Department of Economics

Essays on Information and Communications Technology, Structural Change, and Economic Growth

Tero Kuusi

Aalto University

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Abstract

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Abstract

Over the past few decades technology has been a source of profound economic transformation. This dissertation is a collection of essays concerning the key features of the process. The work extends traditional macroeconomic growth models to better describe and quantify the reorganization of production associated with the information and communications technology (ICT) revolution and the structural change accompanied by technological progress. Furthermore, it seeks new ways to analyze the economic impact of the policy changes involved in the transformation.

The first essay concerns the dynamics of ICT adaptation and the productivity gaps across advanced nations. Recent productivity statistics suggest that the ICT revolution is accompanied by widening productivity gaps. They may reflect differences in countries ability to make complementary innovations in organizations to foster successful adaptation of the technology. The essay provides an elaborate theoretical description of the productivity impacts of ICT adaptation, when complementary innovations exist. It suggests that the use of standard methods may lead to underestimate the role of ICT in generating productivity gaps. Instead, this paper uses an alternative labor productivity growth factorization and finds that ICT has a significant role in generating productivity gaps across advanced countries.

The second essay studies structural changes and economic growth in the knowledge economy with a multi-sector dynamic general equilibrium growth model. The essay finds that ICT has a large role in determining long-term economic growth (40.9 percent in Finland). Furthermore, the analysis suggests that the growth rate of the economy remains stable despite large differences in sector-specific trends in technology due to the input-specific nature of ICT. The essay also finds that drivers of structural changes in consumption, value added, and hours have different origins.

The third essay considers the collapse of the Finnish investment-led growth policy as a contributing factor to the Finnish Great Depression of the early 1990s. The policy change is analyzed with a dynamic general equilibrium model as a lifting of an investment-tax credit. The paper finds that the constructed policy change helps the model to replicate the depth and the persistence of the Finnish crisis in terms of a fall in employment, output, and investment. A reasonably sized financial crisis alone cannot explain the contraction and largely fails to account for the following long slump.

Keywords information technology, growth differentials, multi-sector growth models, manufacturing and service industries, depression, transition, industrial policy

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Tekijä
Tero Kuusi

Väitöskirjan nimi
Esseitä informaatio- ja viestintäteknologiasta, rakennemuutoksesta ja talouskasvusta

Julkaisija Kauppakorkeakoulu

Yksikkö Taloustieteen laitos

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Tutkimusala Taloustiede

Tiivistelmä

Teknologinen kehitys on viimeisten vuosikymmenien aikana ollut voimakkaan taloudellisen rakennemuutoksen lähde. Tämän väitöskirjan esseissä tarkastellaan rakennemuutoksen keskeisiä piirteitä. Väitöskirja parantaa nykyisiä makrotaloudellisia kasvumalleja, jotta ne ottaisivat paremmin huomioon informaatioteknologisen (ICT) vallankumouksen synnyttämiä muutoksia organisaatioissa ja talouden toimialarakenteessa. Lisäksi väitöskirja tutkii rakennemuutokseen liittyvien talouspoliittisten uudistusten kansantaloudellisia vaikutuksia.

Työ jakautuu kolmeen esseeseen ja johdantolukuun. Ensimmäinen essee tarkastelee ICT:n käyttöönoton tuottavuusvaikutuksia. Samalla, kun ICT mahdollistaa tuotantotapojen kehittämisen laajasti sen oman tuotannon ulkopuolella, tilastot viittaavat myös siihen, että uusi teknologia on edesauttanut maidenvälisten tuottavuuserojen kasvua. Essee esittelee makrotaloudellisen kasvumallin, jossa teknologian käyttöön liittyvät komplementaariset innovaatiot vaikuttavat tuottavuuseroihin. Teoreettinen analyysi osoittaa, että teknologian merkitys tuottavuuserojen selittäjänä voi hämärtyä, jos sen merkityksen mittaamiseen käytetään perinteistä, tuotantojoustoon perustuvaa, mittaustapaa. Essee esittää vaihtoehtoehtoisen tavan eritellä ICT:n tuottavuusvaikutuksia ja osoittaa menetelmän avulla, että ICT:llä on tiedettyä suurempi merkitys tuottavuuserojen selittäjänä.

Toinen essee tarkastelee tietotalouden rakennemuutosta ja kasvua sektoritasoisen kokonaistasapainomallin avulla. Tarkastelu osoittaa, että ICT:llä on keskeinen rooli talouskasvussa (40.9 prosenttia pitkän aikavälin kasvusta Suomessa). Lisäksi kansantalouden kasvuvauhti voi pysyä vakaana riippumatta suurista eroista teknologisessa kehityksessä eri sektoreilla, koska ICT vaikuttaa kansantaloudessa pääsääntöisesti tuotantopanoksena ja tukee palvelusektorin tuottavuuskasvua. Essee tutkii myös kulutuksen, tuotannon ja työn rakennemuutoksen lähteitä.

Kolmas essee käsittelee Suomessa vallinneen investointivetoisen kasvupolitiikan murenemista 1990-luvun lamassa. Politiikan muutosta tarkastellaan dynaamisen kokonaistasapainomallin avulla. Esseessä osoitetaan, että kasvupolitiikan muutos kriisiolosuhteissa voi synnyttää syvän ja pitkittyneen työllisyyden, tuotannon ja investointien romahduksen. Sen sijaan finanssikriisi yksin ei tuota tarpeeksi suurta tuotannon romahdusta, eikä voi selittää lamaa seurannutta pitkittynyttä matalan resurssikäytön jaksoa.

Avainsanat informaatioteknologia, kasvuerot, monen sektorin kasvumalli, teollisuus ja palvelut, lama, siirtymätalous, teollisuuspolitiikka

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Helsinki, September 2013
Tero Kuusi

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Unpublished manuscript.

Investment-led Growth in Crisis: The Finnish Great Depression Revisited
Tero Kuusi
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Part I

Overview of the Dissertation

1 Introduction

Over the past few decades technology has been a source of profound economic transformations. The period has witnessed the onset of the information and communications technology (ICT) revolution that has facilitated the widespread reorganization of production in sectors using the new technology and given rise to expanding production of high-tech goods and services. Meanwhile, economic growth in advanced economies has been accompanied by the increasing role of the service sector, reflecting technology-related changes in consumption patterns and deindustrialization. Furthermore, the transformation has involved major policy changes that have been motivated by the need to foster technological progress more powerfully. In many European countries economic liberalization and deregulation have followed the end of a long period of technological catch-up, and the countries are gradually adopting a new growth model that emphasizes innovation and creative destruction over the use of existing technologies.

This dissertation is a collection of essays concerning the key features of the transformation. The work extends traditional macroeconomic growth models to better describe and quantify the reorganization of production associated with ICT and the structural change accompanied by technological progress. Furthermore, it seeks new ways to analyze the economic impact of the policy changes involved in the transformation.

The work consists of three essays. The first essay concerns the dynamics of ICT adaptation and the productivity gaps across advanced nations. Recent productivity statistics suggest that the ICT revolution is accompanied by widening productivity gaps, especially between the US and Europe (van Ark, 2011). Micro level evidence suggests that the gaps may reflect differences in countries' ability to make complementary innovations in organizations to foster successful adaptation of the technology (Bresnahan et al., 2002). Along these lines, the first essay uses Basu and Weil's (1998) growth model to provide an elaborate theoretical description of the productivity impacts of ICT adaptation, when complementary innovations exist. The theoretical analysis shows that the functional relationship between output and ICT capital can become S-shaped. That is, because complementary innovations moderate the productivity gaps of relatively similar users of ICT, while they divide high and low intensity users into separate groups with larger productivity differences. The shape of the relationship may lead to the underestimation of the role of ICT in generating productivity gaps when standard output elasticity estimation is used. Instead, this paper uses labor productivity growth factorization, based on the work of Kumar and Russell (2002), and finds that ICT has a significant role in generating productivity gaps across advanced countries.

The second essay concerns structural changes resulting from technological change and ICT in particular. Fast technological progress in the production of ICT relative to the rest of the economy may generate growth declining structural changes, when the resources of the economy shift to support price inelastic demand of goods produced in less productive sectors. The essay uses a multi-sector growth model consisting of sectors producing ICT, traditional goods, and traditional services. The analysis suggests that the growth rate of the economy can remain stable despite large differences in sector-specific rates of productivity growth. Rather, the model implies that the effect of ICT on structural change is growth enhancing, because the technology fosters productivity growth in the service sector, where productivity growth has been slow historically. Indeed, removing ICT leads into a stronger growth declining structural change in the simulations.

The third essay concerns the short-term economic consequences of growth policy changes. In particular, the paper considers the collapse of the Finnish investment-led growth policy as a contributing factor to the Finnish Great Depression in the early 1990s. The policy change is analyzed with a dynamic general equilibrium model as a lifting of an investment-tax credit. The paper finds that the constructed policy change helps the model to replicate the depth and the persistence of the Finnish crisis in terms of a fall in employment, output, and investment. A reasonably sized financial crisis alone cannot explain the contraction and largely fails to account for the following long slump.

Next, short introductions to the specific literatures are provided and the current work is related to them. The section then provides the abstracts of the essays.

1.1 The Dynamics of ICT Adaptation and Productivity Gaps

Recent productivity statistics suggests that the benefits of the modern knowledge economy have differed greatly between advanced economies. When the world economy faced a substantial acceleration in the ICT price decline in the mid-1990s, the US economy responded with a remarkable surge of investments and labor productivity growth (Jorgenson et al., 2005).

The productivity resurgence after decades of stagnancy struck many as a surprise, because it could be traced back to industries where productivity growth had been traditionally weak, namely market services. For example, the retail trade industry has changed in a short time from a low-tech industry, where workers mainly shifted boxes from the producer to the consumer depending on the availability of stock, into an industry whose main activity is trading information by matching the production of goods and services to customer demand on a continuous basis (van Ark, 2011). The transformation reflects, among other things, the greater use of barcode scanners, communication equipment, inventory tracking devices, and transaction processing software.

It is striking to notice that the new technology did not have a similar effect in Europe, where labor productivity growth actually weakened during the same time period. The widening gaps in labor productivity means the end of a long technological catch-up growth phase in Europe (see, e.g., Eichengreen, 2007). It is likely that the pattern reflects slower emergence of knowledge economy in Europe, as the productivity gaps between the two continents mainly emerged in the same industries where the US productivity resurged (van Ark, 2011). While it should be acknowledged that there are other possible explanations for the pattern, it is unlikely that they would have a major long-run effect on productivity growth. [1]

The first essay focuses on the role of ICT in generating productivity gaps. It

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[1] Europe has experienced an increase in the labor force participation rate since the early 1990s that may have affected labor productivity growth by lowering real wages and the capital-labor ratio, as well as by increasing the share of low-skilled workers in the labor force. However, it is unlikely that the increased labor force participation rate has a long-term effect on growth. Furthermore, there are concerns that the gaps may reflect statistical problems in measuring productivity in the service industries. However, even after considerable revisions in productivity statistics it appears that the gaps still exist (van Ark, 2011).

discusses new ways to use macroeconomic growth models to capture the essential features of the underlying mechanism and their quantification. Next, a short review of the earlier literature is given.

The first prominent candidate model to explain the gaps is the standard AK growth model of Lucas (1988). (It is noticeable that the expanding varieties model of Romer (1990) has very similar implications, when ICT is considered as an outcome of innovative activities.) In the model, the way to sustain high economic growth rates is to invest heavily in ICT, some of which finds its way into providing a higher rate of technological change. The technological change may reflect externalities in the form of network effects, production spillovers and the benefits of agglomeration, or productivity enhancing organizational changes complementing the new technology. US industries use ICT more intensively compared to their European counterparts and thus linking productivity differences to externalities is a natural starting point. Furthermore, the externalities can generate differences in multi-factor productivity (MFP) (see, e.g., Stiroh, 2002a). As the majority of productivity differentials can be explained with the differences in MFP (van Ark, 2011), it seems at face value that the AK model explains the productivity gaps well.

However, the actual mechanism seems to be more complicated. An extensive literature finds that building a solid empirical connection between ICT and MFP is difficult (Stiroh, 2002b; Draca et al., 2006; Inklaar et al., 2008). The literature finds that ICT capital's elasticity of output is not above its nominal factor share, which contradicts the standard externality story. Rather, the finding is consistent with the neoclassical model, which, however, provides no explanation for the productivity gaps. Technology flows freely across countries and thus differences in the use of ICT should not exist in the first place.

Thus, more elaborate models to understand the adaptation pattern are warranted. Recently, the focus has turned to models where adaptation of technology is difficult. It has been argued among others (Basu et al., 2003; Basu and Fernald, 2007) that the benefits of technology emerge slowly, distorting the correlation between MFP and ICT. When firms adopt new production processes, they will lose old technology-specific expertise and have to start from the bottom of the learning curve (Parente, 1994; Greenwood and Yorukoglu, 1997). The installment of complementary knowledge capital stock may induce a positive correlation between MFP and ICT capital in the long run, while the correlation in the short-run can even be negative. These models are consistent with the substantial micro-level evidence on the organizational innovations that the successful adaptation of technology requires (Breshnanan et al., 2002).

Indeed, it is reasonable to claim that many European countries have lacked the institutional capacity to undergo the organizational changes. Several features may contribute to the problem. For example, in Europe educational systems are more geared towards vocational schooling rather than to higher education; capital markets are biased towards large incumbent firms rather than start-ups; labor market regulation promotes on-the-job training but hinders reallocations across firms; and innovation systems, including patent protection laws and public R&D-institutes, stimulate incremental innovation rather than major breakthroughs (Inklaar et al., 2008).

A natural framework for understanding the implications of these institutional differences is the model of Schumpeterian growth pioneered by Aghion and Howitt (1992). It emphasizes creative destruction as a source of productivity growth, and the aforementioned features have made the European system less prone to its positive effects. In particular, it is often argued that Europe reached the world's technological frontier by the 1990s and now it should abandon the old catch-up based growth model and embrace the innovation and technological change based growth model to make better use of its own innovative capabilities (Acemoglu et al., 2006).

However, standard models of Schumpeterian growth do not recognize the input-specific nature of productivity growth, reflecting organizational innovations made to use particular equipment. Furthermore, it is likely that the innovations generate knowledge spillovers, creating complex relationships between countries that learn to use the new technology together. Keller (2004) reviews the literature on the diffusion of technology and argues that in a typical OECD country the majority of MFP productivity growth is related to R&D efforts in other countries.

To further elaborate the role of complementary innovations, the first essay investigates international productivity gaps through the lens of the Basu and Weil (1998) growth model. It collects many of the features described above. In the model, the shift towards more ICT-intensive production generates a constant need for learning. Formally, technology is indexed by its ICT capital intensity and when a country invests in new, more ICT-intensive technology, it has to gather complementary innovations regarding the use of the new technology, while part of the earlier innovations regarding the old technology becomes obsolete. Some of the knowledge finds its way into providing higher efficiency in the use of the technology, and the country converges towards a world technological frontier (captured with an AK production function) in the use of the particular technology. The existing knowledge, at least partially, spills over to other countries which later choose to adopt the same technology.

The theoretical analysis shows that the complementary innovations may moderate the productivity gaps of relatively similar users of ICT, while they divide high and low intensity users into separate groups with larger productivity differences. The shape of the relationship may lead to the underestimation of the role of ICT in generating productivity gaps when standard output elasticity estimation is used.

The paper makes industry-level productivity comparisons based on EU KLEMS data and the productivity growth decomposition of Kumar and Russell (2002). The paper finds evidence that there is substantial productivity growth potential associated in the increasing use of ICT, while meeting the productivity targets appears to be difficult. These findings are consistent with the Basu and Weil (1998) model.

Furthermore, the essay provides new evidence on the EU–US productivity gaps. The US operates with more ICT intensive technology and the majority of its productivity growth is associated with improvements in the best practices of production. On the other hand, the EU 15 countries operate with less ICT intensive technologies and the dominant source of productivity growth is the shift towards technologies and production practices that have already shown their potential.

The observed spillover potential suggests that there may be scope for renewed catch-up growth in Europe. The essay suggests that policies fostering an exchange of information regarding the use of ICT are highly recommendable. However, it should be acknowledged that there are skeptical views on the prospects of catch-up. For example, van Ark (2011) argues that innovations in services are more difficult to imitate than ‘hard’ technologies based in manufacturing. Greater emphasis on organizational innovations means that they may be intangible and strongly specific to individual firms and countries.

1.2 Structural Change, ICT, and Economic Growth

At the dawn of the 21st century, most advanced countries have become service economies in terms of the service sector’s share of the total workforce, nominal value added, and consumption expenditures. The literature pioneered by Baumol (1967) suggests that productivity differentials across sectors can explain the structural change. The service sector with its low productivity growth has to compete for the same inputs, especially labor, with more progressive sectors, which will cause their product prices to rise relative to the average price level. If the final consumption is price inelastic, the share of the service sector in total production increases over time. When the structural change shifts resources for maintaining production of sectors with lower productivity, the aggregate productivity growth rate may start to decline. This ominous prediction of Baumol (1967) has received support in more recent research. In Ngai and Pissarides’s (2007) paper differences in technological progress drive structural change. Acemoglu and Guerrieri (2008) analyze how sectorial differences in factor shares and capital deepening can lead to structural change.

The second essay considers the role of ICT in generating structural change dynamics by constructing a novel multisector general equilibrium growth model. The choice of focus is motivated by the fact that, in recent decades, the strongest productivity growth is measured in the ICT producing sector, where MFP growth can exceed the economy’s average by an order of magnitude. As a result, in many countries, and most visibly in Finland, the economic growth during the last two decades has been predominantly based on technological change in a narrow segment of the economy (Jalava and Pohjola, 2008).

The study takes a stand on several questions that are important in quantifying technology’s impact, but are not clearly addressed in the earlier literature. First, it is important to understand how sectors are interlinked. Oulton (2001), for example, shows that if resources are shifting towards industries producing intermediate inputs, the aggregate productivity growth rate will rise however low the MFP growth rates are in those industries, provided only that they are positive. Much of the service sector expansion can be explained by intermediate production, such as financial and business services.

The same argument also applies for information technology, as it is still primarily used as a factor of production. Indeed, stability of the economic growth in the standard model of investment-specific technological change of Greenwood et al. (1997) is based on the assumption that the high productivity sector does not change the structure of final consumption at all. Recent work on the role of ICT in this framework includes that of Bakhshi and Larsen (2008) and Martinez et al. (2010). This assumption achieves a major analytical simplification but it is not clear how much its relaxation would change the model's behavior.

The second important factor not taken into account by the most traditional models of structural change is international trade. Recently, Matsuyama (2009) employs a simple Ricardian model to demonstrate that high manufacturing productivity growth need not lead to a decline in manufacturing employment in an open economy. Yi and Zhang (2010) construct an international trade model with changing patterns of comparative advantage that can change the direction of structural change.

Finally, structural change optimists see the structural change as merely a symptom of an increasing income and consumption capacity. Along these lines, Kongsamut, Rebelo, and Xie (2001) assume neutral technological progress, while non-homothetic preferences drive structural change patterns.

The contribution of the dissertation's second essay is to combine these features into a single structural change model of the Finnish economy and analyze the relationship between ICT and aggregate economic growth. Based on long-run projections of economic growth and under different counterfactual scenarios, the paper finds that ICT has a large role in determining economic growth. In Finland, it accounts for 40.9 percent of long-run economic growth.

The essay finds that ICT does not generate structural changes that would decrease economic growth substantially. If ever, the model suggests that its effect on the relative prices of consumption goods is growth-enhancing. The technology benefits growth in the service sector, where it has been historically difficult to improve productivity.

The essay also finds that drivers of structural changes in consumption, value added, and hours have different origins. Increasing the consumption share of services can be replicated with a model, where the sector-specific expenditure shares of production factors remain constant. Changing factor shares reflecting the substitution of labour by intermediate services and the increasing role of ICT as a factor of production are needed to account for the increasing share of services in value added and hours.

1.3 Growth Policy Change and the Finnish Great Depression

The Finnish Great Depression of the early 1990s, one of the worst economic crises in industrial countries since the World War II, has received much attention in economic literature. An established view regarding the depression is that both Finland and Sweden experienced very similar, severe currency and banking crises resulting from financial liberalization, while the deeper contraction in Finland can be explained by the fact that the Finnish economy suffered more from the collapse of the Soviet Union. However, results of a recent paper by Gorodnichenko et al. (2012, 2009) shows that neither the Soviet trade shock nor financial shock is fully consistent with the widespread and persistent nature of the crisis (Gorodnichenko et al., 2009, figure 5). Production and especially investments fell substantially in all sectors of the economy and the economic contraction was very persistent, affecting the economy until the 2000s, while the Finnish export market recovered fairly rapidly. The findings suggest that other explanations may still be warranted to understand the anatomy of the crisis.

The third essay relates the crisis to the profound change in the Finnish growth policy in the late 1980s and the early 1990s. In particular, it investigates how the collapse of the Finnish investment-led growth policy contributed to the economic crisis. The explanation has received relatively little attention in international literature, although it led to marked changes in the Finnish economy during the crisis. From the 1960s to the early 1990s, economic growth in the country was based on a high level of capital growth supported by the low price of investments.

The low price was maintained with accommodative monetary policy, the tight control of capital, and heavy state involvement in the private sector. The system fostered the rapid economic growth after World War II that was largely based on the adoption of existing technology from other countries.

The Finnish Great Depression marked the end of the system and the focus of the Finnish policies turned from catch-up growth to the support of innovation and R&D. In many other European countries a similar transformation was already experienced in the 1970s during the oil crises, while the Finnish system survived longer due to the sheltered position provided by Soviet trade. An extensive description of the policy change in Finland can be found in the work of Pohjola (1996). Landesmann (1992) discusses the Swedish experience in the 1970s. Discussion of the policy change in other European countries can be found in Eichengreen (2007). Recently, Karanassou et al. (2008) suggest that capital accumulation plays a fundamental role in shaping unemployment movements in Sweden and Finland. Furthermore, Maliranta et al. (2010) describe how the beginning of financial liberalization and deregulation in the mid-1980s coincided with a period of rapid productivity improvements and creative destruction in Finland. An illustrative theoretical framework to understand the long-run effects of the change in the technological paradigm is given by Acemoglu et al. (2006).

The third essay constructs a general equilibrium model to quantify the collapse of the Finnish investment-led growth model in the early 1990s and investigates its role in the Finnish Great Depression. It reports a permanent fall in the country's investment rate and an increase in the relative price of investment. The paper shows that with reasonable parameterization and financial frictions, lifting of an investment tax credit in the crisis conditions can explain a sizable fraction of the depression and the following long slump.

