taylor approximation: $F(\kappa_t) \simeq F'(0)\kappa_t$. Therefore, the sufficient condition boils down to the condition for $F'(0) > 0$[2]. In order to simplify the analysis define:

$$\begin{aligned} g_{A,t} &= g_A^{PI}(1+g_0\kappa_t)^{\frac{\rho}{1-\rho}};\, g_0 \equiv \hat{z}_2\left(\tilde{R}-1\right) \\ g_{A,t+1} &= g_A^{PI}(1+g_1\kappa_t)^{\frac{\rho}{1-\rho}};\, g_1 \equiv \hat{z}_2\left(\tilde{R}-1\right)\tilde{R} \\ g_{A,t+2} &= g_A^{PI}(1+g_2\kappa_t)^{\frac{\rho}{1-\rho}};\, g_2 \equiv \frac{z_1}{z_2}(\tilde{R}z_2 - z_1)\left(\tilde{R}-1\right) \end{aligned}$$

This implies $\mathrm{Cov}\left(\phi_{t+1+k}, \phi_{t+2+k}|\Omega_{t+k}\right) > 0$, $\mathrm{Cov}\left(\phi_{t+2+k}, s_{t+k}|\Omega_{t+k}\right) < 0$. With $\mathrm{Var}\left(\phi_{t+1+k}, \phi_{t+2+k}|\Omega_{t+k}\right) > 0$, $q_2 > 0$.

[2]The sufficient conditions for the higher order terms not to reverse this outcome are also examined. The resulting conditions on the parameter's values are in line with the ones derived for the first-order terms.

and:

$$
\begin{aligned}
F(\kappa_t) &= g_A^{PI}\left[(1+g_0\kappa_t)^{\frac{\rho}{1-\rho}}-1\right] \\
&\quad -g_3\kappa_t\left[1+g_A^{PI}(1+g_1\kappa_t)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}(1+g_2\kappa_t)^{\frac{\rho}{1-\rho}}\right] \\
;g_3 &\equiv \frac{\alpha\left[\tilde{R}z_1z_2+\left(\tilde{R}z_2-z_1\right)^2\right]}{\tilde{R}z_2}
\end{aligned}
$$

Therefore:

$$
\begin{aligned}
F'(\kappa_t) &= g_A^{PI}\frac{\rho}{1-\rho}(1+g_0\kappa_t)^{\frac{\rho}{1-\rho}-1}g_0 \\
&\quad -g_3\left[1+g_A^{PI}(1+g_1\kappa_t)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}(1+g_2\kappa_t)^{\frac{\rho}{1-\rho}}\right] \\
&\quad -g_3\kappa_t g_A^{PI}\frac{\rho}{1-\rho}(1+g_1\kappa_t)^{\frac{\rho}{1-\rho}-1}g_1\left[1+g_A^{PI}(1+g_2\kappa_t)^{\frac{\rho}{1-\rho}}\right] \\
&\quad -g_3\kappa_t g_A^{PI}\frac{\rho}{1-\rho}(1+g_2\kappa_t)^{\frac{\rho}{1-\rho}-1}g_2\left[1+g_A^{PI}(1+g_1\kappa_t)^{\frac{\rho}{1-\rho}}\right]
\end{aligned}
$$

For $\kappa_t = 0$, then $F'(0) = g_A^{PI}\frac{\rho}{1-\rho} - g_3(1+g_A^{PI})^2$. Therefore, the sufficient condition for $F'(0) > 0$ is that parameters need to satisfy the following condition:

$$
\frac{g_A^{PI}}{(1+g_A^{PI})^2}\frac{\rho}{1-\rho} > g_3 \tag{C.7}
$$

The proof that there are parameters that ensure the existence of $\kappa_t > 0$ such that: $C_{t+3} > C_{t+3}^{PI}$ is similar the the one above. Consumption in period $t+3$ is

$$
\begin{aligned}
C_{t+3} &= -\tilde{R}z_1\Gamma\Delta\hat{\phi}_{t+1}A_t^{PI}(1+g_{A,t})(1+g_{A,t+1})(1+g_{A,t+2}) \\
&\quad +A_t^{PI}(1+g_{A,t})(1+g_{A,t+1})\frac{\tilde{R}}{\alpha}\Gamma\phi
\end{aligned}
$$

and $C_{t+3} > C_{t+3}^{PI}$ if there exist $\kappa_t > 0$, such that $G(\kappa_t) \geq 0$, where:

$$\begin{aligned} G(\kappa_t) \quad \equiv \quad & \left[(1+g_{A,t})\left(1+g_{A,t+1}\right) - \left(1+g_A^{PI}\right)^2\right] \\ & -\alpha \tfrac{z_1}{z_2}\left(\tilde{R}z_2 - z_1\right)\kappa_t(1+g_{A,t})(1+g_{A,t+1})(1+g_{A,t+2}) \end{aligned}$$