Key features of the model are taken from the recent paper by Hall (2011). It builds on the Keynesian notion that during a crisis the real interest rate is above its market-clearing level, and consequently the supply of current output exceeds demand. The collapse of the growth model, as well as the financial crisis, had a strong lowering effect on final demand, and thus the market-clearing real interest rate was low. The higher price of investments decreased investment spending and the real interest rate should have fallen in order to generate other forms of demand.

However, in the liberalized financial markets, neither the real interest rates, nor public policies, were responsive to slackness in the economy.

With respect to the crisis literature, this paper complements the view that the fall of Soviet trade was an important factor in the crisis, as Gorodnichenko et al. (2012) argue. However, it proposes a different channel instead of the trade shock. Soviet trade helped to maintain the growth policy until the 1980s, while its collapse generated a far greater and more persistent shock than the trade shock alone could have produced. The paper is also closely related to the work of Conesa et al. (2007). The authors find that the Finnish crisis was mostly driven by MFP shock, which, however, their real business cycle model cannot easily explain. This paper proposes that the shock can be explained as the unmeasured lowering of the utilization rate of capital. Conesa et al. (2007) also argue that tightened fiscal policy during the crisis could be a partial explanation. This explanation is not discussed here, as evidence of a significant tightening of fiscal policy is not apparent in the data (Gorodnichenko et al., 2012).

Finally, evidence of the real impacts of financial constraints during the crisis is ample. Honkapohja et al. (2009) discusses thoroughly their effect on both firm and household behavior. This paper quantifies their importance while not attempting to capture the underlying financial accelerator mechanism. Recently, Freystätter (2012) studied the Finnish crisis with a DSGE model based on the framework of Gerthler et al. (2007). Compared to Gorodnichenko et al. (2012), Freystätter (2011) shows that the model captures the effects and the magnitude of the collapse of Soviet trade more accurately by modeling it as a capital obsolescence shock and combining this shock with balance sheet constrained firms. In this paper the financial frictions are taken into account in a more reduced form, while the focus is on replacing the capital obsolescence shock with an alternative description of the factors affecting investments.

2 Overview of the Essays

2.1 Essay 1: The Dynamics of ICT Adaptation and the Productivity Gaps across Advanced Nations

The objective of the first essay is two-fold. First, it uses the Basu and Weil (1998) growth model to illustrate how the ICT related complementary innovations affect the distribution of productivity across countries in interaction. Second, the paper constructs production frontiers using Data Envelope Analysis (DEA) and applies Kumar and Russell's (2002) growth decomposition to empirically analyze the productivity impact of ICT.

Basu and Weil (1998) provide an illustrative framework to analyze the role of complementary innovations. In the model movement towards more ICT intensive production generates a constant need for learning. Formally, technology is indexed by its ICT capital intensity and when a country invests in more ICT intensive technology it has to gather complementary innovations regarding the use of the new technology, while part of earlier innovations regarding the old technology becomes obsolete. Some of the knowledge finds its way into providing higher efficiency in the use of the technology and the country converges towards a world technological frontier (captured with an AK production function) in the use of the particular technology. The existing knowledge, at least partially, spills over to other countries that later choose to adopt the same technology.

The complementary innovations might split the users of technology into groups. The spillovers benefit technological followers (with lower ICT capital stock) by gaining them access to technology that has already matured in the use of the leaders (with higher ICT capital stock). However, while spillovers decrease productivity differences among relatively similar countries, countries with considerably higher saving rates or better learning skills can break-off from the group and form another one. Between groups the productivity impact of gained innovations (externalities from the AK production function) dominates the effect of maturity differences.

The model implies that the equilibrium relationship between capital and output may become S-shaped. The spillovers moderate the productivity effects of

ICT within groups of relatively similar users, while productivity differences are larger between groups of relatively different users. In the empirical exercise the existence of the S-shaped productivity pattern is investigated by benchmarking the productivity performance of individual countries relative to their ICT intensive peers. The approach is consistent with the productivity profile implied by the model, where a (linear) production frontier governed by an ICT intensive peer corresponds with the world technological frontier up to a multiplier. While the standard elasticity of output estimates are affected by the S-shaped pattern and may yield a downward biased estimate of the elasticity of the underlying world technological frontier, the current approach allows the measurement of the actual movement of countries relative to the observed frontier along the pattern.

In practice, the DEA and Kumar and Russell's (2002) growth decomposition are used to separate the productivity impact of movement along the frontier from the movement relative to it. The first component measures the spillover potential of movement along a non-parametric empirical frontier towards the observation's (ICT intensive) peer, while the latter component captures the growth contribution of the changes in the maturity of the technology in individual countries.

Covariance between the estimated components and the rate of ICT capital growth provide key insights to the role of ICT. The decomposition nests the neoclassical model as a special case and thus provides novel rejection tests for its validity. Under the neoclassical assumptions (neutral technological change and full efficiency of input use) movement relative to the frontier reduces back to the traditional MFP growth term and movement along the frontier to the aggregate productivity growth contribution of input growth. Covariance of the first term should not be significantly different from zero, while for the second term the covariance should not be different from the nominal share of ICT if the neoclassical model is correct.

The paper uses an extensive international industry level dataset (EU KLEMS) and finds significant supportive evidence for the S-shaped pattern. The covariance of the component measuring movement along the frontier is substantially higher than the nominal cost share of ICT in production. However, increasing the rate of capital growth above the long-run level would significantly penalize the country by decreasing the growth rate of its position relative to the frontier.

Furthermore, the empirical analysis revisits the productivity gaps between the US and Europe and reports a leader–follower pattern. The US operates with more ICT intensive technology and majority of its productivity growth is associated with improvements in the peers' productivity performance. On the other hand, the EU 15 countries operate with less ICT intensive technologies and the dominant source of productivity growth is the shift towards technologies and production practices that have already shown their potential in the use of the peers. In particular, the results suggest that fast pace of ICT adaptation in Europe has an adverse effect on meeting the productivity targets set out by its peers in accordance with movement along the S-shaped pattern.

2.2 Essay 2: Structural Change in the Information Era: Perspectives from a Multisector Model of the Finnish Economy

The second essay calibrates a multi-sector neoclassical growth model to study the relationship between ICT, structural change, and aggregate economic growth. It analyses the movement of resources between sectors and investigates the stability of aggregate productivity growth under given long-run trends in sector-specific technological change. In the quantitative exercise the model is matched with key features of the Finnish economy. Being one of the world leaders in production and adaptation of the new technology, the country can provide a prototype example of structural changes in advanced knowledge economies.

The considered model consists of sectors producing ICT (ICT related manufacturing and services), traditional services (other private and public services), and traditional goods (other industries). The production side of the economy closely resembles Ngai and Samaniego's (2009) version of an investment-specific technological change model. In the model each sector has a unique Cobb–Douglas production function with industry-specific factor intensity shares and multi-factor productivity terms, which are calibrated using the National Accounts. The sectors produce sector-specific intermediate and capital goods, the difference being that intermediate goods have to be used during the period of its production. There are two capital stocks based on ICT and traditional goods.

Unlike the model of Ngai and Samaniego (2009), the model allows structural changes in consumption. The representative household is assumed to consume sector-specific goods according to a CES aggregator with intratemporal elasticity strictly lower than 1. This relates the model to the recent papers by Ngai and Pissarides (2007) and Acemoglu and Guerrieri (2008). The model differs from Acemoglu and Guerrieri's (2008) by assuming that changing relative prices affect the composition of production inputs and final consumption differently; a case considered by Ngai and Pissarides (2007). The unit elasticity of substitution of production functions reflects the fact that nominal factor shares remain stable over time in input-output tables. The intratemporal elasticity of substitution is based on the relationship between nominal consumption patterns and the relative prices of consumption goods.

Furthermore, the considered economy is open to capture the changing comparative advantage between sectors and countries, especially the increasing share of high-tech goods and services in the exports of advanced countries. The modeling of international trade is based on the work of Yi and Zhang (2010) who consider a version of Ngai and Pissarides's (2007) model in an open economy. Tradable sectors consist of heterogeneous firms and sector-specific goods are composites of firm-level goods produced either domestically or abroad. Domestic, sector-specific production functions are aggregates over the firm-level production functions, which are identical up to the MFP term. The distribution of firm-level MFP terms follows the assumptions in Eaton and Kortum's (2002) model of international trade, which makes it easy to estimate the unit costs of foreign countries and trade barriers. Unlike in Yi and Zhang's work (2010), the size of the foreign market and unit costs abroad are taken to be exogenous.

This paper first studies the nature of economic growth with a simplified version of the model that allows for analytical solutions. Analysis of the relationship between structural change and the type of technological progress is similar to the work of Ngai and Pissarides (2007) and Yi and Zhang (2010). It is shown that under the assumptions commonly made in the model of investment-specific technological change the growth rate of the economy can remain stable despite differences in MFP growth rates across sectors. A necessary condition is that the sectors with high productivity growth rates have to produce factors of production.

However, this assumption is not sufficient. For example, when sectors use factors of production differently (as the data suggests), the growth rate of the economy is affected by a changing consumption pattern and is no longer stable. Thus, even though ICT has a small direct role in final consumption, ICT-specific productivity growth may indirectly change the relative prices of other consumption goods and lead to the reallocation of resources. The same is true, when the economy is open. Specialization in the production of ICT is accompanied by changes in terms of trade, which may alter the relative price of all tradable and non-tradable goods.

The quantitative model is then applied to investigate structural change and economic growth. In the simulations the representative household has perfect foresight regarding exogenous variables (demographics, sectorial technological progress, foreign prices, and the sizes of foreign markets) and the expectations reflect historical long-term patterns. Future paths of the exogenous variables are projected over the years 1980–2060, and simulations for the period 1990–2030 are used to study the dynamics of the model.

This paper uses the quantitative model and counterfactual experiments to analyze the origins of the observed structural changes in the Finnish economy. First, structural changes are compared between simulations where ICT-related technological change after 1995 exists and where it is removed. A general finding is that structural changes in consumption are unresponsive to the inclusion of ICT, because the share of the stagnant service sector in consumption rises, even without ICT. Second, the origins of structural change in consumption, production, and hours appear to be different. The baseline specification (where technological trends drive the structural change) is capable of replicating structural changes in nominal consumption shares between the years 1991 and 2011, while hours and nominal value added shares are more stable than what is seen in the data.

Instead, structural change in employment and nominal value added appears to be related to the reorganization of production across sectors, not to changes in relative prices induced by the technological change. To see this, the baseline simulation (with constant factor shares of the year 2000) is augmented by letting the factor shares evolve according to the observed changes in input-output tables. While the observed factor shares are mainly constant over time, there are some changes reflecting outsourcing of work to the service sector and the rising share of ICT. Considering these changes improves the fit of the model in terms of it better capturing the service sector's increasing share of hours and nominal value added. Interestingly, the changes improve the relative productivity of the service sector, which shows up as a decreasing growth rate of the relative price of services compared to traditional goods.

The paper then investigates economic growth using the model's predictions for the years between 1991 and 2030. Comparing counterfactual scenarios with and without ICT shows that removing all ICT-specific technological change decreases economic growth by 40.9 percent on average in the period 2011–2030. Domestic production of ICT explains a large part of this effect. If the country is forced to import all ICT in exchange for exports of traditional manufactured goods, the growth rate of the Finnish economy is approximated to fall by 33 percent. The stability of economic growth is studied by measuring economic growth in different subintervals. It is found that in the baseline scenario the economic growth is almost constant, whereas without ICT the economic growth rate falls by 16 percent between 2011–2020 and 2021–2030. This finding implies that ICT is not associated with growth declining structural changes. Rather, the results suggest that it operates as a counterforce to such changes.

2.3 Essay 3: Investment-led Growth in Crisis: The Finnish Great Depression Revisited

The third essay considers the collapse of the Finnish investment-led growth policy as a contributing factor to the Finnish Great Depression. In the decades after World War II, a high rate of investments was administratively maintained in the country with accommodative monetary policy, tight control of capital, and heavy state involvement in the private sector. As a consequence, the country's production capacity was large at the onset of the crisis, while the marginal product of capital was low.

The policy change is analyzed with a dynamic general equilibrium model as a lifting of an investment-tax credit. The modeling choice is reasonable given that the main function of the policy (which consisted of a complex system of state regulation) was to lower the price of investment. Indeed, the crisis coincided with a permanent increase in the price of investments relative to consumption when compared to Sweden and the US. During the crisis the country's investment rate fell permanently to the rates of the US and Sweden.

Key features of the model are taken from the recent paper by Hall (2011). It builds on the Keynesian notion that during a crisis the real interest rate is above its market-clearing level, and consequently the supply of current output exceeds demand. The collapse of the growth model, as well as the financial crisis, had a strong lowering effect on final demand and thus the market-clearing real interest rate was low. The higher price of investments decreased investment spending and the real interest rate should have fallen in order to generate other forms of demand.

However, it appears that the real interest rate was not responsive to the slackness. In the liberalized financial markets the world real interest rate was exogenous, while the room for public policies to manipulate interest and exchange rates, as well as to provide fiscal easing, was limited by the financial crisis. Furthermore, the Finnish experience contrasts with the dynamics in a standard Walrasian model where firms respond to sudden demand shocks by lowering prices. In the standard model this generates inflation expectations, which lower the real interest rate and return equilibrium in goods markets. Rather than this, a key feature of the current model is that inflation does not respond to slackness in product markets. To support the assumption, this paper reports evidence from Finnish industry-level prices showing that they were irresponsive to contraction in output. Furthermore, the findings reflect well those reported by Hall (2011) during the current US crisis.

Instead of adjusting prices, firms are assumed to respond to falling demand conditions by adjusting the utilization rate of capital. When the utilization rate falls, fewer workers are needed in production and unemployment emerges. In the model wages do not respond to lowering the surplus that workers can provide in firms during downturns that generate less demand for labor. A reduced-form search model based on Hall's (2009) model is used where the surplus depends on the slack in the use of capital, generating a tight relationship between the capital utilization rate and unemployment. Here the model also responds to downward wage rigidity during the depression of which there is substantial evidence (see, e.g., Gorodnichenko et al., 2012).

To model the financial liberalization, saving behavior is assumed to be governed by an exogenous return on investments in international financial markets. Households are the sole investors in the model and can invest in domestic and foreign bonds, as well as in capital and durable goods. Return on foreign assets becomes a binding constraint for domestic return on capital when assets can be traded across countries. However, domestic conditions are allowed to affect household behavior. The consumption based real interest rate is partly affected by the changing price of domestic durable goods. Furthermore, during the financial crisis a fraction of households become credit constrained and are forced to save. Frictions in the financial markets affect investments in durable and capital goods and are modeled as property taxes on holding the assets.

When the price of installed capital starts to increase as a response to the policy change, the marginal product of capital must also increase in order to maintain the required return on investments. Consequently the capital stock starts to decline. However, increasing the marginal return on capital is costly, which forces the capital stock to react slowly to the overcapacity problem and the economy faces a long period of slackness.

Using model simulations this paper shows that, with reasonable parameterization and financial frictions, lifting of an investment tax credit in the crisis conditions can explain a sizable fraction of the depression and the following long slump. In particular, it can explain the difference in the depth of the Swedish and Finnish crises as well as the technology shock identified by Conesa et al. (2007). The findings are consistent with Karanassou et al. (2008) who also consider investments as an important factor in the Finnish crisis. Similarly to Pohjola's (1996) argumentation, this paper argues that a rapid fall in investments is an indication of competitiveness problems and unemployment arises when firms face conditions that prevent them from rapidly adjusting the use of capital and labor.

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Part II

Original Essays

Essay 1

The Dynamics of ICT Adaptation and the Productivity Gaps Across Advanced Nation

Tero Kuusi

Unpublished manuscript.

The Dynamics of ICT Adaptation and the Productivity Gaps Across Advanced Nation

Tero Kuusi[2]

Abstract

Recent productivity statistics suggest that the ICT revolution is accompanied by widening productivity gaps, especially between the US and Europe. Micro level evidence suggests that the gaps may reflect differences in countries' ability to make complementary innovations in organizations to foster successful adaptation of the technology. This paper provides an elaborate theoretical description of the productivity impacts of ICT adaptation, when complementary innovations exist. The theoretical analysis shows that the complementary innovations may moderate the productivity gaps of relatively similar users of ICT, while they divide high and low intensity users into separate groups with larger productivity differences. The shape of the relationship may lead to the underestimation of the role of ICT in generating productivity gaps when standard output elasticity estimation is used. Instead, this paper uses an alternative labor productivity growth factorization and finds that ICT has a significant role in generating productivity gaps across advanced countries. Keywords: MFP, ICT capital, growth differentials.

JEL classification: O3, O4,C2, C4.

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1 Introduction

Based on recent productivity statistics, it appears that the ICT revolution is accompanied by widening productivity gaps, especially across the U.S. and Europe (van Ark, 2011). Micro-level evidence suggests that the gaps may reflect differences in countries' ability to make complementary innovations in organizations to foster successful adaptation of the new technology (Bresnahan et al., 2002). The complementarity, on the other hand, suggests that innovations are inherently input-specific and may generate complex interactions between countries as they together learn to use the new technology. However, standard macroeconomic growth models do not recognize their effect on the distribution of productivity, which may obscure the interpretation of productivity statistics and conceal the true importance of information technology as a source of productivity gaps.[3]

The objectives of this paper are two-fold. First, it uses the Basu and Weil (1998) growth model to illustrate how the complementary innovations affect the distribution of productivity across countries in interaction.[4] The model shows how the equilibrium relationship between capital and output may become S-shaped. That is because a world comprising of numerous countries that have slightly different saving rates or adaptation skills might be expected to break up into discrete convergence groups of leaders and followers (Basu and Weil, 1998). The theoretical analysis shows that the functional relationship between output and ICT capital can become S-shaped. That is, because complementary innovations moderate the productivity gaps of relatively similar users of ICT, while they divide high and low intensity users into separate groups with larger productivity differences.

Second, the paper constructs production frontiers using the Data Envelope Analysis (DEA) and applies the Kumar and Russell (2002) growth decomposi-

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[3] In particular, ICT elasticity of output estimates are typically low, indicating that the technology has only a limited role as a source of productivity gaps, according to standard growth models. On the traditional interpretation of the output elasticity, see Stiroh (2002). The low elasticity is reported (among others) by Stiroh (2002), Draca et al. (2006), and Inklaar et al. (2008), while O'Mahony and Vecchi (2005), Oulton and Srinivasan (2005), and Venturini (2009) report a larger long-term effect.

[4] An introduction to the macroeconomics of technology diffusion can be found in Acemoglu (2010). A list of other ICT-related growth models can be found in Basu & Fernald (2007). The current framework distinguishes from them by analyzing countries' interaction in technology adaptation.

tion to empirically analyze the productivity impact of ICT. The existence of the S-shaped productivity pattern is investigated by benchmarking the productivity performance of individual countries to their ICT-intensive peers. The approach is consistent with the productivity profile implied by the model, where a (linear) production frontier governed by an ICT-intensive peer corresponds with the world technological frontier up to a multiplier. While standard elasticity of output estimates are affected by the S-shaped pattern and may yield a downward-biased estimate of the elasticity of the underlying world technological frontier, the current approach allows the measuring of the actual movement of countries relative to the observed frontier along the pattern.[5] The paper uses an extensive international industry-level dataset (EU KLEMS) and finds supportive evidence for the S-shaped pattern.

In particular, the empirical analysis revisits the productivity gaps between the U.S. and Europe and reports a leader-follower pattern. The U.S. operates with more ICT-intensive technology and the majority of its productivity growth is associated with improvements in the peers' productivity performance. On the other hand, the EU-15 countries operate with less ICT-intensive technologies, and the dominant source of productivity growth is the shift towards technologies and production practices that have already shown their potential in the use of peers. In particular, the results suggest that the fast pace of ICT adaptation in Europe has an adverse effect on meeting the productivity targets set out by the peers in accordance with movement along the S-shaped pattern.

Basu and Weil (1998) provide an illustrative framework to analyze the role of complementary innovations. In the model, the shift towards more ICT-intensive production generates a constant need for learning. Formally, technology is indexed by its ICT capital intensity and when a country invests in new, more ICT-intensive technology, it has to gather complementary innovations regarding the use of the new technology, while part of the earlier innovations regarding the old technology becomes obsolete. Some of the knowledge finds its way into providing higher efficiency in the use of the technology, and the country converges towards a world

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[5] The relationship is further illustrated in the figure (1). The implied production frontier is a special case of a more general class of frontier used in the empirical exercise. That is, while the assumptions of the Basu & Weil (1998) model are not expected to exactly hold, the focus is on finding similar features in the data.

technological frontier (captured with an AK production function) in the use of the particular technology. The existing knowledge, at least partially, spills over to other countries which later choose to adopt the same technology.

The complementary innovations might split the users of technology into groups. The spillovers benefit technological followers (with lower ICT capital stock) by gaining them access to technology which has already matured in the use of the leaders (with higher ICT capital stock). However, while spillovers decrease productivity differences among relatively similar countries, countries with considerably higher saving rates or better learning skills can break off from the group and form another one. Between groups, the productivity impact of gained innovations (externalities from the AK production function) dominates the effect of maturity differences, and an S-shaped pattern may arise.

The paper then searches empirical evidence for the implied productivity pattern. In practice, Kumar and Russell (2002) growth decomposition is used to separate the productivity impact of movement along the frontier (g^K) from movement relative to it (g^R). The first component measures the spillover potential of movement along a non-parametric empirical frontier towards the observation's (ICT-intensive) peer, while the latter component, g^R, captures the growth contribution of the changes in the maturity of the technology in individual countries.[6] The paper makes cross-country comparisons of ICT-using manufacturing and service industries covering the period between 1990 and 2005, as provided by the EU-KLEMS project (see Timmer et al., 2007, March 2008 release). [7]

Covariance between the estimated components and the rate of ICT capital growth provide key insights to the role of ICT. The decomposition nests the neoclassical model as a special case and thus provides novel rejection tests for its validity. Under the neoclassical assumptions (neutral technological change and full efficiency of input use), g^R reduces back to the traditional MFP growth term and g^K to the aggregate productivity growth contribution of input growth. Thus,

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[6] In practice, it combines individual countries' movement towards and away from the world technological frontier and the upward movement of the empirical frontier in the Kumar & Russell (2002) decomposition.

[7] For a list of industries, see tables 1.1 and 1.2 in appendix B. Included countries are the EU-15, excluding Greece: AUT, BEL, DNK, ESP, FIN, FRA, GER, IRL, ITA, LUX, PRT, SWE, and the UK, plus AUS, JPN, and USA.

if the neoclassical model is correct, covariance between g^K and capital growth rate should equal the nominal share of ICT capital in production. g^R should not be correlated with the capital growth rate. Evidence for the Basu and Weil (1998) model is found if the covariance for g^K is higher than the nominal share (spillovers), and for g^R it is negative (learning effects).

A battery of rigorous econometric tests[8] confirms evidence for the opposite forces in a data-set covering most advanced nations. The empirical analysis suggests that the covariance of g^K is substantially higher than the nominal cost share of ICT in production. A 10 percent increase in the ICT capital would step up the labor productivity by 1.5 percent if the country remained on the production frontier. The estimate is much higher than the neoclassical model would suggest. The impact would be only 0.26 percent, based on the average nominal share of ICT in the EU KLEMS data. However, increasing the rate of capital growth above the long-run level would significantly penalize the country by decreasing the growth rate of its position relative to the frontier. On average the country would lose 0.5 to 1 percent of the potential growth, depending on the estimation method.

Furthermore, the majority of productivity growth in the U.S. is associated with increases in g^R, while in the EU-15 the dominant source of productivity growth is g^K. Furthermore, evidence of the pattern's intimate link with ICT and its dynamic nature is presented. The EU-15 industries operate with less ICT-intensive technologies and movement toward ICT-intensive best practices of production is associated with spillover potential. That is, the covariance of g^K with ICT capital growth is significantly above the nominal share of ICT. However, an aggressive strategy for gaining the potential is associated with falling behind the productivity targets set by the observed best practices. The g^R component has a significantly negative covariance with the growth rate of ICT capital. For the U.S. industries operating with more ICT, the negative relationship is missing and the correlation with g^K is lower, indicating that a similar possibility of inheriting matured technology does not exist.

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[8] In particular, an instrumental variable estimation in the spirit of Zhengfei and Lansink (2006) is used.

2 ICT and Productivity Gaps : Theory

2.1 A Model of ICT diffusion : Basu and Weil (1998)

Following the established literature, the technology diffusion is captured by implementing a world technological frontier, a description of the production function under full information with respect to its use. Individual countries are assumed to gather the information gradually from a common frontier and move closer to the full information production style (see, e.g., Acemoglu, 2009). The world production frontier is described with a constant return-to-scale Cobb-Douglas production function and decreasing marginal product of (ICT) capital

$$Y = AK^{\alpha},$$

where A denotes MFP associated to the best possible way to use the capital stock and α is the nominal share of capital in production.[9] Technological change is endogenous and driven fully by capital accumulation. The spillovers are modeled by assuming a non-neutral world technological frontier (AK production function):

$$A = A(K) = K^{1-\alpha},$$

The spillovers may reflect network effects and complementary innovations, such as labor-saving changes in organizations or quality changes in product lines. (Stiroh, 2002A). For the sake of simplicity, there exists two countries with equal population, $L_j = 1 \mid j = 1, 2$. The countries absorb knowledge from the world technological frontier and produce according to the country-specific production functions

$$Y_j = (B_j A_t(K_j))K_j^{\alpha},$$

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[9] In the empirical analysi,s industry-level data is used. Here for the sake of clarity the models are discussed at the country level, but the idea is fully compatible with industry data, when the exogenous productivity term is also thought to include the impact of inter-sectoral dynamics within countries. Furthermore, the analysis focuses on one type of capital good. The effects of the use of other input factors and the way the output transforms into capital goods as well as country-level general equilibrium dynamics are controlled in the empirical analysis.

where the country-level MFP $(B_j A_t(K_j))$ consists of two elements. $A_t(K_j)$ is the maturity of the technology with given capital intensity and common to all countries. B_j, on the other hand tells how efficiently individual countries are using the available information and translating it to actual productivity.[10] Capital accumulates according to a standard Solow model. Country invests a constant share, s, of income which translates into capital in the next period and a constant fraction of the capital stock depreciates in each time period.

In the BW model, countries gather information which helps to use only certain technology, indexed by its capital intensity. Firms lose old technology-specific expertise and have to start from the bottom of the learning curve to use new technology efficiently (Parente, 1994; Greenwood and Yorukoglu, 1997). Conversely, new organizational innovations may not be compatible with the old technology, or they may not be as productivity-enhancing when less intensive technology is used. A few papers have found evidence suggesting that efficient adaptation of technology is not easy. There appears to be a positive lagged relationship between ICT and MFP growth (O'Mahony and Vecchi, 2005; Oulton and Srinivasan, 2005; Venturini, 2009). Using industry-level data, Basu et al. (2003) and Basu and Fernald (2007) report a positive lagged correlation between ICT intensity and MFP growth while contemporaneous correlation is negative.

Similarity is captured in the model by assuming that the learning of technology with intensity K_i improves other technologies, K, uniformly within an interval $[K_i - \gamma < K < K_i + \gamma]$, where γ is a constant parameter. Although capital intensity differences restrict its flow, information is potentially available for everyone. Its current state $A_t(\cdot)$, the maturity of technology with given capital intensity, is a result of information gathering in both countries and the accumulated stock is freely available for current and future users of similar technology. Thus, the model is consistent with the observed large knowledge flows across countries.

For a given level of capital K, the dynamics of the information stock follows a technology absorption process:

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[10] It also captures how exogenous conditions such as investments in other goods, human capital, institutions, and policies affect productivity.

$$\dot{A}_t(K) = \beta(A(K) - A_t(K)) \sum_{i=1,2} I(K_i - \gamma < K < K_i + \gamma), \quad (1)$$

where I is an indicator function for the event that country i operates with technology similar to K and A denotes the full information stock, a function of capital. I captures the knowledge spillovers. If both countries learn to use similar technology simultaneously, current information regarding its use improves twice as much in *both* countries. If the difference in capital intensity is more than γ, the follower country will be able to benefit from the spillovers once it increases capital intensity sufficiently.

There is substantial evidence on knowledge flows. Keller (2004) reviews the literature on the diffusion of technology and argues that in a typical OECD country, 90% of MFP productivity growth is related to R&D efforts in other countries. The flow seems to be towards the follower countries as the rate is much smaller for the countries with the highest GDP level. In the particular case of ICT, there is some evidence of rapid knowledge flows. Van Reenen et al. (2010) show with the U.S. data, how an increase of geographic distance between cited and citing patents tends to matter less for ICT patents compared to average patents. Peri (2006) draws similar conclusions from global patenting patterns. However, other studies have argued that the more sophisticated the information becomes, the less it flows. Keller and Yeaple (2009), for example, show how in the knowledge-intensive industries there is less decentralization of operations of U.S. multinational firms across countries because of the increasing difficulty to transfer tacit knowledge. Van Reenen et al. (2010) show how affiliates of U.S. multinationals manage to maintain higher productivity compared to firms in the host country because of their superior, ICT-intensive organizations.

2.2 Low ICT Elasticity of Output and the Productivity Gaps

To outline the model behavior, let us first characterize the equilibrium in a two-country case, when countries have different savings rates[11]. With sufficiently similar saving rates, there exists a balanced growth path where the leader (high saving rate) and the follower (low saving rate) are growing at the same, constant rate. However, the follower is aligned closer to the world technological frontier due to the access to more matured technology, while the position of countries relative to the frontier remains constant along the balanced growth path. Furthermore, the short-run effects of an increase in the saving rate can be analyzed. The following short-term increase in the rate of capital growth is generally associated with a decline in the maturity of the used technology, and thus the country falls further below the world technological frontier. Details of the dynamics are provided in the Appendix.

In a larger group of countries, the Basu and Weil (1998) model implies that the observed equilibrium relationship between capital and output may be S-shaped.[12] To see this, consider two groups of countries with large differences in the ability to absorb technology between groups. Let B of the group of leader countries be sufficiently higher than in the follower group so that growth differentials may emerge. Higher B indicates that the leaders will be closer to the world technological frontier, and their higher level of investments means that they will spend less time devoted to learning a particular technology. While spillovers from the leader still help the followers, the higher investment rate decreases their importance and may ultimately break up the balanced nature of growth. The leaders grow faster than the followers and over time stop receiving spillovers. Their growth rate becomes independent of the followers, while at the same time the balanced nature of growth may remain within the groups.[13]

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[11] In terms of model dynamics, s high saving rate is isomorphic to having high B, and thus the example directly generalizes to technological differences. However, welfare implications may be different.

[12] The conclusions regarding group dynamics reflects the results of the numerical analysis in the original article.

[13] As an analogy, consider a group of racing cyclists. In principle, the group can benefit from each other's slipstream. However, if there is too much heterogeneity in the group, a group of

The findings question the interpretation of standard output elasticity estimates. According to the traditional view, the role of ICT in generating recent productivity patterns is limited, based on the findings that ICT elasticity of output estimates are consistently low or close to the nominal share of the ICT capital stock (see, e.g., Inklaar et al., 2008; Stiroh, 2002A; Van Reenen et al., 2010). However, the interpretation does not generalize to the Basu and Weil (1998) model, where the usefulness of being a follower and the difficulty in catching up may generate a low correlation between capital and output, both in the short run and the long run. Rather, the equilibrium relationship between ICT capital and output is non-linear and is affected by short-run learning dynamics. Still, complementary innovations related to ICT can generate sustained productivity gaps in the model.

2.3 Institutional Differences Across Countries

While the Basu and Weil (1998) model is illustrative, it can give only approximate reasons for the productivity gaps. Ultimately the gaps reflect more fundamental institutional differences across countries. In these lines, corollaries are next drawn with Acemoglu, Aghion and Zilibotti (2006), who argue that the mid-1990s marked the end of a catch-up phase for the European countries. Further productivity growth would have required a transition towards an economic system that encourages more innovation. However, institutions in the European countries have not been geared towards that goal. For example, educational systems emphasize vocational schooling rather than higher education; capital markets are biased towards large incumbent firms rather than start-ups; labor market regulation promotes on-the-job training but hinders reallocations across firms and innovation systems, including patent protection laws; and public R&D institutes stimulate incremental innovation rather than major breakthroughs (Inklaar et al., 2008).

Acemoglu et al. (2006) describe the institutional transformation elegantly. In their model multi-factor productivity (A) growth can be characterized as a combination of innovation (γ_1) and imitation ($\gamma_2 \frac{\overline{A}_{t-1}}{A_{t-1}}$),

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better cyclists may find it useful to break off while leaving the others to try to catch up as a group.

$$\frac{A_t}{A_{t-1}} = \gamma_1 + \gamma_2(\frac{\overline{A}_{t-1}}{A_{t-1}} - 1)$$

where $\frac{\overline{A}_{t-1}}{A_{t-1}}$ is distance to the world leading technology with the highest productivity $\overline{A}$. When a country closes the gap with the frontier, there are fewer innovations to imitate, and thus its growth effect weakens. Furthermore, they assume that policies affect γ_1 and γ_2, and ultimately maintaining the rate of productivity growth requires a transition towards innovation-orientated policies which reflect an increase in γ_1. Acemoglu et al. (2006) show that the timing of the shift from imitation towards innovation is critically dependent on the institutional set-up. Policies supporting imitation tend to be related to the use of established firms and lower competition. They also tend to be hard to implement due to lack of competition and possible political pressure to maintain the system. On the other hand, innovations are associated with stronger competition and more developed financial markets.

However, in their model, technology is not input-specific as in the Basu and Weil (1998) model and thus is not directly applicable to analyze adaptation of ICT. However, the Basu and Weil (1998) model can describe a similar transition, although in more reduced form. In the model, ICT capital intensity can be considered to reflect a similar trade-off between imitation and innovation. Intensifying the use of capital generally means that there is less available knowledge spillover from other countries. On the other hand, investment rate, s, can be seen as the policy tool. The golden rule level of investments depends on the maturity of technology. When the ICT capital stock is low, this policy may be welfare-enhancing, as it may help a country to gain access to mature technology developed in other countries. However, an extended period of high investments may lead the country to a growth path where it ends up using immature technology and to consume below the golden rule level. Thus investment in the technology is highly context-dependent.

Furthermore, it can be postulated that the country's saving rate, s, and success in making the complementary innovations, B, are likely to be interrelated. For example, a high rate of investment can be typically achieved by large incumbent companies for which borrowing tends to be less constrained than for smaller companies. Smaller companies, on the other hand, have higher credit constraints and thus can invest less, but they are typically more innovative and less prone to have an adverse effect on the competitiveness of the market. Thus, lowering s may be associated with increasing B.

Due to the spillovers, the policy implications of productivity gaps in the two models are somewhat different. In Acemoglu, Aghion and Zilibotti (2006), productivity gaps tend to be a sign of a convergence trap, which implies that the country's growth strategy fails to generate convergence. To fix the problem, a transition towards an innovation-based system is needed. In this context, intensifying the use of ICT has been seen as one possible way to foster innovative economy, for example, in the Lisbon agenda. In contrast, the Basu and Weil (1998) model shows that catching up to ICT-intensity differences is not a self-evident policy target when spillovers exist.

3 Quantitative Analysis

The theoretical model suggests that traditional output elasticity estimation provides a poor basis for the analysis of ICT when maturity of the technology affects productivity, because of the short-term learning dynamics and the nonlinearity of the underlying relationship between output and ICT. Figure 1 illustrates the emerging S-shaped relationship between ICT capital and output. Dots mark individual countries which are split into two groups. Within groups, spillovers moderate productivity differences, while a larger difference is observed between the groups.

The figure illustrates the usefulness of Data Envelope Analysis (DEA) in the current exercise. The method isolates countries that produce the most with a given set of inputs and combines the observations to a piece-wise linear, convex production frontier which represents the maximum output with a given set of inputs. The longer dashed line in the figure shows a constant returns to scale and concave production frontier based on DEA. The frontier is governed by the productivity observation of an ICT-intensive peer, and the capital's output elasticity of the frontier corresponds with the theoretical world technological frontier

(AK production function) in the Basu and Weil (1998) model.[14] Furthermore, the productivity effect of movement of individual countries along and relative to the frontier is illustrated with an example pointed by the arrow.

In particular, this paper analyzes productivity performance of individual countries relative to their ICT intensive peers. It studies whether the elasticity of the generated frontiers and movement of individual countries relative to the frontier corresponds with similar patterns in practice. In particular, it asks whether the ICT elasticity of the frontier is consistently higher than the nominal share of ICT reflecting externalities,[15] and on the other hand whether high growth rate of ICT is associated with a decline in the position of the observation relative to the production frontier reflecting movement along the S -shaped pattern and the short-term dynamics.

This section first describes the method to find the frontier and to measure movement of the observations relative to it. The second part discusses construction of econometric tests based on the measures.

DEA and the Growth Decomposition

This paper compares productivity performance of national entities (still referred as countries) within narrowly defined industries provided in the EU KLEMS data. A frontier is estimated separately for each industry with DEA. Producers use labor, ICT, and non-ICT services to produce output which is the value added. All variables are considered in per hour terms.

The details of the estimation closely follow Los and Timmer (2005) closely. Following their suggestion, the frontiers are estimated for each period with a dataset that also includes historical observations. Technologies that previously have been used by the leaders should still be available in the future for the followers, and thus

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[14] In particular, the frontier corresponds with a function Y(K) = B*A(K*)*K=Constant*K, where Y is production in the peer country, B is the distance of the peer to the frontier (a constant in equilibrium), A(K*) is the externality and K* is the peer's level of capita. The elasticity $d\log(Y)/d\log K = 1$ corresponds with the AK production function.

[15] Under the assumption of competitive input markets and input exhaustion, the equilibrium condition in the neoclassical model is that the input's nominal factor share equals its output elasticity (Solow, 1957). However, ICT can cause the elasticity to exceed its measured input share and generate a correlation between capital and measured MFP reflecting externalities (Stiroh, 2002A).

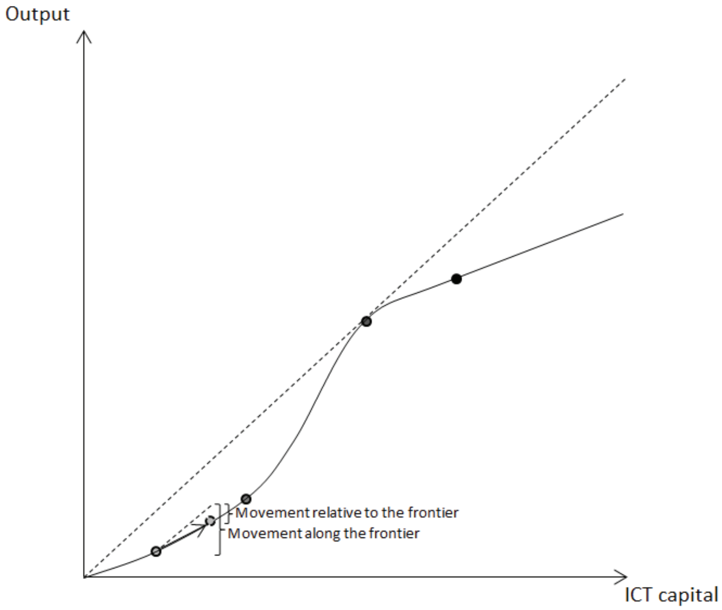

Figure 1: The equilibrium output - ICT capital relationship and a simple decomposition of growth.

lagging behind earlier levels of productivity should be considered as falling further from the frontier, rather than technological regression. Thus, the estimations are based on a set of observations that are current and from the previous 10 years.[16]

To study the movement of the observations both in relation to the frontier and on the frontier, the tripartite decomposition of labor productivity growth by Kumar and Russell (2002) is used. Its more detailed derivation is outlined in Appendix C, while a graphical illustration of the decomposition with a single input is given in the figure (2). With endpoints denoting vectors, the decomposition can be stated as:

$$\begin{aligned}
&(1+g^{eff})\times(1+g^{tech})\times(1+g^{K}) \\
&=\Big(\frac{\overrightarrow{0y^{t}(x_t)}}{\overrightarrow{0\overline{y}^{t}(x_t)}}\times\frac{\overrightarrow{0\overline{y}^{t-1}(x_{t-1})}}{\overrightarrow{0y^{t-1}(x_{t-1})}}\Big)\times\Big(\frac{\overrightarrow{0\overline{y}^{t}(x_t)}}{\overrightarrow{0\overline{y}^{t-1}(x_t)}}\times\frac{\overrightarrow{0\overline{y}^{t}(x_{t-1})}}{\overrightarrow{0\overline{y}^{t-1}(x_{t-1})}}\Big)^{1/2} \\
&\times\Big(\frac{\overrightarrow{0\overline{y}^{t}(x_t)}}{\overrightarrow{0\overline{y}^{t}(x_{t-1})}}\times\frac{\overrightarrow{0\overline{y}^{t-1}(x_t)}}{\overrightarrow{0\overline{y}^{t-1}(x_{t-1})}}\Big)^{1/2},
\end{aligned} \tag{2}$$

where $y^t(x_t)$ is the actual observed and $\overline{y}^t(x_t)$ is the highest potential value of labor productivity with inputs x_t corresponding to a point on the frontier. Superscripts indicate the date of the reference technology, t. It is noticeable that in this paper x_t is a vector, whereas the original Kumar and Russell (2002) decomposition is defined for a single variable, the capital stock. Later in this paper, the role of individual inputs are estimated using a second stage parametric model.

The first term in the decomposition measures the changes in the position of a country relative to the frontier between periods t and t-1. The second term is a geometric mean of gross shifts of the frontier upwards with period t and period t-1 input combinations. The last term captures the productivity growth based on movements along the frontier, that is movement from efficient production with period t-1 inputs to efficient production with period t inputs. Index theory is required, because in each time period, a reference to two technological frontiers

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[16] In the actual estimations, free disposability of inputs was assumed and the frontier was allowed to exhibit variable returns to scale, while being convex. (For further information, see Coelli et al. (2005)) The estimations were conducted using FEAR 1.11 by Wilson (2007).

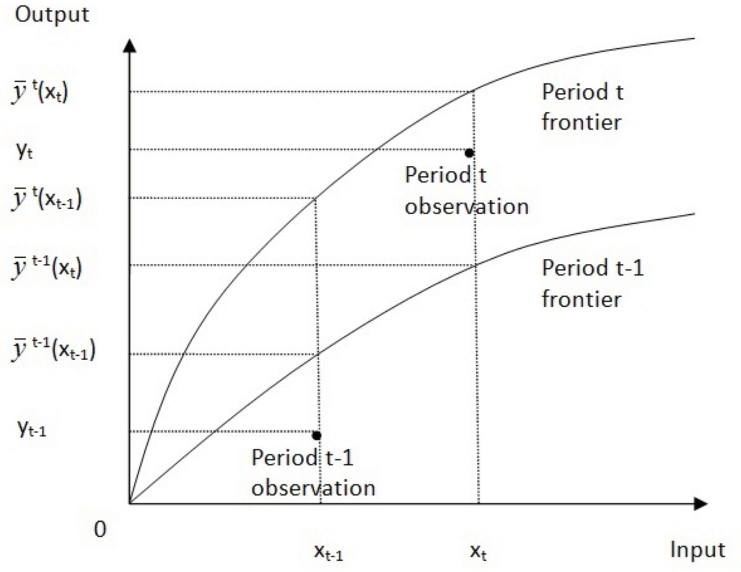

Figure 2: Kumar & Russell (2002) growth decomposition

are needed: the original one in t-1 and the new one in period t. Under neoclassical assumptions, that is, neutrality of technological change, g^{tech}, and learning dynamics, g^{eff}, Eq. (2) becomes the traditional growth accounting decomposition. The shape of the frontier does not change over time, rendering the geometric mean (Fisher decomposition) useless. g^K is independent of the date of frontier and solely reflects the growth contributed to the input factor growth. Under the neutrality assumptions, g^{tech} and g^{eff} together become the traditional MFP growth term.

Components of the Kumar and Russell (2002) decomposition can be used to measure the elasticity of the frontier and quantify movement relative to it. First, the elasticity is clearly captured by g^K. It compares productivity of efficient peers on the production frontiers, and it measures the potential extra amount of production a country gains, when it moves from one set of inputs to another, that is, the spillover potential of the technology (Los and Timmer, 2005). The rest of the elements in Eq. (2) illustrates the learning dynamics, i.e., movement relative to the goal set out by the peers. Let us denote their sum as

$$g^R \equiv g^{eff} + g^{tech17}$$

Some discretion regarding the role of technological change component, g^{tech}, is required. Upward movement of the frontier corresponds to the (changing) shape of the frontier and thus the index method cannot fully distinguish between the two. If ever, in the empirical analysis this may lead to underestimate the elasticity of output and the learning effect, not false rejections of the hypothesis considered in the next subsection. The reasons for the choice of g^R are pragmatic. First, leaving g^{tech} out would make g^R a truncated variable. Moreover, in practice, learning on the empirical frontier would have a decreasing effect on g^{eff} components and an increasing effect on g^{tech} in other countries using similar input combinations whereas learning just below the frontier would not have such an effect.