Hence, $G(\kappa_t) =$

$$\begin{aligned} & \left[1+g_A^{PI}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] - \left(1+g_A^{PI}\right)^2 \\ & -g_4\kappa_t\left[1+g_A^{PI}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_2\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] \end{aligned}$$

Note that $G(0) = 0$, and $G'(\kappa_t) =$

$$\begin{aligned} & g_A^{PI}\tfrac{\rho}{1-\rho}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}-1}g_0\left[1+g_A^{PI}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] \\ & +g_A^{PI}\tfrac{\rho}{1-\rho}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}-1}g_1\left[1+g_A^{PI}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] \\ & -g_4\left[1+g_A^{PI}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_2\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] \\ & -g_4\kappa_t\tfrac{\rho}{1-\rho}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}-1}g_0\left[1+g_A^{PI}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_2\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] \\ & -g_4\kappa_t\tfrac{\rho}{1-\rho}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}-1}g_1\left[1+g_A^{PI}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_2\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] \\ & -g_4\kappa_t\tfrac{\rho}{1-\rho}\left(1+g_2\kappa_t\right)^{\frac{\rho}{1-\rho}-1}g_2\left[1+g_A^{PI}\left(1+g_1\kappa_t\right)^{\frac{\rho}{1-\rho}}\right]\left[1+g_A^{PI}\left(1+g_0\kappa_t\right)^{\frac{\rho}{1-\rho}}\right] \end{aligned}$$

For $\kappa_t = 0$, then $G'(0) = g_A^{PI}\frac{\rho}{1-\rho}(1+g_A^{PI})(g_0+g_1) - g_4(1+g_A^{PI})^3$. The sufficient condition for $G(\kappa_t) > 0$ for the existence of a sufficiently small $\kappa_t > 0$, is:

$$\frac{g_A^{PI}}{(1+g_A^{PI})^2}\frac{\rho}{1-\rho} > \frac{g_4}{g_0+g_1} \tag{C.8}$$

To summarize, by (C.7) and (C.8), the sufficient condition for the existence of a small strictly positive κ_t that provides $C_t \geq C_t^{PI}$, for any t, is:

$$\frac{g_A^{PI}}{(1+g_A^{PI})^2}\frac{\rho}{1-\rho} > \min\left\{\frac{g_4}{g_0+g_1}, g_3\right\}$$

This condition is likely to be satisfied for sufficiently low levels of congestion, i.e. high ρ.

C.7 Parameters used for the numerical solution of the infinite-horizon model

parameters	T	α	ρ	η	L	$\tilde{R}$	λ	τ	β_ϕ	β_ν	$\beta_{\widetilde{\phi}}$	β_s
values	6	0.3	0.9	1	13.46	1.33	0.14	2	2.5	2.5	2.5	2.5

In the initial path: $s_{t+k} = 0$, $\phi_{t+k} = 1$, $\overline{\phi} = 1$, $\widehat{\phi}_{t-T+k} = 1$ and $\widetilde{\phi}_{t-T+k} = 1$ for all $k \in (-\infty, \infty)$.

The results are for $T = 6$[3]. The choice for the capital share, α, is standard. The congestion parameter, ρ, is from Comin and Gertler (2006). The gross interest rate, $\tilde{R}$, corresponds to yearly interest rate of approximately 6.6 per cent and is chosen such that $M_t = 0$ (for all t) for the initial path. The labour force, L, is chosen to normalize $\Gamma \equiv 1$. The scale parameter of the R&D productivity, λ, is chosen to give R&D growth, $g_{A,t}$, of 0.1 (this corresponds to ≈ 2 per cent yearly growth rate). The coefficient of risk aversion, τ, is the same as in Bacchetta and Wincoop (2007). The precision parameters β_ϕ, β_ν, $\beta_{\widetilde{\phi}}$, and β_s are chosen to be equal. This results in around 30% of the weight in the investors' expectations being put on the public signal.

[3] The length of one time period can be viewed to be 5 years. Thus, given the setting, consumers receive public and private signals about the productivity around 30 years ahead

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