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[17] In actual estimations, logs are used as proxies for the growth rates.

Testing the productivity impacts of ICT

The empirical strategy is based on the fact that Kumar and Russell (2002) decomposition nests the neoclassical model as a special case. Thus, elements of the decomposition can be subjected to rejection tests of the neoclassical model under the standard production theory. If the neoclassical model is valid, the measured ICT elasticity of the frontier should not be different from the nominal share of ICT capital (neutral technological change), and the learning dynamics should not be correlated with the rate of ICT capital accumulation (neutral learning effects). Of course, the approach based on DEA is not without problems. The success of the frontier countries may be due to some unobservable characteristics correlated with ICT, luck, or even a plain statistical illusion in which case the shape of the frontier reflects poorly on the true spillover potential of the technology. This paper controls for these problems by resorting to an instrumental variable method described at the end of this section.

Let us discuss the construction of the empirical tests. The first test measures the spillover potential of the technology embodied in the g^K component. The ICT elasticity of the term is measured similarly to a standard output elasticity measurement. Apart from the explained variable, g^K, the structure of the equation follows earlier empirical literature. The estimated equation is

$$g^K_{tic} = \alpha^K \times \Delta \log(k^{IT}_{tic}) + \boldsymbol{\gamma}'\mathbf{X}_{tic} + \varepsilon_{tic}, \tag{3}$$

where t is time, while i and c are indices of industries and countries included in the regression, k^{IT}_{tic} is ICT capital services per hour, and $\mathbf{X}$ contains a set of control variables including rates of growth in other inputs per hour, lagged ICT capital stock levels, and growth rate of hours. Unobserved heterogeneity is controlled with entity-level (*industry* × *country*) fixed effects. Country-specific time trends (*country* × *year*) are introduced to control for macro-economic shocks and inflationary price indices. In all estimations autocorrelation and heteroscedasticity consistent standard errors are used. The specifications are discussed in more detail when results are presented.

To test whether spillovers exist, $\widehat{\alpha}^K$ is then compared with the observed nominal share of the ICT capital stock. The null hypothesis is that $\widehat{\alpha}^K$ equals on average the nominal share of ICT.

The set-up of the 2^{nd} test, measuring the conditional covariance between ICT capital growth and g^R, is very similar to the one used before:

$$g^R_{tic} = \alpha^R \times \Delta \log(k^{IT}_{tic}) + \boldsymbol{\gamma}'\mathbf{X}_{tic} + \varepsilon_{tic}, \tag{4}$$

where the set of control variables, $\mathbf{X}_{it}$, includes similar control variables as in the first estimation. Additional control variables are also used to measure the technological distance between the maximum productivity with the observed input combination and the highest productivity on the frontier to try to capture the pure catch-up effect. Again, more details are given in the results section.

Here, the test is to determine whether α^R is significantly less than 0, implying that above average (as relative to country, year and industry) rate of ICT is penalized with a negative impact on the growth rate in the shift relative to the empirical frontier, which would be consistent with the BW model.

In addition to using standard panel data methods, an instrumental variable approach is considered to alleviate several potential problems in the statistical inference. First, efficiency scores and the derived growth indices rely on estimates instead of the actual true technological frontier and do not take the possibility of errors in observations into account. Second, the estimators may be biased also because more standard statistical problems, such as unobserved heterogeneity and reverse causality. Let us next address the problem of DEA errors and the proposed way to resolve it, before discussing the other problems.

An error in one observation can affect efficiency scores extensively if it elicits a false shift of the frontier and thus creates a cross-sectional correlation between error terms in a complicated manner. Simar and Wilson (2007) suggest using a two-stage bootstrapping procedure to overcome problems emerging in the first stage estimation. Since second-stage estimations are made using panel data, the bootstrapping procedure is hard to carry out. Zhengfei and Lansink (2006) offer an alternative solution to the endogeneity problem, which is the instrumental variables estimation. While they use lagged productivity estimates in a dynamic panel model, the instruments in this paper are constructed with parallel, uncontaminated information from other industries.

The instruments are constructed with the following procedure:

- First the deterministic frontiers and the resulting growth components are estimated separately for each industry, i, using DEA.
- Let us then consider one industry at a time. A linear model is estimated separately for each growth component, $g^{(\cdot)}$:

  $$g^{(\cdot)}_{t-ic} = \alpha^{(\cdot)}_{-i} \Delta \log(k^{IT}_{t-ic}) + \textbf{constant} + \varepsilon_{tic}$$

  with a data-set that only includes observations from industries other than i.
- Using the estimated models, the conditional expectations for the growth components are then predicted for industry i, that is, for each national entity's input observation within industry i.
- The procedure is repeated until the uncontaminated conditional expectations for the growth components in each industry are found.

Models 3 and 4 can then be estimated using the constructed expectations as instruments for $\Delta \log(\frac{K^{IT}_{tic}}{H_{tic}})$. From a DEA estimation error perspective, the instruments are valid by construction, since frontiers for each industry have been estimated separately. On the other hand, if ICT is truly a general purpose technology, the relationship between growth components and input growth should behave similarly in different industries, thus making the instrument strong.

The approach also allows one to deal with the other statistical problems. The instruments are independent of idiosyncratic shocks to productivity of individual entities or industries, which is important because these may cause a bias due to unobserved heterogeneity. However, the instruments are likely to be correlated with factors affecting the productivity growth beyond the industry-level. Both permanent country-level differences and business cycles are known to affect productivity across industries. In the empirical estimations, these factors are controlled with $(country \times year)$ -fixed effects.

Furthermore, the estimates are biased if there exists an unobservable factor common to all industries beyond X and correlated with both ε and $\Delta\log(K^{IT})$. In particular, simultaneity bias may arise because investment decisions are based on good economic performance, not the other way around. It can be expected to affect the contemporaneous productivity growth, g^R, more than the shape of the production frontier and thus g^K.[18] As a result, the covariance of g^R with $\Delta\log(K^IT)$ may be estimated above its true value. However, as this paper's finding is that the covariance is negative, removal of the bias is only likely to increase its significance.

Let us then formally consider the approach that is based on two linear models (for the final estimation and for the construction of instruments):

$$\begin{aligned} g^{(\cdot)}_{tic} &= \alpha^{(\cdot)}_{i}\Delta\log(k^{IT}_{tic}) + \boldsymbol{\gamma}'\mathbf{X}_{tic} + \varepsilon_{tic} \\ g^{(\cdot)}_{t-ic} &= \alpha^{(\cdot)}_{-i}\Delta\log(k^{IT}_{t-ic}) + \varepsilon_{t-ic}, \end{aligned} \tag{5}$$

where t is time, i denotes industry, c country and $-i$ indicates that the model is estimated without industry i. $\mathbf{X}_{tic}$ is a set of controls containing factors affecting productivity beyond the industry-level. ε_{tic} consists of two components, $\varepsilon_{tic} = e_{tic}+$ ξ_{tic}. e_{tic} is regular idiosyncratic shock, while ξ_{tic} is a zero-meaned DEA estimation error, which can be correlated between observations in the same industry. ε_{tic} may be autocorrelated and e_{tic} correlated with $\Delta\log(k^{IT}_{tic})$ and $\mathbf{X}_{tic}$. Similarly, $\varepsilon_{t-ic} =$ $e_{t-ic}+$ ξ_{t-ic}. e_{t-ic} is likely to be correlated with $\Delta\log(k^{IT}_{t-ic})$, but also with $\mathbf{X}_{tic}$ through the common factors of productivity.

Importantly, $\xi_{tic} \mathrm{II}\, \xi_{t'-ic'}$ for all observations, because productivity decomposition is estimated separately for each of the industries. Furthermore, when the common factors are controlled for in the first equation, e_{tic} is independent of them, and thus $\alpha^{K}_{-i}\Delta\log(k^{IT}_{t-ic})$ II e_{tic}.[19]Therefore, although $\Delta\log(k_tic^IT)$ and ε_tic may

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[18] When instrumentation is used, the reverse causality affects the elasticity of g^K only when the growth rates of capital are consistently correlated with the errors in the shape of the frontier, not only in the industry i, but also between industries. This effect should be captured by the (year x country) controls.

[19] Notice that the methodology does not help to eradicate systematical factors in the relationship between ε and $\Delta\log(K^{IT})$. That is, the estimations are biased if there exists an unobservable common factor across industries beyond X which is correlated with both variables. In industry-

not be independent and thus invalidate the standard OLS, the constructed conditional expectation

$$E(g^{(\cdot)}_{t-ic}|\Delta\log(k^{IT}_{tic})) = \alpha^{(\cdot)}_{-i}\Delta\log(k^{IT}_{tic})$$

is a valid instrument because it is independent of the error terms in the industry i:

$$\alpha^{(\cdot)}_{-i}\Delta\log(k^{IT}_{tic}) \amalg \varepsilon_{tic}$$

In addition, it is relevant if the true ICT elasticities are not zero in general: $\alpha^K_i, \alpha^K_{i-1} \neq 0$, because then the conditional expectation is both correlated with the instrumented exogenous variable and the dependent variable. To see this, consider first the correlation with the dependent variable:

$$\begin{aligned} &corr\left[E(g^{(\cdot)}_{t-ic}|\Delta\log(k^{IT}_{tic})), g^{(\cdot)}_{tic}\right] \\ &= corr\left[\alpha^{(\cdot)}_{-i}\Delta\log(k^{IT}_{tic}), \alpha^{(\cdot)}_{i}\Delta\log(k^{IT}_{tic})\right] \neq 0 \end{aligned}$$

Second, the correlation with the exogenous variable is clearly non-zero:

$$\begin{aligned} &corr\left[E(g^{(\cdot)}_{t-ic}|\Delta\log(k^{IT}_{tic})), \Delta\log(k^{IT}_{tic})\right] \\ &= corr\left[\alpha^{(\cdot)}_{-i}\Delta\log(k^{IT}_{tic}), \Delta\log(k^{IT}_{tic})\right] \neq 0. \end{aligned}$$

The conditional expectations measured for different growth components ($g^{(\cdot)}$) yield moment conditions for GMM estimation in the second stage:

$$E(\alpha^{(\cdot)}_{-i}\Delta\log(k^{IT}_{tic}) \times \varepsilon_{tic}) = 0$$

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level estimations, this problem is likely to be small..

4 Data

This study uses the EU -KLEMS database[20] constructed to provide internationally comparable and consistent time series on output, inputs and productivity by industry. (Timmer et al., 2007) The EU KLEMS database covers EU-25 as well as several other industrialized countries. In general, data for 1970-2005 is available for the old EU-15 nations as well as for the U.S., Australia, and Japan. Series from 1995 onwards are available for the new EU member states that joined the EU on 1 May 2004. Due to data limitations, the coverage differs across countries, industries, and variables (Timmer et al., 2007). The used set of ICT-using industries (Table B1, Appendix B) covers a large portion of the manufacturing and service-based market economy. It consists of all manufacturing industries in the EU KLEMS dataset, as well as a wide variety of services, including trade and transportation services, business services, hotels, restaurants, and personal services.

In order to analyze productivity, this study uses industry labor productivity to combine industry-specific, heterogeneous products into a single measurable output. It is measured as the aggregated value of outputs minus the intermediate goods and services used in production. Recognizing the potential of output measurement problems, a well-measured subset of industries is also used, following the list provided in Nordhaus (2008)[21]..

As in a traditional growth accounting exercise, capital goods and labor are seen as carriers of services that constitute the actual input in the production process, which can be found by measuring their approximate value to users. While productivities of inputs are assumed to reflect their rental value within the input type, the frontier estimation allows the usage of any particular type inefficiently without assumptions of the nature of frictions. A distinction between three ICT assets (office and computing equipment, communication equipment, and software) and four non-ICT assets (transport equipment, other machinery and equipment, residential buildings and nonresidential structures) are made. ICT assets are deflated using a quality-adjusted investment deflator based on the methodology described in Timmer et al. (2007). Capital service flows are derived by weighting the growth

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[20] March 2008 release.

[21] In practice, this excludes business services and real estate activities.

of stocks by the share of each asset's compensation in total capital compensation using the Törnqvist index. In this way, the aggregation takes into account the widely different marginal products from the heterogeneous stock of assets by using weights related to the user cost of each asset. The user cost approach is crucial for the analysis of the contribution of capital. This approach is based on the assumption that marginal costs reflect the relative marginal productivities within the corresponding capital type.

The productivity of various types of labor input, such as low-skilled versus high-skilled, also differs. In order to take this into account, the labor is cross-classified in EU-KLEMS according to educational attainment, gender and age with the aim to proxy for differences in work experience, providing 18 labor categories (3*2*3 types). It is assumed that service flows are proportional to the hours worked, and wages reflect the relative marginal productivities within labor. (see, Timmer et al., 2007)

Finally, purchasing power parity (PPP) tables constructed by Inklaar and Timmer (2008) are used to obtain comparability between countries. The tables provide comparisons of output and input prices at the industry level in different countries. The PPPs are compiled from comparable sets of national symmetric input-output tables and detailed output and input PPPs at the sub-industry level. Then the industries are aggregated using the price-variant of the multilateral index number approach advocated by Caves et al. (1982), also known as the CCD-method. The benchmark table is calculated for the year 1997. Following the example of Inklaar and Timmer (2008), PPPs were extrapolated for the entire time period using country-level real changes. As these authors point out, there are problems involved with this procedure. Mainly, weights of the base year are preserved as the weighting system for the time series (fixed-weight bias) in the extrapolated benchmark and the time series is based on the national weights of each individual country (weight inconsistency).[22] Thus results are reported only for 1990-2005, even though the dataset for historical reference technology starts already from 1980.

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[22] See Inklaar & Timmer (2008, appendix B)

5 Results

Tables B1.1 and B1.2 in Appendix B represent features of the estimated production frontiers on the industry level. Table B1.1 shows the cross-country average growth rates of labor productivity and inputs within a specific industry and the estimated growth components between the years 1990 and 2005. [23] While the rate of ICT capital growth has been rapid in all industries, there is much variation across sectors in productivity performance. Generally, the strongest average growth is seen in the goods -producing industries, while market services are the poorest performers. The difference between the strongest and the weakest average industry growth performance are substantial, ranging from over 4.02 % in chemical production to almost no growth in some of the market services. The weak productivity performance in services is expected and accompanied by an increased share in the total hours which reflect more general structural changes in the economies.

The growth decomposition suggests that the labor productivity growth is mostly attributed to the creation of the spillover potential, g^K. The greatest average growth is seen in the industries where this element is large, while the other component of growth, the learning dynamics has a lesser impact. It is noticeable that there seems to exist a positive relationship between g^K and g^R. Where learning the technology is fast, it seems also to provide possibilities for large spillovers. On the other hand, in many of the industries with the weakest productivity performance, the spillover potential seems on average not to have been captured. This indicates that there are considerable differences in the individual countries' ability to absorb technology from the technological frontier, or that the average conditions for production have deteriorated over time.

Next, it is illustrative to study the set of countries that define the best practices of production on the industry level. Table B1.2 provides a description of the peers for two subintervals, 1985-1994 and 1995-2005. First, it shows that the frontiers are updated relatively frequently. Since the year 1985 there are 497 new entries to the empirical frontiers, indicating an average annual rate of 1.38 entries for each industry. Particular focus is given on the ICT-intensive peers. They are defined

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[23] The reported estimates are for the countries listed in the introduction, while the whole EU KLEMS data was used in the estimations of the growth components. The data and algorithms are available from the author upon request.

as the efficient producers with the ICT intensity exceeding the industry median the most during the year they enter the frontier. In the table, the peer with the highest single value during the subintervals is reported.[24] It should be noticed that for the majority of industries one country appears frequently as the ICT intensive peer.

In the theoretical framework, the ICT-intensive peers represent the best practices of production that the follower countries try to imitate. Table B1.2 allows one to address whether the empirical correspondents for these targets are feasible. The table suggests that ICT-intensive targets indeed exist: for most industries the peer's ICT intensity is considerably higher than the industry median. Furthermore, the data indicates that the intensive peers also set desirable goals for others in terms of high labor productivity. In most cases, they have the highest labor productivity ranking in the year of entry.

Generally, the peers reflect well classical examples of comparative advantage, such as transportation, trade, and food production in the Netherlands, manufacturing industries in Belgium, and forestry in the Nordic countries. Furthermore, when compared to the CIA world factbook[25] listing of the most important manufacturing industries (in terms of the share in annual output) by country, it shows how the selection of peers follows the comparative advantage of countries quite closely. However, the rise of U.S. industries after the mid 1990s is apparent. Before the year 1995, U.S. industries do not show up as an efficient peer, but thereafter the U.S. has the highest number of ICT-intensive entries to the frontier (transport equipment, basic metals and fabricated metal, and business services).[26] The peers are also compared with other indicators of industry-level competitiveness as an additional validity check. The selection is in line with the recent trade-based rankings of MFP in manufacturing industries by Fadinger and Fleiss (2011, Figure 1). Furthermore, in service industries, the peers reflect well the industry-level listing of MFP leaders in Inklaar (2008, Table A3).

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[24] For most of the industries, the same peer contributes many times to the movement of the frontier.

[25] The 2000 listing is used but the listings are relatively constant over time. Country entries can be found on the Internet at: https://www.cia.gov/library/publications/the-world-factbook/ and are available in Appendix D.

[26] It is noticeable, that outside the considered sectors, the U.S. also has the leading position in the production of ICT and financial services after the mid 1990's.

The results are next reviewed. First, a cross-regional decomposition of growth based on the Kumar and Russell (2002) decomposition is reported in Table 2.

TABLE 2: A cross-regional growth comparison

Average for	U.S.		EU-15 (weighted)		
18 industries	g^{R}	g^{K}	g^{R}	g^{K}	$\frac{K_{US}^{ICT}}{K_{EU}^{ICT}}$
83-05	1.15%	1.03%	0.68%	1.44%	120%
83-95	0.35%	0.88%	0.99%	1.50%	97.5%
95-05	1.85%	1.18%	0.51%	1.36%	144.8%

The comparison shows that on weighted average the ICT intensity is roughly 20% higher in the U.S. compared to the EU-15 throughout the period and the gap has increased over time.[27] The sources of growth are very different in the regions. The U.S. contributes more to the shifts of the frontier for ICT intensive technology. For the U.S. the main contributor to growth has been improvements in the best production practices associated with its input mix, g^R, with 1.15%, while in the EU-15 countries this part is dramatically lower, 0.68%.[28] On the other hand, EU-15 compensates the difference by having a much higher growth rate in the other component of growth. Growth through the creation of spillover potential, g^K has contributed on average 1.44% in comparison to 1.03% in the U.S. The results also indicate that differences between the regions are generated for the most part during the period 1995-2005. They also show that g^{R} component has increased in the U.S. after 1995, while it has decreased in Europe. The g^{K} component has been higher in EU-15 throughout the years between 1983 and 2005.

In order to see the relationship with ICT more clearly, regional ICT elasticities of the growth components are measured in Table B3 using models 3 and 4 with country-level data. $\Delta \log(k_{tic}^{IT})$ is replaced with two regional terms in which the growth rate of ICT capital stock is multiplied with a regional indicator variable

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[27] At the same time the average position relative to the observed frontier is 7 percentage points higher in the U.S. This may imply that the U.S. industries on average are compared with less mature technology or have on average higher B. Furthermore, it tells that the aggregate comparison hides considerable amount of industry-level and country-level heterogeneity across the regions.

[28] A further decompositon of g^R shows that g^{eff} is on average -0.33% in the EU-15 while this term is negligible in the US.

($(I[region] \times \Delta \log(k_{tic}^{IT}))$) while controlling for entity-level (country × industry) fixed effects and country-level time trends.[29]

TABLE 3: Cross-regional ICT elasticities

18 industries	U.S.		EU-15	
Period	g^{R}	g^{K}	g^{R}	g^{K}
83-05	-.007	.044	-.119***	.189***
(standard error)	(.018)	(.013)	(.035)	(.038)
83-95	-.013	.054	-.086***	.127***
(standard error)	(.027)	(.017)	(.019)	(.014)
95-05	-.019	.067	-.143*	.230***
(standard error)	(.073)	(.031)	(.056)	(.056)

g^{R} : Confidence levels for rejecting $|\beta| = 0$) : *,**,*** = 5%,1%,0.1%. g^{K} :Confidence levels for rejecting | nominal share − output elasticity | = 0 : *,**,*** = 5%,1%,0.1%

The elasticity of the observed frontier (0.189) implies that ICT has an impressive spillover potential when measured for the EU-15 countries. The elasticities are consistently above the region's average nominal share of ICT. On the other hand, increasing the growth rate of ICT capital above the average rate results in an adverse effect on the movement in relation to the observed technological frontier (-0.119). This signals that the learning dynamics are indeed negatively associated with ICT capital growth. Neither of the effects arises significantly in the U.S. data (0.074 and -0.007, respectively). An analysis of the covariances over different time periods suggests that the role of ICT has increased after the year 1995, albeit the same relationship also exists in the earlier period of 1983-1995.

To conclude, the cross-regional patterns support the view that the productivity growth observed in the U.S. is associated with improvements in the ICT-intensive best practices of production, while in the EU-15 countries the dominant source of

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[29] The estimations are made with STATA xtreg program. The standard errors are adjusted for potential clusters in the entity-level as well as heteroscedasticity. The dataset consists of the ICT-using industries in the EU-15 countries and the corresponding U.S. industries.

productivity growth is the shift towards high intensity production styles. In EU-15, attempts to increase ICT to a high rate (above the entity - country average) seem to be penalized with a decline in the growth rate relative to the observed frontier.

While the cross-regional results seem to favor the features of the BW model, more rigorous tests are needed due to the econometric problems discussed. Here, pooled data is used including the set of advanced countries in the EU-KLEMS data. [30]

g^K is first studied. The Eq (3) is used with various sets of controls and different estimators. The results are reported in Table 4 in Appendix B.[31] A short description of the models is given first. Benchmark Model 1 includes all input variables and omits the constant. Model 2 also includes entity-level fixed effects and country-level time trends. The first two models use the full set of data for the years between 1983 and 2005. To analyze the robustness of the results, Models 3 and 4 repeat the estimations using data for subintervals 1983-1995 and 1995-2005. Models 5 and 6 are estimated with data divided into service and manufacturing industries. The estimations are conducted with a fixed effects linear panel estimator. Heterogeneity robust standard errors and potential clusters across time are taken into account.

Model 7 uses the instrumental variable approach introduced in the previous section. Two instruments are constructed based on g^R and g^K. In the second-stage estimation the two conditional expectations are used as instruments for $\Delta \log(k_{tic}^{IT})$ while entity-specific fixed effects and country specific trends are used as additional controls.[32]

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[30] Included countries are the EU-15 excluding Greece: AUT, BEL, DNK, ESP, FIN, FRA, GER, IRL, ITA, LUX, PRT, SWE, and the UK, plus AUS, JPN, and USA.

[31] It is noticeable that there are some gaps in the data due to negative capital service measurements. This problem mainly exists in construction and hotels and restaurants. Also, in the earlier period some countries are not included in the data. In particular, SWE, LUX, and PRT enter the panel only in the mid 1990s. However, the panel is found to be fairly balanced before and after 1995.

[32] The STATA ivreg2 algorithm is used in the estimation. Standard errors are heteroscedasticity and autocorrelation (bandwidth 3) consistent. The Kleibergen-Paap under-identification test suggests that the instruments are valid. The Sargan-Hansen over-identifying restrictions test is conducted, and the null hypothesis that the instruments are valid cannot be rejected. Finally, the weak identification test (Cragg-Donald Wald F statistic and Kleibergen-Paap rk Wald F statistic) rejects the hypothesis of weak identification.

In all estimations the covariance between g^K and ICT growth rate is significantly higher than the corresponding average nominal share of ICT. So the results consistently show that spillover potential exists. The ICT elasticity estimate is found to be consistently close to 0.15. Increasing the ICT capital by 10 percent would increase labor productivity by 1.5 percent instead of 0.26 percent, as is suggested by the nominal shares. In comparison, when labor productivity and its growth are explained with ICT capital (growth), the estimated output elasticity is not significantly different from the nominal shares when the fixed effects and other inputs are used as controls.

In most estimations, the elasticities of labor composition ($\Delta \log(\frac{LAB_{tic}}{H_{tic}})$) and non-ICT capital ($\Delta \log(k_{tic}^{NIT})$) are found to be not significantly different from the actual nominal share, a fact which supports the validity of the results. In some cases the elasticities are found to be lower than the nominal share of the input, but never higher. The results are also consistent with earlier studies that measure the long-term elasticity of ICT. Based on a long-run cointegration relationship, O'Mahony and Vecchi (2005) approximate the elasticity of output of 0.18 with respect to ICT capital for the U.S. market industries, whereas the pooled regression on U.S. and UK data delivers a substantially smaller coefficient (0.07). With similar methodology, Venturini (2009) finds estimated returns to the ICT capital range at the country-level from 0.08 to 0.14 in EU-15 and US (1980–2004), depending upon the type of specification and control variables used.

g^R is next studied. Model (4) is used to examine whether the learning dynamics are consistently dependent on the rate of capital accumulation. The results are reported in Table 5, appendix B. The considered fixed effects and subsamples are the same as in the previous estimations. In Model 3, the growth rate of other inputs and the lagged levels of ICT capital are applied as controls, as well as variables measuring pure convergence. The first one is constructed in line with Inklaar et al. (2008) to measure the difference between the industry's highest efficient productivity level and the efficient productivity of the given input combination ($\log(\frac{\overline{y}_{t-1}^{\max}}{\overline{y}_{t-1}})$). Furthermore, the last period's distance to the frontier is used as a measure of the pure learning effect (δ). Model 3 also includes the lagged growth rate of ICT capital stock.

Finally, Model 8 uses the IV approach.[33] Two instruments are used based on $g^R$and g^{tech}.

The results indicate that there is indeed a negative association between higher growth rate of capital stock and position relative to the frontier. A 10 percent increase in the growth rate of capital above the average rate is associated with an approximately 1 percent decline in the labor productivity growth rate with respect to the potential on the frontier. The figure is slightly smaller, 0.59 percent, when instrumentation is used.[34]

Other features are also worth discussing. In Model 3, a large negative correlation between other inputs and g^R is reported. Thus, the results indicate a similar possibility of learning frictions also for other inputs. However, their size is likely to be much smaller than for ICT, as its average growth rate has been by an order of magnitude higher. The results may also be partly explained by the small number of labor classifications in the EU-KLEMS data. Nevertheless, the result seems to suggest that labor market frictions could also be one of the explanations behind the recent productivity gaps, as is suggested by van Ark et al. (2011) and may also help to explain the conflicting views on the link between MFP and human capital in the recent literature. (Vandenbussche et al., 2006; Inklaar et al., 2008).

Another interesting feature of Model 3 is the estimated positive correlation with lagged ICT capital growth rate and g^R. The finding is broadly consistent with Basu and Fernald (2007), who use a dataset of 40-ICT using industries in the U.S, for the period 1987-2004. They find that the short-term ICT elasticity may even be negative while in the long run, it turns positive.

Finally, previous period's distance to the frontier has a highly significant positive correlation with the following movement towards the empirical frontier. Thus,

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[33] Statistics robust to heteroskedasticity and clustering on country and year were also considered, but the results remained significant. The Sargan-Hansen over-identifying restrictions test is conducted and the null hypothesis that the instruments are valid cannot be rejected. The Kleibergen-Paap under-identification tests also suggest that the instruments are valid. Finally, the weak identification test (Cragg-Donald Wald F statistic and Kleibergen-Paap rk Wald F statistic) rejects the hypothesis of weak identification.

[34] Some additional robustness checking was made. One concern is that industries may be affected by similar macroeconomic shocks differently. For instance, manufacturing may be more procyclical than services. In that case, introducing time fixed effects may not resolve the problem of common shocks. As an additional robustness check year-country fixed effects were introduced separately to both manufacturing and services, but that did not change the results.

in line with the Basu and Weil (1998) model, the assimilation of technology seems to become stronger, when the distance to the technological frontier increases.

6 Conclusions

This paper concerns the relationship between ICT and the emerged productivity gaps across the advanced nations. A theoretical framework is constructed based on the Basu and Weil (1998) growth model, in which countries make complementary innovations to adopt technology. The model shows how the equilibrium relationship between capital and output may become S-shaped because a world comprising of numerous countries that have slightly different saving rates or adaptation skills might be expected to break up into discrete convergence groups of leaders and followers. While it is consistent with a low ICT elasticity of output often found in empirical literature, large ICT-related productivity gaps may arise in the model.

The paper reports empirical evidence on the model features by resorting to DEA and the growth decomposition introduced by Kumar and Russell (2002), which is found to be consistent with the Basu and Weil (1998) model. The paper finds a leader–follower pattern between the U.S. and the EU-15. The U.S. operates with immature ICT-intensive technologies, while productivity growth is based on learning to use them more efficiently. EU-15 countries choose less ICT-intensive technologies, and the dominant source of productivity growth is the shift towards technologies that have already shown their potential. Furthermore, the paper uses the IV estimation approach to confirm that the elasticity of the world technological frontier is significantly above the nominal input share of ICT, while a high rate of investment has a decelerating effect on productivity growth.

On the basis of the analysis, it may be asked when it is a good idea to eliminate the ICT gaps by promoting policies that aim at higher ICT investments rates. Such policy is welfare-improving only up to the level of the consumption maximizing Golden Rule. Forcing the investment rate beyond the level is bad policy as it leads the country to ignore the need for learning and potentially to receive less matured technology from other countries. Rather, good policy could aim at improving the flexibility of the economy towards adopting new technologies. Indeed, from the welfare standpoint, positive growth outliers can only emerge if the country's capacity to absorb new technology is high relative to other countries. Furthermore, the cross-country spillovers suggest that policies promoting ICT can be successful if the efforts are openly and internationally coordinated.

This paper's approach may be subjected to some critique. First, it can be argued that the productivity patterns are ultimately based not on ICT but on the ability of individual countries to learn new technology fast. Indeed, the results imply that the way in which high quality labor is used is most certainly another factor dividing countries. However, even after careful control of other factors, ICT stands out in the results. Thus, it is natural to emphasize its role as a driver of the opportunities for improving productivity. Second, while the implications of the BW model are reasonable, the mechanisms advocated are of reduced form. Much work can be done in the future to understand the mechanism better. Endogenous growth theory could be used to give the growth process proper incentives. The setup also provides the rationale for strategic behavior in the choice of technology. For instance, under imperfect competition, it may be beneficial for the leader to take a leap in technology in order to gain market power. Studying the determinants of cross-country differences in the learning dynamics provides another interesting field for further research.

Appendix

Dynamics in the Basu and Weil (1998) model

This appendix formally presents the relationships discussed in the text.

Without any loss of generality, Bs are normalized so that the highest observed B_j is 1, while it always holds $0 < B_j \leq 1$. The observed world production frontier ($A_t(K_j)K_j^{\alpha}$) thus reflects productivity with full information in the country with highest B. Let the position of country j relative to the world technological frontier be denoted as $R_j(K_j) \equiv B_j \frac{A_t(K_j)}{A(K_j)}$. The relative position is, on the one hand due to country-specific differences, B_j, and on the other hand, to the maturity of the used technology $\frac{A_t(K_j)}{A(K_j)}$. With the new notation, the AK production function becomes

$$Y_j = R_j K_j,$$

while the relative growth rates of capital and income are

$$\begin{aligned}\dot{K}_j(t) &= s_j F(k_j(t)) - \delta K_j(t) \\ \Leftrightarrow \frac{\dot{K}_j(t)}{K_j(t)} &= s_j R_j - \delta \end{aligned} \tag{6}$$

and

$$\frac{\dot{Y}_j}{Y_j} = \alpha \frac{\dot{K}_j}{K_j} + (1-\alpha)\frac{\dot{K}_j}{K_j} + \frac{\dot{R}_j(K_j)}{R_j(K_j)}. \tag{7}$$

Eq. (7) states that output growth is a sum of three distinctive elements: the accumulation of capital ($\alpha\frac{\dot{K}_j}{K_j}$), the spillover potential from the world technological frontier ($(1-\alpha)\frac{\dot{K}_j}{K_j}$), and, finally, changes in the country's position relative to the world technological frontier ($\frac{\dot{R}_j}{R_j}$).Elements of MFP growth, the spillover potential and the position relative to the frontier, are both functions of K_j. In comparison, in the neoclassical model, the output grows as a function of capital according to

$$\frac{\dot{Y}_j}{Y_j} = \alpha \frac{\dot{K}_j}{K_j},$$

which indicates capital elasticity of output α.

Importantly, the two elements in the BW model have an opposite effect on MFP, because $\frac{\dot{R}_j}{R_j}$ is a decreasing function of the growth rate of capital. To see this, consider the diffusion equation (1) for $A_t(K_j)$. In the simplest case, country j receives no spillovers from other countries, which may happen for example, if it is a technological leader far ahead of the other country. Furthermore, if the capital stock grows at constant rate g, it can be shown by integrating the equation (1) with respect to time that the productivity gap between the world technology frontier and the country remains at a constant level:

$$R_j = B_j(1 - e^{-\frac{\beta\gamma}{g}}),$$

where R_j is now a decreasing function of the growth rate of capital, g. Thus, the model has a mechanism that penalizes a high rate of investment. The smaller the time interval devoted to learning the technology, the less becomes known about its full potential, an observation that is supported by earlier literature regarding the use of ICT. In the case of varying rates of growth, the same property clearly remains, but such an explicit formulation for R_j may not exist. When spillovers from other countries are included, the negative relationship between R and g also remains.[35]

The learning dynamics mutes the relationship between MFP and the capital in a cross-section of countries. In the long-run R_j is found to be a decreasing function of K_j and thus the observed elasticity in a cross-section is lower than the elasticity of the world technological frontier. To see this, details of this result are analyzed in the simplest scenario when the distribution of income is stable. Given the two-country assumption, let us assume without loss of generality that Country 1 saves more than Country 2. The other factors, B, are the same in both countries. The capital accumulation equations

$$\begin{aligned} g &= s_1 R_1^* - \delta \\ g &= s_2 R_2^* - \delta \end{aligned}$$

imply that in order to have a common growth rate, Country 1 must have constant, lower position relative to the frontier at each capital stock ($R_1^* < R_2^*$). The intuitive reason for the stable distribution is that Country 1 bequeaths an improved level of technology for Country 2, which helps to keep its growth rate equally high despite the lower savings rate.

The analytical result is obtained by integrating (1) w.r.t time for both countries yielding

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[35] If country j is the leader (with higher K), lowering its growth rate will always increase R, through its own learning and potential spillovers from lowering the technological distance between the two countries. When the distance is small, the leader spends more time with technology, which the follower also improves. On the other hand, increased g may, if anything, have the opposite effect on spillovers. Similarly, if j is the follower (with lower K), lowering g would not change the level of spillovers, while higher g would potentially decrease them.

$$R_1^* = B(1 - e^{-\frac{\beta(2\gamma - d)}{g}})$$
$$R_2^* = B(1 - e^{-\frac{\beta(2\gamma + d)}{g}}),$$

where d is the relative difference in capital intensity ($\log(K_1) - \log(K_2)$). The four equations above then solve the stable growth path values for d, g, R_1^*, R_2^*. To have the stable path in which Y, K, and A all grow at the same rate in both countries, the implied technological difference, d, must be within the interval γ.Otherwise, A's would grow at different rates.

Furthermore, the short-term dynamics also imply that the relationship is muted. Consider the case where Country j starting from the equilibrium, increases its saving rate (or B_j increases). The resulting short-term output growth follows Eq. (7):

$$\frac{\dot{Y}_j}{Y_j} = \alpha\frac{\dot{K}_j}{K_j} + (1-\alpha)\frac{\dot{K}_j}{K_j} + \frac{\dot{R}(K_j)}{R(K_j)},$$

First, a higher rate of investment increases the growth rate of capital stock in the period that leads to an increased growth rate of output. The increased capital accumulation is accompanied by a mixed reaction of the MFP components. On the one hand, the investment boosts MFP through the externality component. On the other hand, the position of the country relative to the frontier falls ($\frac{\partial}{\partial \frac{\dot{K}_j}{K_j}} \frac{\dot{R}(K_j)}{R(K_j)} < 0$). Thus the model again predicts a muted relationship between $\frac{\dot{A}_j}{A_j}$ and $\frac{\dot{K}_j}{K_j}$. While the transitional dynamics of the model cannot be explicitly formalized, BW show that the model is stable as long as the countries are reasonably close to each other; and thus the long-run equilibrium, where R has permanently fallen to a lower level, is eventually reached.

B. Tables

TABLE 1: Summary statistics

Industry:	code[#]	Labor productivity growth and components (%) Total	g^K	g^R	Growth rates of input factors (%) LAB/H	K(IT)/H	K(NIT)/H	H
Chemicals and ch. products	24	4.7	2.9	1.8	0.5	13.4	3.3	-0.8
Electricity, gas, and water supply	E	3.9	4.1	-0.2	0.4	13.5	3.0	-1.3
Transport equipment	34t35	3.6	1.9	1.6	0.5	13.2	3.4	-0.8
Rubber and plastics	25	3.4	3.3	0.2	0.5	13.5	2.8	-0.1
Other non-metallic mineral	26	2.8	1.5	1.3	0.5	14.9	2.7	-1.3
Machinery, nec	29	2.8	1.3	1.5	0.5	13.5	2.5	-0.7
Wood and of wood and cork	20	2.8	2.9	-0.1	0.4	13.0	2.3	-0.4
Pulp, paper , printing, and publ.	21t22	2.7	2.5	0.2	0.5	15.6	3.7	-0.6
Textiles, leather, and footwear	17t19	2.5	3.2	-0.7	0.6	16.3	4.1	-4.7
Basic metals and fabr. metal	27t28	2.3	1.3	1.0	0.5	12.3	1.8	-0.7
Wholesale and retail trade	G	2.3	1.8	0.5	0.4	14.2	2.5	0.6
Transport and storage	60t63	2.0	2.0	0.1	0.3	12.4	2.0	1.0
Food , beverages, and tobacco	15t16	2.0	1.6	0.4	0.5	13.9	2.6	-0.7
Manufacturing nec; recycling	36t37	1.8	1.7	0.2	0.5	15.5	3.2	-0.7
Construction	F	0.6	0.7	-0.1	0.4	13.0	1.0	1.0
Real estate activities	70	0.1	0.6	-0.5	0.5	12.7	0.2	2.6
Business services	71t74	-0.1	1.1	-1.2	0.4	12.7	2.6	4.9
Hotels and restaurants	H	-0.2	1.2	-1.4	0.3	13.3	2.3	1.7
Average		2.3	2.0	0.4	0.5	13.7	2.6	-0.1

#: European Nace rev. 1 classification

TABLE 1.2: Efficient peers

Time period	1985-1995					1995-2005				
Subject	All peers		ICT-intensive peer			All peers		ICT-intensive peer		
Industry	N	$\frac{K^{IT}}{med}$	CNT	$\frac{K^{IT}}{med}$	$R(\frac{VA}{H})$	N	$\frac{K^{IT}}{med}$	CNT	$\frac{K^{IT}}{med}$	$R(\frac{VA}{H})$
Chemicals and ch. products	18	0.77	NLD	1.68	1	20	0.78	IRL	2.34	1
Electricity, gas, and water supply	4	1.05	BEL	1.43	4	14	0.65	FRA	1.04	8
Transport equipment	5	0.67	ITA	0.8	1	12	0.79	USA	1.21	1
Rubber and plastics	9	2.08	BEL	2.52	1	24	0.91	BEL	2.34	1
Other non-metallic mineral	8	0.50	DNK	1.09	5	28	0.31	ITA	0.53	2
Wood and of wood and cork	13	1.11	FIN	1.80	1	28	1.11	SWE	2.32	2
Pulp, paper, printing, and publ.	17	1.49	BEL	2.28	2	20	1.32	AUT	4.02	3
Textiles, leather and footwear	18	1.40	NLD	2.53	1	14	1.14	BEL	2.46	2
Machinery, nec	24	1.05	BEL	1.56	1	21	0.69	JPN	1.70	1
Wholesale and retail trade	21	1.35	NLD	1.97	1	26	1.49	BEL	3.47	1
Basic metals and fabr. metal	4	0.64	GER	0.81	9	16	0.36	USA	1.52	1
Food, beverages, and tobacco	20	0.91	NLD	1.56	1	13	1.32	NLD	2.05	1
Transport and storage	8	1	NLD	1.13	1	13	0.74	NLD	1.1	1
Manufacturing nec; recycling	8	0.27	DNK	1.01	1	6	0.48	UK	2.42	1
Real estate activities	10	3.21	ITA	4.03	2	6	1	ITA	4.89	1
Construction	8	0.46	AUS	1.55	1	14	1.06	AUS	2.05	1
Business services	4	1.42	DNK	2.17	2	5	0.91	USA	1.51	1
Hotels and restaurants	-	-	-	-	-	6	0.65	AUT	1.14	1

N is the total number of new entries to the frontier during the period. $\frac{K^{IT}}{med}$ measures the efficient peer's ICT capital stock relative to the median in the year it enters the frontier. ICT -intensive peer is the peering country with the highest $\frac{K^{IT}}{med}$ during the period. $R(\frac{VA}{H})$ is labor productivity ranking (or in case of multiple entries, the median ranking) of the intensive peer in the year of entry.

TABLE 4. ICT and movements along the frontier

Dependent: g^K	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Industries	All	All	All	All	Services	Manufact.	All
Period	83-05	83-05	83-95	95-05	83-05	83-05	83-05
$\Delta \log \left(\frac{K^{NIT}}{H} \right)$	.106***	.152***	.103***	.178*	.152***	.162***	.171***
(Standard error)	(.019)	(.037)	(.015)	(.058)	(.025)	(0.052)	(.014)
Control variables:							
$\Delta \log \left(\frac{LAB}{H} \right)$	.456	.502	.616	.462	.619	0.344**	-
$\Delta \log \left(\frac{K^{NIT}}{H} \right)$	.220	.133***	.233	.180	.200**	0.192	-
$\Delta \log (H)$	-	-.117***	-	-	-	-	-
Fixed effects:							
Entity-level	No	Yes	Yes	Yes	Yes	Yes	No
Country trends	No	Yes	Yes	Yes	Yes	Yes	Yes
R^2	-	.366	.335	.387	.477	.381	.312
# of obs	5655	5655	2746	3153	1871	3784	5337
CRS rejected	No	No	No	No	No	Yes	-

#: Confidence levels for rejecting $|$ nominal share $-$ output elasticity $| = 0$: *,**,*** = 5%,1%,0.1%

In models 1-6, an OLS panel estimator (STATA xtreg) was used. SEs are robust for clustered error terms on entity level and heteroscedasticity. Model 7 uses GMM IV estimation (ivreg2, gmm2s). SE are heteroscedasticity and autocorrelation (bandwidth 3) consistent. CRS rejected : tests whether the sum of input coefficients differs from 1 on a 95% conf. level.

Variables: $\Delta \log(\cdot)$ is the coefficient for the input growth. Entity-level = (country x industry), country trends = (country x year). Services = E,G,H,60t63,70,71t74, Manufacturing = All excluding services

TABLE 5: ICT and movements relative to the frontier

Dependent: g^R	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Industries	All	All	All	All	All	Services	Manufact.	All
Period	83-05	83-05	83-05	83-95	95-05	83-05	83-05	90-05
$\Delta \log\left(\frac{K^{IT}}{H}\right)$	-.090***	-.097**	-.118***	-.073*	-.112**	-.061*	-.112**	-.094*
(Standard error)	(0.23)	(.032)	(.036)	(.022)	(.052)	(.030)	(.042)	(.021)
Control variables:								
$\Delta \log\left(\frac{K^{IT}_{t-1}}{H_{t-1}}\right)$			.044*					
$\Delta \log\left(\frac{K^{NIT}}{H}\right)$			-.111*					
$\Delta \log\left(\frac{LAB}{H}\right)$			-.410***					
$-\log(\delta_{t-1})$			.064***					
$\log\left(\frac{\overline{y}^{\max}_{t-1}}{\overline{y}_{t-1}}\right)$			-.000*					
$\Delta \log(H)$			-.510***					
Fixed effects:								
Entity-level	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Country trends	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	.034	.158	.247	.165	.141	.236	.215	.162
# of obs	5655	5655	5347	2746	3153	1871	3784	5337

Confidence levels for rejecting $|\beta| = 0$) : *,**,*** = 5%,1%,0.1%.

Estimations of the models 1-7 are based on an OLS fixed effects panel estimator (Stata xtreg, fe). SEs are robust for clustered error terms on entity-level and heteroscedasticity. Model 7 uses GMM IV estimation (ivreg2, gmm2s). SEs are heteroscedasticity and autocorrelation (with bandwidth 3) consistent.

Variables: $\Delta\log(\cdot)$ is the coefficient for the corresponding input growth variable. $\log\left(\frac{K^{IT}_{t-1}}{H_{t-1}}\right)$ and $\delta_{t-1}$are the previous period's ICT capital intensity and efficiency score, respectively. $\frac{\overline{y}^{\max}_{t-1}}{\overline{y}_{t-1}}$is the gap between the entity's and the industry's max VA in the given year. Entity-level = (country x industry), country trends = (country x year).

Services = E,G,H,60t63,70,71t74, Manufacturing = All excluding services

C. Kumar and Russell (2002) growth decomposition

Formally, the decomposition is based on the usage of the distance function. In one output case, the output orientated distance function measures maximal feasible increase in production,y ,given the input vector, $\mathbf{x}$. It is defined given the efficient production frontier (outer boundary of the feasible production set) P($\mathbf{x}$) as:

$$d(\mathbf{x}, y) = \min(\delta : (y/\delta) \leq P(\mathbf{x}))$$

(Coelli et al., 2005).

To develop an economic meaning for the distance function, the concept of efficiency is needed. A country operating in a way that takes full advantage of its output potential (technological efficiency) and using an optimal input combination (allocative efficiency) is fully efficient (Farrell, 1957). Using Farrell's conceptualization, this paper is restricted solely to the analysis of technological efficiency. The (output-orientated) technological efficiency measure is defined as the distance between the observed productivity and the production function:

$$TE(\mathbf{x}, y) = \delta$$

(Coelli et al., 2005).

The distance functions and efficiency concepts can be used to distinguish between different sources of growth in labor productivity over time. If the technological frontiers for two consecutive periods $t-1$ and t are known, by definition it holds:

$$\begin{aligned} \frac{y_t}{y_{t-1}} &= \frac{TE^t(\mathbf{x}_t, y_t)}{TE^{t-1}(\mathbf{x}_{t-1}, y_{t-1})} \times \frac{\overline{y}^t(\mathbf{x}_t)}{\overline{y}^{t-1}(\mathbf{x}_{t-1})} \\ &= (1 + g^{eff}) \times (1 + g^{tech+K}) \end{aligned} \tag{8}$$

where $\overline{y}^t(x_t)$ is the highest potential value of labor productivity with inputs

x_t corresponding to a point on the frontier. Superscripts indicate date of the reference technology, t. The first term on the right hand side of (8) measures changes in the position of a country relative to the production frontier between t-1 and t. The latter term in (8) includes change in two factors: shifts of production function upwards and movements along the frontier attributed to change in input combination. It is important to have these effects separated due to their distinctive role in technological diffusion. Unfortunately, no single correct method exists for finding the separation since both measures are dependent on the date of the underlying technology and input combinations. Kumar and Russell (2002) suggest decomposing Eq. (8) by multiplying the top and the bottom of the right hand side by $(\overline{y}^{t-1}(x_t) \times \overline{y}^{t}(x_{t-1}))^{1/2}$. The first term remains the same and the second becomes:

$$\begin{aligned}\frac{\overline{y}^t(\mathbf{x}_t)}{\overline{y}^{t-1}(\mathbf{x}_{t-1})} &= (\frac{\overline{y}^t(x_t)}{\overline{y}^{t-1}(x_t)} \times \frac{\overline{y}^t(x_{t-1})}{\overline{y}^{t-1}(x_{t-1})})^{\frac{1}{2}} \\ &\times (\frac{\overline{y}^t(x_t)}{\overline{y}^{t}(x_{t-1})} \times \frac{\overline{y}^{t-1}(x_t)}{\overline{y}^{t-1}(x_{t-1})})^{\frac{1}{2}} \\ &= (1+g^{tech}) \times (1+g^K)\end{aligned} \tag{9}$$

The first term in (9) is the geometric mean of gross shifts of the frontier upwards with different input combinations. It equals technological growth in the more commonly used Malmqvist productivity index (Caves et al., 1982; Färe et al., 1994). Finally, the second term in (9) captures the effect of movements along the frontier.

D. CIA World Factbook entries for the peer countries in 2000

Australia: mining, industrial and transportation equipment, food processing, chemicals, steel

Austria: construction, machinery, vehicles and parts, food, chemicals, lumber and wood processing, paper and paperboard, communications equipment, tourism

Belgium: engineering and metal products, motor vehicle assembly, processed food and beverages, chemicals, basic metals, textiles, glass, petroleum, coal

Denmark: food processing, machinery and equipment, textiles and clothing, chemical products, electronics, construction, furniture, and other wood products, shipbuilding

Finland: metal products, shipbuilding, pulp and paper, copper refining, foodstuffs, chemicals, textiles, clothing

France: steel, machinery, chemicals, automobiles, metallurgy, aircraft, electronics, mining; textiles, food processing; tourism

Germany: among world's largest and technologically advanced producers of iron, steel, coal, cement, chemicals, machinery, vehicles, machine tools, electronics, food and beverages; shipbuilding; textiles

Ireland: food products, brewing, textiles, clothing; chemicals, pharmaceuticals, machinery, transportation equipment, glass and crystal; software

Italy: tourism, machinery, iron and steel, chemicals, food processing, textiles, motor vehicles, clothing, footwear, ceramics

Japan: among world's largest and technologically advanced producers of motor vehicles, electronic equipment, machine tools, steel and nonferrous metals, ships, chemicals; textiles, processed foods

Netherlands: agroindustries, metal and engineering products, electrical machinery and equipment, chemicals, petroleum, construction, microelectronics, fishing

Sweden: iron and steel, precision equipment (bearings, radio and telephone parts, armaments), wood pulp and paper products, processed foods, motor vehicles

United Kingdom: production machinery including machine tools, electric power equipment, automation equipment, railroad equipment, shipbuilding, aircraft, motor vehicles and parts, electronics and communications equipment, metals, chemicals, coal, petroleum, paper and paper products, food processing, textiles, clothing, and other consumer goods

United States: leading industrial power in the world, highly diversified and technologically advanced; petroleum, steel, motor vehicles, aerospace, telecommunications, chemicals, electronics, food processing, consumer goods, lumber, mining

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Essay 2

Structural Change in the Information Era: Perspectives from a Multisector Model of the Finnish Economy

Tero Kuusi

Unpublished manuscript.

Structural Change in the Information Era: Perspectives from a Multisector Model of the Finnish Economy

Tero Kuusi[36]

Abstract

This paper studies structural changes and economic growth in the knowledge economy. The paper uses an open economy general equilibrium model consisting of sectors producing ICT, traditional goods and traditional services calibrated for the Finnish economy. Based on different counterfactual scenarios, the paper finds that ICT has a large role in determining long-run economic growth (40.9 percent in Finland). The paper also finds that ICT does not generate structural changes that would decrease economic growth substantially. The technology benefits growth in the service sector, where it has been historically difficult to improve productivity. Drivers of structural changes in consumption, value added, and hours are found to have different origins. Increasing the consumption share of services can be replicated with a model, where the sector-specific expenditure shares of production factors remain constant. Changing factor shares reflecting the substitution of labour by intermediate services and the increasing role of ICT as a factor of production are needed to account for the increasing share of services in value added and hours.

Keywords: Multisector Growth Models, Manufacturing and Service Industries, Information Technology

JEL classification: O41, O14, E29

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1 Introduction

Economic growth in the information era is intrinsically linked to structural change. Rapid technological progress in information and communications technology (ICT) facilitates wide-spread reorganization of production in sectors using the new technology and gives rise to an expanding production of high-tech goods and services. Meanwhile, economic growth in advanced economies is accompanied by an increasing role of the service sector reflecting not only the emergence of ICT but also changes in the composition of final demand and deindustrialization. As the structural change is likely to continue, anticipating its effect on aggregate economic growth is important. However, current economic models make conflicting predictions about the relationship. For example, in the standard model of investment-specific technological change (Greenwood et al., 1997), the growth contribution of technology is captured under assumptions that ensure a constant growth path. In more general multi-sector models (see, e.g., Ngai and Pissarides, 2007; Acemoglu and Guerrieri, 2008), technology can give rise to sectorial reallocation of resources which lowers the growth rate of the economy over time.

This paper calibrates a multi-sector neoclassical growth model to study the relationship between ICT, structural change, and aggregate economic growth. It analyzes the movement of resources between sectors and investigates the stability of aggregate productivity growth under given long-run trends in sector-specific technological change. In the quantitative exercise, the model is matched with key features of the Finnish economy. Being one of the world leaders in production and adaptation of the new technology, the country can provide a prototype example of structural changes in advanced knowledge economies.

The results give new insights on the origins of economic growth and structural change. Conducted counterfactual experiments suggest that ICT has a large role in long-run economic growth. In a scenario where ICT-specific technological progress is removed, the growth rate of the economy falls by 40.9 percent compared to a scenario with ICT. Meanwhile, the analysis suggests that the growth rate of the economy remains stable despite large differences in sector-specific trends in technology. Rather, ICT's effect on structural change appears to be growth-enhancing, because it fosters productivity growth in the service sector where productivity growth has historically been slow. Indeed, removing ICT leads to a stronger growth declining structural change. Finally, the paper finds that drivers of structural changes in consumption, value added, and hours have different origins. Technological trends can generate a substantial increase in the consumption share of services. However, changing factor shares reflecting outsourcing of work towards services and an increase in the (nominal) intensity of ICT use are needed to account for the increasing share of services in value added and hours.

The considered model consists of sectors producing ICT, traditional goods, and traditional services.[37] The production side of the economy closely resembles Ngai and Samaniego's (2009) version of the investment-specific technological change model. In the model, each sector has a unique Cobb-Douglas production function with industry-specific factor intensity shares and multi-factor productivity terms, which are calibrated using the National Accounts. The sectors produce sector-specific intermediate and capital goods, the difference being that intermediate goods have to be used during the period of its production. There are two capital stocks based on ICT and traditional goods.

Unlike Ngai and Samaniego (2009), the model allows structural changes in consumption. The representative household is assumed to consume sector-specific goods according to a CES aggregator with intratemporal elasticity strictly lower than 1. This relates the model to the recent papers by Ngai and Pissarides (2007) and Acemoglu and Guerrieri (2008). The model differs from Acemoglu and Guerrieri (2008) by assuming that changing relative prices affect the composition of production inputs and final consumption differently, a case considered by Ngai and Pissarides (2007). The unit elasticity of substitution of production functions reflects the fact that nominal factor shares remain stable over time in input-output tables. The intratemporal elasticity of substitution is based on the relationship between nominal consumption patterns and relative prices of consumption goods.

Furthermore, the considered economy is open capturing changing comparative advantage between sectors and countries, especially the increasing share of high-tech goods and services in exports of advanced countries. Modeling international trade is based on Yi and Zhang (2010), who considers a version of Ngai and

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[37] ICT = ICT related manufacturing and services; traditional services = private and public services; traditional goods = other industries.

Pissarides (2007) in an open economy. Tradable sectors consist of heterogeneous firms and sector-specific goods are composites of firm-level goods produced either in a domestic country or abroad. Domestic, sector-specific production functions are aggregates over the firm-level production functions, which are identical up to the MFP term. Distribution of firm-level MFP terms follows the assumptions in the Eaton and Kortum (2002) model of international trade, which makes it easy to estimate unit costs of foreign countries and trade barriers. Unlike in Yi and Zhang (2010), the size of the foreign market and unit costs abroad are taken to be exogenous.

This paper first studies the nature of economic growth with a simplified version of the model which allows for analytical solutions. Analysis of the relationship between structural change and the type of technological progress is similar to Ngai and Pissarides (2007) and Yi and Zhang (2010). It is shown that under the assumptions commonly made in the model of investment-specific technological change, the growth rate of the economy can remain stable despite differences in MFP growth rates across sectors. A necessary condition is that the sector with a high productivity growth rate has to produce factors of production. However, this assumption is not sufficient. For example, when sectors use factors of production differently (as the data suggests). the growth rate of the economy is affected by a changing consumption pattern and is no longer stable. Thus, even though ICT has a small direct role in final consumption, ICT-specific productivity growth may indirectly change relative prices of other consumption goods and lead into reallocation of resources. The same is true when the economy is open. Specialization in the production of ICT is accompanied by changes in terms of trade, which may alter the relative price of all tradable and non-tradable goods.

The quantitative model is then applied to investigate structural change and economic growth. In the simulations the representative household has perfect foresight regarding exogenous variables (demographics, sectorial technological progress, foreign prices, and sizes of foreign markets) and the expectations reflect historical long-term patterns. Future paths of the exogenous variables are projected over years 1980-2060, and simulations for the period 1990-2030 are used to study the dynamics of the model.

This paper uses the quantitative model and counterfactual experiments to analyze the origins of the observed structural changes in the Finnish economy. First, structural changes are compared between simulations where ICT-related technological change after 1995 exists, and where it is removed. A general finding is that structural changes in consumption are unresponsive to inclusion of ICT, because the share of a stagnant service sector in consumption rises even without ICT. Second, the origins of structural change in consumption, production, and hours appear to be different. The baseline specification (where technological trends drive the structural change) is capable to replicate structural changes in nominal consumption shares between the years 1991 and 2011, while hours and nominal value added shares are too stable compared to data.

Rather than being a consequence of the changes in the composition of consumption, structural change in employment and nominal value added appears to be related to reorganization of production across sectors, not to changes in relative prices induced by the technological change. To see this, the baseline simulation (with constant factor shares of the year 2000) is augmented by letting the factor shares evolve according to the observed changes in input-output tables. While the observed factor shares are mainly constant over time, there are some changes reflecting outsourcing of work towards the service sector[38] and the rising share of ICT. Considering these changes improves the fit of the model in terms of better capturing the service sector's increasing share in hours and nominal value added. Interestingly, the changes improve the relative productivity of the service sector, which shows up as a decreasing growth rate of the relative price of services compared to traditional goods.

The paper then investigates economic growth using the model's predictions for the years between 1991 and 2030. Comparing counterfactual scenarios with and without ICT shows that removing all ICT-specific technological change declines economic growth on average by 40.9 percent in the period 2011-2030. Domestic production of ICT explains a large part of this effect. If the country is forced to import all ICT[39] in exchange for exports of traditional manufactured goods,

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[38] referring to a pattern where the share of labor in total factor expenditures decreases, while the share of intermediate services increases.

[39] The calculation is based on a scenario in which MFP growth in the domestic sector matches MFP growth of traditional goods after 1995, while unit cost of production in other countries follows the observed rates.

the growth rate of the Finnish economy is approximated to fall by 33 percent. Stability of economic growth is studied by measuring economic growth in different subintervals. It is found that in the baseline scenario the economic growth is almost constant, whereas without ICT, the economic growth rate falls by 16 percent between 2011-2020 and 2021-2030. This finding implies that ICT is not associated with growth declining structural changes. Rather, the results suggest that it operates as a counterforce for such changes.

This paper is related to several strands of economic literature. Literature pioneered by Baumol (1967) suggests that productivity differentials across sectors can explain the structural change. Service sector with low productivity growth has to compete for the same inputs, especially labor, with more progressive sectors which will cause their product prices to rise relative to the overall price level. If final consumption is price inelastic, the share of the service sector increases over time. The structural change shifts resources towards maintaining production in sectors with low productivity, which decreases the aggregate productivity growth rate over time. Recently, several papers reached the same conclusion. In Ngai and Pissarides (2007), differences in technological progress drive structural change. Acemoglu and Guerrieri (2008) analyze how sectorial differences in factor shares and capital deepening can lead to structural change. Nordhaus (2008) provides evidence on the implied relationships between prices and productivity. Buera and Kaboski (2009) and Verma (2012) are recent examples of the use of similar multisector models to analyze structural change.

This paper finds that structural change in final consumption does not necessarily lead to a declining rate of aggregate growth. With the Finnish example, it confirms that if technology progresses in sectors predominantly devoted in production of investment or intermediate goods, the economy can expand without the consumption patterns affecting the long-run aggregate growth rate of the economy, as in Greenwood et al. (1997), Oulton (2001), and Ngai and Samaniego (2009). Furthermore, in line with Matsuyama (2009) and Yi and Zhang (2010), the paper finds that in a Ricardian model of trade, high manufacturing productivity growth does not necessarily lead to a decline in manufacturing employment in an open economy.

This paper is also related to the literature on the quantifying ICT's growth contribution. This paper confirms the findings of Jalava and Pohjola (2008) that ICT has a major importance for economic growth in Finland. The results are also comparable to the estimates based on general equilibrium model. By using a variant of the Greenwood et al. (1997) model, Bakhshi and Larsen (2008) find that in the UK, ICT investment-specific technological progress makes a significant contribution to productivity growth along the balanced growth path, explaining as much as 20-30 percent of labor productivity growth. Martinez et al. (2010) finds that ICT accounts for about 35 percent of total growth in labor productivity during the period 1980-2005 in the U.S. Using a widely different model, this paper finds that the estimates for Finland are very close to the earlier international findings.

Furthermore, recent literature suggests that the ICT revolution is not over. For example, Byrne et al. (2013) show that since 2004 ICT has continued to make a significant contribution to U.S. labour productivity growth, though it is no longer providing the boost that it did during the productivity resurgence from 1995 to 2004. However, they present evidence that semiconductor technology, a key ingredient of the IT revolution, has continued to advance at a rapid pace. This finding suggests that the pace of labour productivity growth could rise back up to the long-run average after the recent economic crisis.

The paper is organized as follows. Section 2 discusses the decomposition of the economy and collects empirical facts on the observed structural changes and differences of production functions across sectors. Section 3 describes the model. In Section 4, a simplified version of the model is used to give an intuitive understanding of the relationship between technology and structural change. In Section 5, quantitative results of the analysis with the numerical model are introduced, while Section 6 concludes.

2 Structural Change and its Origins: Empirical Foundations

This section describes structural changes in key macroeconomic variables. In particular, it collects information regarding sector-specific production functions and elasticity of final demand. Differences in the use of production factors and in the rate of technological progress across sectors are both potential sources of structural changes, which is further elaborated with simple models in Section 4.

Before going into further detail, the decomposition of the economy is discussed. This paper uses a three-sector division of the economy. Reflecting a much used decomposition of the economy to a progressive and stagnant part, this paper distinguishes between a traditional service sector and traditional goods production. Furthermore, the paper considers ICT production as a separate sector[40]. Appendix A provides further definitions of the sectors on the industry and product levels for different variables.

Recently Timmer and Jorgenson (2011) use a similar decomposition and argue that the traditional division of the economy among agriculture, industry, and services has lost most of its relevance as the agricultural sector has become small.[41] In terms of technological typology, the decomposition is also related to Ngai and Samaniego (2009), who distinguish between equipment-specific, structure-specific, and consumption-specific technological change. ICT has a major role in equipment-specific technological change, while consumption-specific technology is mainly comprised of services. In this paper, the traditional service sector is closed, while sectors producing ICT and traditional goods engage in international trade. In recent decades, some trade in the traditional services has emerged, but its role in total exports is still small, and thus the simplifying assumption is reasonable.

Next, structural changes are described based on the decomposition. Table 1 reports nominal consumption, value added, and employment shares for the ICT-producing sector (ICT), the traditional goods-producing sector (Goods), and traditional services (Services). They indicate a shift of resources and production from traditional goods production towards traditional services and ICT production in the Finnish economy during the years 1991-2011. The table also shows how the

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[40] This paper makes no distinction between production of goods and services in the ICT sector. In the sector, the role of services has become ever larger, both reflecting the fragmentation of production as well as the changing nature of the final goods.

[41] It is noticeable that the distinction leaves heterogeneity within sectors. For example, Timmer & Jorgenson (2011) finds in international data that within the service sector, productivity growth has generally been high in distribution services, while the performance is more modest in finance, business services, personal services, and non-market services.

country's comparative advantage is turning towards production of ICT:

Table 1 : Key structural change variables, 1991-2011

	ICT	Goods	Services
Changes in sector share (percentage points):			
Nominal Consumption	0.7	-4.6	3.9
Nominal VA	2.1	-6.5	4.4
Hours	1.9	-9.4	7.4
Exports (1992-2009)	12.0	-12.0	omitted
Consumption Price (Goods=100)	-71.8	0	36.3
Average shares:			
Nominal Consumption	2.8	32.9	64.4
Nominal VA	8.5	34.1	57.4
Hours	4.9	33.7	61.3
Exports (1992-2009)	20.9	79.1	-

Consistent with the supply-side explanation, the rates of technological progress (proxied with MFP) have been uneven across sectors, which especially reflect the emergence of ICT. Between the years 1980-2005, annual average growth rates of MFP were 3.3 percent, 0.69 percent, and 0.11 percent in ICT, traditional good, and traditional service production, respectively.[42] The estimates are based on the EU KLEMS data; and industry-level gross MFP growth rates are aggregated to the sector level by using Törnqvist weights based on nominal gross output. The MFPs can be found in figure (3).

Furthermore, Table 2 reports sector-specific expenditure shares of production factors (excluding energy, land, and raw materials). The factors are divided into six classes following the three-sector specification. The primary factors are labor and two classes of capital based on ICT and traditional goods. Information regarding ICT use is from the EU KLEMS data. Intermediate goods are classified based on the industry of origin and are taken from the industry-level OECD input-output tables[43].

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[42] MFP growth in the ICT sector is comparable to the U.S. (3.4 percent) during the same time period, while in traditional manufacturing, MFP growth has been higher in the U.S.

[43] OECD currently provides the longest comparable data-set of input-output tables for the

Table 2 : Factor intensities

Sector	ICT			Goods			Services		
Factor	1995	2000	2005	1995	2000	2005	1995	2000	2005
Share of value added	32.3	33.7	34.4	38.2	35.2	34.7	60.0	58.7	57.1
from capital, ICT	8.3	11.0	11.4	2.7	2.9	2.0	4.1	5.9	4.1
from capital, goods.	33.8	48.7	39.5	32.4	30.6	31.2	27.6	29.1	29.9
from labor	57.9	40.2	49.1	64.9	66.5	66.8	68.3	64.9	66.1
Share of intermediates	67.7	66.3	66.5	61.8	64.8	65.3	40.0	41.3	42.9
from ICT	52.4	56.2	51.1	2.8	4.2	3.9	9.2	13.0	12.7
from goods	23.6	15.6	13.1	72.5	68.7	67.3	26.1	25.6	22.0
from services	24	28.2	35.8	24.7	27.2	28.8	64.7	61.5	65.3

The table suggests that factor intensities are relatively stable over time, but there are differences in the use of primary factors as well as intermediate goods across sectors. Labor share in nominal value added are almost the same in goods and services, while ICT capital is used more intensively in the service sector. The same applies for the intermediate use of ICT.

Based on the table, the Cobb-Douglas (constant factor shares) form provides a reasonable functional approximation for the sector-specific production functions. However, there are some changes in the factor shares over time, which may affect the results. It seems that the overall factor share of ICT has increased over time and labor is increasingly substituted for intermediate services. The trend features domestic outsourcing of labor-intensive support tasks, including transportation, construction, marketing, and IT services. (See, e.g., Lehti et al., 2012). The following table summarizes the changes after summing up the sector-specific contributions of capital and intermediates:

Finnish economy.

Table 3 : Changes in factor use 1995-2005

sector:	ICT	Goods	Services
ICT	-0.3	0.1	1.6
Goods	-4.6	-2.4	-0.5
Services	7.6	3.5	2.1
Labour	-1.8	-1.6	-3.2

Finally, implications of relative price changes for structural change depend on the elasticity of substitution of final demand. While unit elasticity of substitution appears as a good starting point for the production functions, it is not a valid choice for the intratemporal elasticity of the consumption aggregator. Figure (3) plots the relative price of consumption of services and traditional goods against changes in real consumption of services and traditional goods. The elasticity is very significantly below 1 and not significantly different from 0.5.

When final consumption is price inelastic, changes in relative prices lead to changes in the nominal share of the goods in final production shifting consumption towards goods with the highest price. It is noticeable that before the year 1991 real consumption of services increased relative to goods despite its increasing relative price, whereas after 1991 real consumption of services has declined in relative terms while its relative price continues to increase.

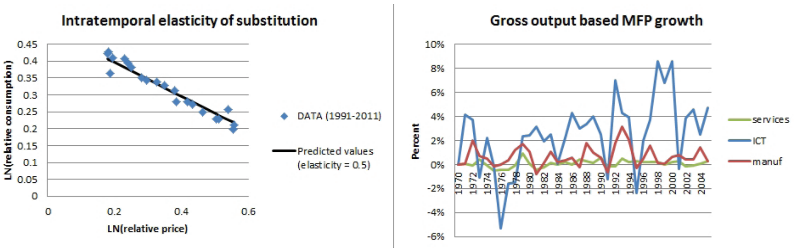

Figure 3: Details of the Finnish economy

3 Technology and Structural Change in a Multisector Model

This section introduces the general equilibrium model used in the exercise. In the next section, a simplified version of the model (without capital and with identical production functions up to MFP) is used to derive some analytical results, while Section 5 uses the full model in a numerical exercise.

To give the first impression of the model, its sector-level structure is outlined in Figure (4). The figure shows how a domestic good produced by a competitive and profit-maximizing firm in one of the sectors is used in the economy. In the tradable sectors (ICT sector and traditional goods production), the good is either combined with other domestic and foreign goods into a domestic final good, or it is exported. In the traditional service sector there are only domestic goods. The final domestic goods are either consumed or used as an intermediate good or investment good. Only the tradable sectors produce investment goods, which transform into ICT or traditional capital in the next period. Consumption, investment, and intermediate goods are perfect substitutes.

Intermediate goods and capital are used as factors of production in the domestic sectors together with exogenous stock of labor provided by the households. The factors of production are assumed to flow freely between the sectors. Households are the sole investors in the economy (investment goods operate as a carrier of household savings) and maximize utility according to a utility function which aggregates sectorial consumption goods. Finally, in equilibrium trade is balanced ensuring that the financial position of the country is balanced in the long-run, goods are imported from the location where they are the cheapest, while product and input markets are settled.

Let us next consider the model in more detail.

3.1 Production

For brevity, let us denote the traditional service sector with S, the ICT sector with IT, and the traditional goods sector with G.

In each sector, firms use six factors of production: two capital stocks, three

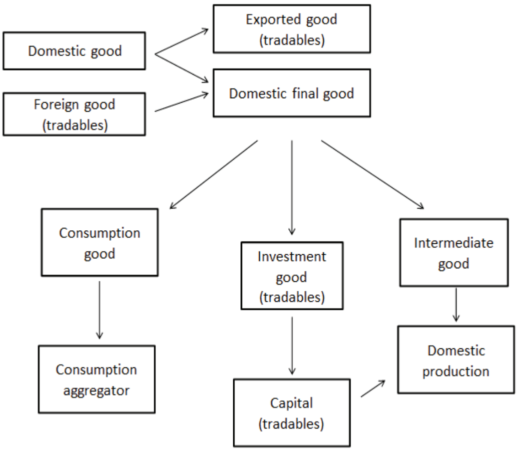

Figure 4: Sectorial structure of the model.

different intermediate goods, and labor. Firms rent capital and labor from the representative household and buy sector-specific domestic final goods for intermediate use. Factors are fully mobile across sectors and factor price equalization holds. [44]

The production technology is described with a constant returns to scale Cobb-Douglas production function. In each sector (omitting the sector index), the firm maximizes static profits:

$$\max \left[\begin{array}{c} p \times MFP \times k_{IT}^{\alpha_{IT}^k} k_G^{\alpha_G^k} m_S^{\alpha_S} m_{IT}^{\alpha_{IT}} m_G^{\alpha_G} l^{\alpha_W} \\ -p_{IT}^k k_{IT} - p_G^k k_G - p_S m_S - p_{IT} m_{IT} - p_G m_G - wl] \end{array} \right] \tag{10}$$

where p is the price of the corresponding sector's good, MFP is multi-factor productivity, $k_{(\cdot)}$ capital based on the $(\cdot)$ sector investment goods, $m_{(\cdot)}$ intermediates from the sector $(\cdot)$, and l is labor. α denotes the corresponding output elasticities. The elasticities sum up to 1. $p_{\cdot}^k$ denotes rental cost of capital based on the sector $(\cdot)$ goods, $p_{\cdot}$ denotes price of the domestic final good in sector $(\cdot)$ and w denotes the wage per unit of labor.

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[44] However, in the empirical exercise multi-factor productivities are adjusted to control for fixed sector-specific differences in factor prices. For details, see the Calibration section.

It is convenient to describe optimum production with a unit cost function.[45] For that purpose, let us consider the profit maximization problem in two stages. First, the unit cost function is obtained by minimizing the cost of production under a given level of production and factor prices. Second, the firm maximizes its level of production (without pricing power), which implies that the unit cost equals the price of the produced good.[46]

The C-D production function implies the following unit cost function (UC):

$$UC = \frac{1}{A}(p^k_{IT})^{\alpha^k_{IT}}(p^k_G)^{\alpha^k_G}(p_S)^{\alpha_S}(p_{IT})^{\alpha_{IT}}(p_G)^{\alpha_G}(w)^{\alpha_w}$$

where UC is the unit cost and $A = MFP \times \prod_i \alpha_i^{\alpha_i}$ is multi-factor productivity augmented by factor-intensity terms arising from the optimization and i is an index for all inputs. Maximization of profits with respect to output ensures that the unit cost equals the price of the final good, $UC = p$.

Sector-specific assumptions follow Yi and Zhang (2010). First, the non-tradable service sector is assumed to produce a homogenous good. The optimality conditions are $UC_S = p_S$ and

$$UC_S = \frac{1}{A_S}(p_{IT})^{\alpha^k_{IT,S}}(p^k_G)^{\alpha^k_{G,S}}(p_S)^{\alpha_{S,S}}(p_{IT})^{\alpha_{IT,S}}(p_G)^{\alpha_{G,S}}(w)^{\alpha_{w,S}}$$

In the tradable sectors, $q \in \{IT, G\}$, goods are produced by a continuum of firms indexed by the type of the goods they produce, $z_q \in [0, 1]$. Firm-level production functions are Cobb-Douglas and identical up to the multi-factor productivity term. The firms are either located in the home country or operate abroad, and their products are combined symmetrically into a domestic final good, f$_q$, which is further used as a consumption, investment, or intermediate good:

$$f_q = \left(\int_0^1 f_{z_q}^{\eta_q} dz\right)^{\frac{1}{\eta_q}}.$$

η_q (< 1) is the substitution elasticity of the goods. Country index is again omitted.

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[45] On the characterization of equilibrium using unit cost functions, see Roe et al. (2010).

[46] From $\underset{Y}{max}(p * Y - UC * Y)$

Each individual good, f_{z_q}, is purchased from a location where the price is the lowest. It is transported to the home country and used as a part of the domestic final good. The transportation generates an iceberg cost $\tau_{q,i,k}$, when the good z_q is shifted from country k to country i ($\tau_{q,i,k} = 1$ if $i = k$). The transportation cost is sector-specific. The price of the good, z_q, in country i is then

$$p_{z_{q,i}} = \min_{k \in CN} \left[\tau_{q,i,k} p_{z_{q,k}} \right],$$

where CN is the set of all countries producing the good and $p_{z_{q,k}}$ is the producer price of good z_q in country k. The price index of the sector-specific domestic final good follows directly from the assumed functional form:

$$p_q = \left(\int_0^1 p_{z_q}^{\frac{\eta_q}{\eta_q - 1}} dz \right)^{\frac{\eta_q - 1}{\eta_q}}$$

A convenient and flexible way to capture patterns of trade and comparative advantage across countries is to assume that the distribution of multi-factor productivity across firms and countries are realizations of random variables. Thus, for each firm the augmented multifactor productivity term $A(z_q)$ is drawn in each time period from a cumulative distribution function $\Phi_{iq}(z) = \Pr(Z_{iq} \leq A)$. Following Eaton and Kortum (2002) the distribution is chosen to be Frechet $\Phi_q(z) = e^{-T_q A^{-\theta_q}}$, where $T_{iq} > 0, \theta_q > 1$. The distribution has a clear economic interpretation, as it corresponds to the distribution of a maximum of a set of productivity draws, where the draws can be considered to represent a new idea from an underlying distribution of ideas. Being proportional to the mean of several draws under F -distribution, T measures the absolute advantage of the sector in production. However, each country will have some production in each sector, as good productivity draws are realized in each country. Their frequency is governed by θ, which can be interpreted as a comparative advantage.

Production of each type z is fully competitive. For each type, profit maximization yields

$$UC_{z_q} = \frac{1}{A_{z_q}} (p_{IT})^{\alpha_{IT,q}^k} (p_G^k)^{\alpha_{G,q}^k} (p_S)^{\alpha_{S,q}} (p_{IT})^{\alpha_{IT,q}} (p_G)^{\alpha_{G,q}} (w)^{\alpha_{w,q}}$$

and $UC_{z_{q,k}} = p_{z_{q,k}}$, where the factor elasticities (α) are sector-specific and sum up to 1. Furthermore, the profit maximization problem is identical up to the MFP term yielding the aggregate unit cost function as an integral over all domestic producers:[47]

$$UC_q = \frac{1}{A_q}(p_{IT})^{\alpha^k_{IT,q}}(p^k_G)^{\alpha^k_{G,q}}(p_S)^{\alpha_{S,q}}(p_{IT})^{\alpha_{IT,q}}(p_G)^{\alpha_{G,q}}(w)^{\alpha_{w,q}}$$

where $A_q = \gamma_q^{-1} T_q^{\frac{1}{\theta_q}} \times \prod_i \alpha_{i,q}^{\alpha_{i,q}}$, $\gamma = (\Gamma(1 - \frac{\eta_q}{1-\eta_q})\frac{1}{\theta_q})^{\frac{1-\eta_q}{\eta_q}}$ (Yi and Zhang, 2010). However, the relationship between the price of domestic final good, p_q, and aggregate unit cost, UC_q, is now different than in the closed sector. It is governed by the distribution of multi-factor productivity terms and trade costs in a manner discussed further in the equilibrium subsection.

3.2 The Representative Household

The representative household receives wages from work and rental income from the capital it owns. In each time period, the household can consume the received income or invest it in new sector-specific assets, which translate to the particular type of capital in the next period. The decisions are driven by maximization of intertemporal utility and determined by the combinations of sector-specific consumption. The size of the household reflects demographics, and its aggregate work effort is divided between the sectors.

The household has CRRA preferences:

$$\sum_{t=0}^{\infty} \beta^{(t)} N_t \frac{C_t^{1-\sigma} - 1}{1-\sigma}$$

where N_t is the size of the household, and C is a consumption aggregator in per person terms. Labor supply is exogenous, a choice which can be justified by the focus on the long-run behavior of the economy. In the long run, technological change and labor supply appear independent: labor productivity has risen dramatically over the past century, whereas labor supply has changed by much less.

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[47] Here, unit cost refers to the home country, while unit costs in other countries are taken to be exogenous and are denoted as $UC_{q,k}$ for a country k.

The household receives wage income and rental (at rental rate p^a) income from assets (a) and buys either sector-specific consumer goods ($c_j \mid j = G, IT, S$) or invests in new assets ($i_j \mid j = G, IT$), yielding the constraint:

$$\sum_{j=IT,G,S} wL_j + p^a_{IT} a_{IT} + p^a_G a_G - \sum_{j=IT,G,S} [p_j(c_j + i_j)] = 0$$

The aggregate final consumption follows a CES aggregator:

$$\begin{aligned} & C(c_S, c_{IT}, c_G, t) \\ = & \left(\omega_S (\frac{c_{St}}{N_t})^{\frac{\varepsilon-1}{\varepsilon}} + \omega_{IT} (\frac{c_{ITt}}{N_t})^{\frac{\varepsilon-1}{\varepsilon}} + \omega_G (\frac{c_{Gt}}{N_t})^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} \end{aligned}$$

Intratemporal elasticity of subtitution ($\varepsilon < 1$) is assigned to capture inelastic demand for consumption goods. $\boldsymbol{\omega} > 0$, and $\sum \boldsymbol{\omega} = 1$. The corresponding aggregate price index is

$$p = \left(\omega_S^{\varepsilon} p_S^{1-\varepsilon} + \omega_{IT}^{\varepsilon} p_{IT}^{1-\varepsilon} + \omega_G^{\varepsilon} p_G^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

and the consumption expenditure share for sector j ($X_j = \frac{p_j C_j}{pC}$) is

$$X_j = \omega_j^{\frac{1}{1-\varepsilon}} (\frac{p_j}{p})^{\frac{\varepsilon}{\varepsilon-1}} \tag{11}$$

3.3 Equilibrium

In equilibrium, international trade is balanced and individual goods are purchased from locations with the lowest price. Households maximize their intertemporal utility, and firms maximize profits. Furthermore, in the equilibrium domestic commodity markets, labor market, and capital markets are cleared.

Let us first describe the equilibrium conditions for international trade. Eaton and Kortum (2002) show that under the distributional assumptions regarding multi-factor productivity, the domestic final good q's relative price in country i is a function of unit costs in other countries and trade costs:

$$p_{q,i} = \gamma \Phi_{q,i}^{-\frac{1}{\theta}} \tag{12}$$

where $\Phi_{q,i} = \sum_{k \in CN} \tau_{q,FIN,k}^{-\theta} UC_{q,k}^{-\theta}$.

Similarly, patterns of trade can be expressed as functions of unit costs. Under the Fréchet distribution, the probability that the lowest price in the country is offered by producers in other countries can be derived from the distribution of prices. This probability is also the expenditure share of goods brought from other countries. The share of country j's goods in country i's sector q ($\pi_{q,i,j}$) is:

$$\pi_{q,i,j} = \frac{\tau_{q,i,j}^{-\theta} UC_{q,j}^{-\theta}}{\Phi_{q,i}} \tag{13}$$

For proofs of eq. (12) and eq. (13), see for example Rodríquez-Clare (2007).

Let us then focus on the Finnish economy. Using these expressions the demand for domestic goods in investments, consumption, and intermediate goods (denoted by subscript $_{DOM}$) can be expressed as a function of the relative unit costs across countries and the total Finnish demands (i_q, m_q, c_q):

$$\begin{aligned} i_{q,DOM} &= \pi_{q,FIN,FIN} i_q \\ m_{q,DOM} &= \pi_{q,FIN,FIN} m_q \\ c_{q,DOM} &= \pi_{q,FIN,FIN} c_q \end{aligned}$$

Furthermore, real foreign demand for Finnish goods depends on the unit costs and size of the foreign markets. The aggregate exports for sector q is

$$x_q = \sum_{i \in \{CN \setminus FIN\}} \pi_{q,i,FIN} d_i.^{48}$$

where d_i refers to total real demand in country i. Unit costs and total real demands

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[48] A practical inconvenience regarding the sum is that it requires keeping account of a large number of exogenous variables during the simulations. Thus, in the actual estimations, the total size of the world market and the share of Finnish products are separated as distinct variables, and the share is proxied with a logit transformed variable. In practice, a proxy function with four exogenous elements is found to capture the shape of the original function very accurately.

in other countries are taken to be exogenous.

Balanced trade condition holds:

$$\sum_q [UC_q x_q - p_q(1 - \pi_{q,FIN,FIN})(i_q + m_q + c_q)] = 0,$$

that is, the sum of sectorial total nominal export income $UC_q x_q$ must equal the sum of the sectorial total value of imports $p_q(1 - \pi_{q,FIN,FIN})(i_q + m_q + c_q)$.

Other equilibrium conditions are then collected. As shown in Appendix B, the necessary conditions for the optimal consumption yields the static conditions

$$\frac{p_j}{p_k} = \frac{U_{[j]}}{U_{[k]}}$$

and the dynamic conditions

$$\frac{U_{[c_q]}}{U'_{[c'_q]}} = \beta(\frac{(p_q^a)'}{p'_q} + (1 - \delta_q))$$

where [] denotes the differential of the function U and (') the next period. q refers to tradable sectors, and indices j and k run through all sectors. [49] p_q^a denotes the rental cost of a unit of capital. The income constraint of the household holds as equality

$$\sum_{j=IT,G,S} [w_j L_j + R_1 a_{IT} + R_2 a_G] = \sum_{j=IT,G,S} [p_j(c_j + i_j)]$$

That is, compensation from asset holdings and work equals the cost of consumption and investments to assets. In the equilibrium, $a_j = k_j$ and $p_j^a = p_j^k$

The production side of the economy uses domestic resources (labor, capital stocks, and domestic intermediate goods) and imported intermediate goods as factors of production. In the equilibrium, supply equals demand. A convenient

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[49] It is worth noting that the two conditions yield a natural zero-arbitrage condition. The real interest rate of the economy is

$$1 + r = \frac{(p_{NIT}^a)' + (1 - \delta_{NIT})p'_{NIT}}{p_{NIT}} = \frac{(p_{IT}^a)' + (1 - \delta_{IT})p'_{IT}}{p_{IT}}.$$

The relative prices in the current period reflect the ratio of the future streams of rental income.

way to formalize the resource constraints is to use Shephard's lemma[50], which yields the following equilibrium conditions for all factor markets (i,j=IT,G,S):

$$\begin{aligned}\sum_i UC_{i[p_q^k]} f_i &= k_q \\ \sum_i UC_{i[W]} f_i &= l \\ \sum_i UC_{i[p_j]} f_i &= m_j\end{aligned}$$

where $UC_{i[\cdot]}$ is the differential of $UC_{i[\cdot]}$ with respect to factor price $(\cdot)$.

Feasibility constraints for the use of domestic products are

$$\begin{aligned}f_q &= c_q^{dom} + i_q^{dom} + m_q^{dom} + x_q \\ f_S &= c_S + m_S.\end{aligned}$$

Finally, both capital stocks accumulate as usual:

$$k_q^{'} = (1 - \delta_q) k_q + i_q$$

4 Taking Stock from a Simple Model

This section lays out a simple model that illustrates the implications of uneven technological change for aggregate growth and structural change. In particular, it shows the conditions under which uneven technological change is consistent with constant aggregate economic growth. Generally that is the case when technological change is faster in sectors that produce only factors of production. In addition, factor use must be symmetrical across sectors, and the economy must be closed.

The example reflects some assumptions that are justifiable in light of empirical evidence. Production functions are Cobb-Douglas, and the intratemporal elasticity

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[50] Differential of the sector i unit cost function with respect to factor price of the factor j, multiplied by the volume of production in the sector i, equals the demand for the factor j in the sector i. For details, see Roe et al. (2010)

of consumption is less than 1. Furthermore, other assumptions are needed to keep the analysis tractable. Factor prices equalize across sectors and the model is static, meaning that all inputs are used during the period. The last part of this section discusses the role of the assumptions.

Expressions for real value added and structural change are next derived in the simple environment and then discussed. Let us begin by addressing relative prices. Unit cost of producing a good in each sector consists of the price aggregate of intermediate goods and labor:

$$UC_j = \frac{1}{A_j} w_j^{\alpha_w} \prod_i p_i^{\alpha_i},$$

where α_w refers to the common factor share of labor and α_i to the common factor share of intermediate goods produced by sector i. The factor shares sum up to 1, reflecting an underlying constant returns to scale, C-D production function. In a closed economy, zero-profit condition states that the unit cost equals the price of the final good in sector j: $UC_j = p_j$.[51] Symmetry of production functions implies that relative prices evolve as a function of sectorial MFP terms

$$\frac{p_j}{p_i} = \frac{UC_j}{UC_i} = \frac{A_i}{A_j}. \tag{14}$$

Nominal value added of the simple economy equals nominal consumption. Under wage equalization, real value added is then a function of real wage and exogenous aggregate labor supply:

$$VA = C = \frac{pC}{p} = \frac{\sum\limits_i wL_i}{p} = \frac{w}{p} l. \tag{15}$$

In the expression $\frac{w}{p} = \frac{w/p_j}{p/p_j}$, denominator and numerator are both functions of relative prices. First, the zero-profit condition yields the following expression for

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[51] In the closed economy, A_j can be interpreted as the expected value of domestic productivity draws from the Frechet distribution.

the numerator:

$$\begin{aligned} p_j &= \frac{1}{A_j} w_j^{\alpha_w} \prod_i p_i^{\alpha_i} \\ \Leftrightarrow & \ (\frac{w}{p_j})^{\alpha_w} = A_j \prod_i (\frac{p_i}{p_j})^{-\alpha_i} \\ \Leftrightarrow & \ \frac{w}{p_j} = A_j \prod_i (\frac{p_i}{p_j})^{-\frac{\alpha_i}{\alpha_w}}. \end{aligned} \tag{16}$$

Second, after taking the price of traditional goods as the numenaire, the denominator can be re-written as:

$$\frac{p}{p_G} = \left(\omega_S^{\frac{1}{1-\varepsilon}} (\frac{p_S}{p_G})^{-\frac{\varepsilon}{1-\varepsilon}} + \omega_{IT}^{\frac{1}{1-\varepsilon}} (\frac{p_{IT}}{p_G})^{-\frac{\varepsilon}{1-\varepsilon}} + \omega_G^{\frac{1}{1-\varepsilon}} \right)^{\frac{1}{\varepsilon}} \tag{17}$$

and after plucking in equations (14), (16), and (17), real value added becomes a function of sectorial MFPs:

$$\frac{w}{p} l = \frac{\frac{w}{p_G}}{\frac{p}{p_G}} l = \frac{A_S^{\frac{\alpha_S}{\alpha_w}} A_{IT}^{\frac{\alpha_{IT}}{\alpha_w}} A_G^{1-\frac{\alpha_S+\alpha_{IT}}{\alpha_w}}}{\left(\omega_S^{\frac{1}{1-\varepsilon}} (\frac{A_G}{A_s})^{-\frac{\varepsilon}{1-\varepsilon}} + \omega_{IT}^{\frac{1}{1-\varepsilon}} (\frac{A_G}{A_{IT}})^{-\frac{\varepsilon}{1-\varepsilon}} + \omega_G^{\frac{1}{1-\varepsilon}} \right)^{\frac{1}{\varepsilon}}} l \tag{18}$$

Eq. (18) describes the relationship between structural change, technological change, and aggregate growth. The numerator reflects the positive impact of the high state of technology on the marginal product of labor. The higher the share of a particular sector-specific technology in production, the higher will its growth contribution be. However, improvements in technology also change the price of consumption. When the elasticity, ε, is less than 1, changes in relative prices will induce a shift in consumption towards sectors with a lower rate of technological change. That will lower the growth rate of the economy over time.

Eq. (18) illustrates the difference between input-specific and consumption-specific technological change. When technological change is input-specific, ω is 0. In that case, technological change does not generate structural changes in consumption. For example, if ICT is the only source of growth in the economy and $\omega_{IT} \approx 0$,

$$\Delta \log(\frac{w}{p}) = \frac{\alpha_{IT}}{\alpha_w} \Delta \log(A_{IT}).$$

The economy's growth rate can remain constant if the trend in sector-specific technological change is constant.

What kind of structural changes does the simple model predict? Consumption shares are given by Eq. (11) and reflect relative price movement. Labor shares reflect changes in the consumption patterns and the role of sectors in the production of intermediates. To see the relationship, notice first that total sales in sector j consists of a sum of consumption and intermediate goods

$$p_j f_j = p_j (c_j + m_j) \tag{19}$$

Now, the intermediate goods can be traced back to consumption after noticing that factor shares denote the share of the factor in nominal output:

$$\begin{aligned} p_j m_j &= \alpha_j \sum_{i=1..3} p_i f_i \\ &= \frac{\alpha_j}{\alpha_w} \sum_{i=1..3} w l_i \\ &= \frac{\alpha_j}{\alpha_w} \sum_{i=1..3} p_i c_i \end{aligned} \tag{20}$$

The last relationship follows from equating aggregate nominal inputs with aggregate nominal outputs. Using Eq. (19) and Eq. (20) yields the sector-specific labor expenditure:

$$w l_j = \alpha_w p_j f_j = \alpha_w p_j c_j + \alpha_j \sum_{i=1..3} p_i c_i \tag{21}$$

Sector-specific labor shares can now be expressed in terms of intermediate production and consumption shares by dividing Eq. (11) with aggregate labor expenditures. Let us denote the labor share by X_j^L:

$$X_j^L = \frac{wl_j}{\sum\limits_{i=1..3} wl_j} = \alpha_w X_j + \alpha_j \tag{22}$$

where X_j is the sector's share in total nominal consumption governed by Eq. (11). When $\varepsilon < 1$, labor shifts towards sectors where productivity growth is the lowest as the consumption shares, X_j, are increasing functions of the good's relative price. However, the share of labor devoted to intermediate production is not dependent on the consumption shares and remains constant.

The last part of this section is devoted to a discussion of assumptions. First, it is natural to ask whether the results regarding the aggregate growth rate and structural dynamics generalize to a model with capital. Recent literature suggests that the answer is yes. Ngai and Pissarides (2007, section V) considers a very similar model, where capital is an aggregate of sector-specific goods, while production and consumption are defined as before. Their findings regarding the nature of aggregate growth are very similar to the static case based on intermediate goods. The growth rate of the economy is governed by the factor-share weighted average of MFP growth rates of capital producing sectors similarly to the intermediate good case described here. Labor shifts due to changing consumption patterns towards the production of more expensive goods, but certain share of the labor force is devoted to the production of capital. Ngai and Pissarides (2007) show that when the intertemporal elasticity of substitution, ρ, is 1, the dynamics of the aggregate economy reduces back to the standard one sector neoclassical growth model, and a balanced growth path exists. However, the balanced nature of growth arises only because value added and consumption are both deflated using the price of the investment good. The choice of deflator does not reflect changes in the structure of consumption and value added. Unless technological change is predominantly investment-specific, it changes consumption patterns and thus the real growth rate of value added, when a more standard consumption deflator is used. Furthermore, weights of sectors in value added and consumption deflators are different, as fixed capital investments now enter value added. Accounting for the role of investments in deflators is bound to differentiate the growth rate of real value added and real consumption.

Appendix C discusses the role of differences in factor use and economic openness with the help of the simple model. In general, both features can break the constancy of economic growth. When sectors use factors of production differently, the rate of economic growth is affected by changing consumption patterns and is no longer stable. Although ICT has directly a small role in final consumption, productivity growth in its production leads to changes in relative prices of other consumption goods and, under price inelastic final demand, to reallocation of resources. The same is true, when the economy is open. Specialization in the production of ICT is accompanied by factor price changes which alter the structure of trade and relative prices of traded goods.

5 Structural Change in the Quantitative Model

In this section, the calibration of the numerical model is discussed. Then the model is used in several counterfactual scenarios to address structural change and economic growth. In the simulations, the effect of technological change on the endogenous movement of labor, value added, and consumption across sectors is measured by proxying technology with exogenous trends in sector-specific multi-factor productivity terms. Exogenous changes in relative prices of imports (especially the falling import prices of ICT) are considered as part of the technological change. Furthermore, while in the benchmark simulations, the nominal expenditure shares of different inputs are held constant (Cobb-Douglas), this paper also investigates how outsourcing of work towards the service sector and the increasing share of ICT in the nominal expenditures affect the structural changes. They are measured by letting the nominal factor shares change over time.

The effect of technology is captured under conditions where some other exogenous variables are allowed to affect the economy. They include changes in the size of the foreign market, population growth, and the demographics governing the fraction of working aged population. Calibration of the model and the used exogenous variables are discussed in the next subsection.

In the simulations, the model is calibrated to initiate from 1980 and exogenous variables are used to simulate the model until the year 2060, after which the exogenous variables remain constant. The model is solved in two steps. Steady states are first solved at a stationary future state (2060) and in the initial state (1980). Steady states are solved in Mathematica. Dynamics of the model are solved using Matlab/Dynare, and in particular the deterministic solution library, simul. An initial state is calibrated using the Finnish data. Quantitative results are based on observations between the years 1990 and 2030, leaving a 10-year burn-in period. In all simulations, estimation error is on the order of magnitude 10^{-9}, well below Dynare's default tolerance, 10^{-5}..

5.1 Calibration

The utility function is first calibrated. In the simulations, intratemporal elasticity of substitution is set to 0.5, based on Figure 3. The intertemporal elasticity is chosen to be the same as in Buera and Kaboski (2009). The discount factor is set at 0.96, also a common choice in the literature. The weight parameters (ω) are estimated using the static optimality conditions for consumption and consumption data for the years between 1991 and 2011. The following table collects the parameters of the utility function:

Table 4 : Parameters of the utility function

	ω_{IT}	ω_G	ω_S	ε	β	ρ
value:	.062	0.190	0.748	0.5	0.96	0.5

It is noticeable that the consumption weight of ICT goods is very low.

Size of the household is governed by population growth, and labor supply is driven by demographics. Since 1975, hours show no long-run trend, partly because of the Finnish Great Depression in the early 1990s. The average over the period 1975-2011 is used as the long-run equilibrium level of hours. After that, hours reflect predicted changes in the ratio of working age population. Size of the representative household changes according to changes in the population and is expected to follow the long-run projection by Statistics Finland until 2060.

The elasticity parameters of production functions are calibrated using the year 2000 nominal share estimates found in Table 1. Sector-specific multi-factor productivity *levels* in 1995 are measured as residuals by dividing the observed unit costs by rental rate estimates, observed hourly wages, and prices of the intermediates. The factor costs are country-level averages and from the EU KLEMS data.[52] MFP growth rates are from the EU KLEMS data. Industry-level MFPs are aggregated to the sector level by using sector-level gross output -based Törnqvist weights.

Following Eaton and Kortum (2001) relative unit costs and bilateral trade barriers are estimated from the bilateral trade data up to the parameter θ. The parameter value of θ is set to 8.3, which is a standard choice. Bilateral trade equations indicate relative prices and unit costs across countries in the year 1995 (for details, see Appendix A). After the year 1995, unit costs in other countries are proxied with relative price movements. In particular, in each country, i, the connection between final good price and the international distribution of unit costs arises from the relationship

$$p_{q,i} = \hat{\Phi}_{q,i}^{-\frac{1}{\theta}}$$

In particular, extending demand and supply schedules after the year 1995 requires a proxy for $\hat{\Phi}_{q,i}^{-\frac{1}{\theta}}$ excluding the Finnish unit costs is required. It captures competition faced by Finnish firms in the domestic market and governs foreign competition in export markets. In particular, after denoting the proxy with $(\widetilde{\Phi})$ the share of domestic goods in Finnish markets is

$$\pi_{q,FIN} = \frac{UC_{q,FIN}^{-\theta}}{\widetilde{\Phi}_{q,FIN} + UC_{q,FIN}^{-\theta}} \tag{23}$$

Similarly, Finnish exports can be expressed as the sum of shares of finnish goods in foreign market (as a function of Finnish unit costs and $\widetilde{\Phi}$ measured for other countries) multiplied by the foreign market size.

The analysis abstracts from possible long-run convergence or divergence in growth rates of individual countries in terms of prices. It is assumed that all elements in country-specific unit cost aggregators $\hat{\Phi}_{q,i}^{-\frac{1}{\theta}}$ are growing at a common, sector-specific rate in which case $\hat{\Phi}_{q,i}^{-\frac{1}{\theta}}$ can be proxied with a single deflator. In

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[52] While in the model, factor prices equalize across sectors, the calibration takes their actual differences –especially in wages– into account. The calibrated MFP is lower in the year 1995 for sectors, where factor prices are actually higher than average. The lower MFP can be considered as sector-specific investments in quality of factors which are proportional to the size of the production.

particular, the uniform rate of change in unit costs is assumed to reflect the average change in the U.S. gross output deflator during 1980-2005. The deflators are taken from Jorgenson and Timmer (2011, Table 7) and are measured relative to the U.S. GDP deflator, which is set as the numenaire in the model.

Furthermore, the sizes of sector-specific foreign markets are taken from the CEPII data in 1995. Afterwards it is assumed that the world economy grows at a 2 percent rate in real terms reflecting the long-run average growth of the U.S. economy. Nominal shares of ICT and traditional goods in the world market is assumed to be constant, which means that the real sector-specific markets must grow at the rate of 2 percent minus the change in relative price. The assumption reflects the constancy of nominal shares in the 2000s reported for instance by Oulton (2011). Exogenous variables governing the size of the foreign markets are collected in the next table:

Table 5 : Exogenous variables governing the international markets

	1995	Growth	Source
World market: real size			
ICT	Trade data	2 % + 3.6 %	2% - rel. price change
Traditional goods.	Trade data	2 % + 0.2 %	2% - rel. price change
World market: relative price			
ICT	Trade data	- 3.6 %	Jorgenson and Timmer
Traditional goods	Trade data	- 0.2 %	(2011, Table 7)

5.2 Results: Simulated Structural Changes

The first application investigates the model's ability to replicate actual structural change in the Finnish economy. It turns out that the model performs reasonably well. Table 6 shows how the model behaves compared to the actual evolution of key structural change variables under different specifications between the years 1991 and 2011.[53]

To benchmark ICT's role in structural change, let us first analyze a specification without ICT. A counterfactual scenario is constructed where the special nature of

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[53] The time period can be considered as representing a full business cycle, because both in the year 1991 and in the year 2011 Finland and Europe were in recession.

ICT -related productivity growth is removed. Instead, MFP grows in the producing sector at the same rate as traditional goods production, while its level matched the MFP in ICT production in the year 1995. Similarly, foreign unit costs in the production of ICT follow the unit costs of traditional goods production while the level is set to match the observed ICT price in 1995. The modifications removes ICT-specific technological change, embodied either in domestic or imported goods.

The results (No ICT, Cons. f. shares) indicate that other types of technological change can explain most of the structural change in consumption. This is an important finding, which is consistent with the notion that ICT is predominantly a production factor-specific technology. It also appears that structural change in consumption may originate from a different source than other forms of structural change, as patterns in hours and nominal value added cannot be explained by the model.

ICT is then included. The model (ICT, Cons. f. shares) can now replicate structural change in value added and hours from traditional goods production towards services, and the falling relative price of ICT. However, adding ICT has only a small effect on the relative price of services.[54] Thus, its role in the structural change in consumption appears to be small. However, for the most part, the model still fails to replicate the increase in the share of the traditional service sector.

Trends in the factor shares shown in Table (1) are next considered. As discussed before, they mainly reflect the substitution of labor by intermediate services and the increasing role of ICT as a factor of production. Trends in the factor shares are captured by linearly extrapolating the observed trends in the factor shares between the years 1995 and 2005. In the simulation, 1995 shares for the years 1990-1995 are used. In the years 1995-2005, the factor shares grow according to the linear trends. It is assumed that the trends continue after the year 2005 and they are extrapolated for the years 2005-2015. After the year 2015, the factor shares remain constant. All other exogenous variables and parameters are left unchanged.

Consideration of the trends (Vary. f. shares) provides a substantial improvement in the model's fit by strengthening the shift of value added and hours towards

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[54] Here, the empirical price index for services is based on consumption. It is noticable, that the rate of increase of production price index, where also intermediate services are included, is smaller.

the traditional service sector. A visible side-effect of adding the trends is that the relative increase in the price of services is even weaker than before. Thus changes in the factor use are improving productivity of the service sector relative to production of the traditional goods.

Table 6 : Structural change

		No ICT	ICT	
	Data	Cons. f. shares	Cons. f. shares	Vary. f. shares
Consumption:				
ICT	0.7	-0.2	-1.0	-1.0
Goods	-4.6	-2.6	-2.3	-1.1
Services	3.9	2.86	3.2	2.1
Value added:				
ICT	2.1	0.3	2.9	10.4
Goods	-6.5	-0.8	-3.5	-14.3
Services	4.4	0.5	0.6	4.0
Hours:				
ICT	1.9	0.3	2.0	3.9
Goods	-9.4	-0.8	-2.8	-10.9
Services	7.4	0.5	0.9	7.0
Price (Goods=100):				
ICT	-71.8	-0.7	-57.3	-63.1
Services	36.3	18.8	17.6	9.3

Figure 5 shows the time series generated by the model and compares them with the data. It appears that the model replicates well the key aspects of the economy. However, the traditional manufacturing sector is moderately too large in the simulations. This may reflect the fact that the sudden rise of ICT sector in the late 1990s is captured as a more gradual event in the model. The figure also illustrates the model's ability to capture international trade patterns. The model reflects the slow change in the Finnish comparative advantage from production of traditional goods towards production of ICT. The model slightly overshoots the share of foreign goods in domestic demand, but captures the declining trend in the share of traditional goods and an increasing trend in the use of ICT.

Overall, the model predicts some non-trivial deviations from the actual patterns, which are worth discussing. First, the ICT sector grows faster than the data suggests, especially when varying factor shares are considered. This overshooting may reflect several issues. Extrapolation of the factor shares beyond the year 2005 shows as a very strong increase in the export share of the ICT sector, implying that they would have a major impact on the comparative advantage. The extrapolation is considered here merely to illustrate the role of factor changes in recent sectorial growth patterns, while constant factor shares are used when economic growth is predicted beyond 2010. Furthermore, the economic crisis in the late 2000s had a strong adverse effect on the Finnish ICT sector. It appears that some of the productivity hikes in the late 1990s were transitory and the sector is currently shifting from production of ICT goods towards production of ICT services. In this paper, productivity observations of the late 1990s are replaced with the more moderate average MFP growth rate in the years 1980 and 2005. However, this does not fully cover the depth of the current contraction, and it remains to be seen what the permanent effect of the crisis will be.

Second, the relative price of a service sector good indicates that the service sector product is not homogenous. The homogeneity assumption leads to underestimating the relative price of services in consumption and overestimating the price of intermediate services. There is no clear-cut way to separate consumption and intermediate services, but one way ahead would be to distinguish between the market and public services. However, for the sake of generality and for this paper's focus on technology it abstracts from the specific features of the Finnish economy in this respect.

5.3 Results: Simulated Economic Growth

This subsection investigates the origins of economic growth in the model and corresponds them with actual data. Aggregate economic growth is the aggregate real value added growth which similarly to Ho, Jorgenson and Stiroh (2005) is defined as the Törnqvist weighted sum of sector-level value added growth:

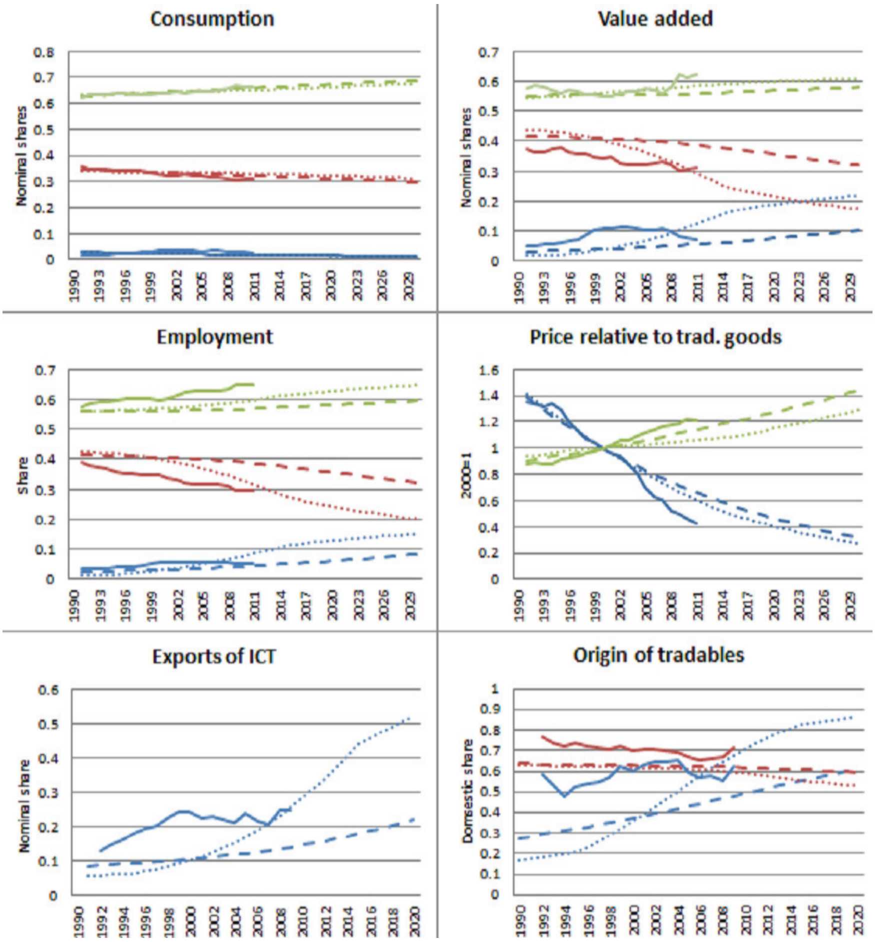

Figure 5: Simulated series. Sectors: green = services, red = traditional goods, blue = ICT. Source: Solid = data, long-dash = constant factor shares, short-dash = varying factor shares.

$$\Delta VA = \sum_i \overline{v}_i^{VA} \Delta VA_i$$

where $\overline{v}_i = \frac{p_{i,t}^{VA} VA_{i,t} + p_{i,t-1}^{VA} VA_{i,t-1}}{2}$ and Δ denote log differences. Nominal value added, $p_{i,t}^{VA} VA_{i,t}$, is the sum of expenditures devoted to primary factors of production.[55]

Table 7 shows the growth rates of real value added, real labor productivity, and real consumption. Furthermore, standard growth decompositions are reported. They show Törnqvist share weighted real sectorial value added and real factor growth rates. The results indicate that the model with constant factor shares is capturing the growth rate of the economy relatively well. Including varying factor shares increases the growth rate over the observed, which may reflect the extrapolation of factor share changes beyond the year 2005. Nevertheless, considering the varying factor shares helps the model to capture the importance of ICT and service sectors in terms of real value added growth.

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[55] Let us denote the share of sector i good in intermediate production as α_i, as before. Then $p_{i,t}^{VA} VA_{i,t} = (1 - \sum_i \alpha_i) p_i Y_i$. The definition of real value added growth in sector i is taken from Ho, Jorgenson & Stiroh (2005):

$$\Delta VA_i = \frac{1}{(1 - \sum_j \alpha_j)} (\Delta Y_i - \sum_j \alpha_j \Delta m_i^j)$$

where Δm_i is the growth rate of intermediate inputs. When factor shares change over time, α are Törnquist shares of the factor's nominal shares.

Table 7: Growth relative to data 1991-2011

	Data	No ICT	ICT	
		Cons. f. shares	Cons. f. shares	Vary. f. shares
Aggregates:				
Real VA growth	2.32	1.25	1.80	2.95
Real VA/H growth	2.2	1.31	1.86	3.00
Real C growth	1.84	1.01	1.50	2.63
VA growth contr.:				
ICT sector	0.92	0.11	0.57	1.19
Good sector	0.54	0.95	0.90	0.47
Service sector	0.79	0.18	0.33	1.28
VA growth contr.:				
ICT cap.	0.42	0.07	0.24	0.33
Trad. cap.	0.38	0.50	0.60	0.69
Labour (QA)	0.16	-0.03	-0.03	-0.03
MFP	1.29	0.72	1.0	1.96

A comparison of the growth rates in scenarios with ICT and without ICT suggests that ICT has a major role in the Finnish economy, even if the actual MFPs are replaced with long-run averages. The results suggest that between the years 1991 and 2011, the growth rate of the Finnish economy would have been 29.6 percent lower without ICT.

To analyze the stability of economic growth, paths of projected economic growth with different specifications are considered. The results are reported in Table 8. The table reports projections of labor productivity growth because they are less affected by demographic changes in the economy and thus gives a clearer view on the productivity impacts of structural change. The table also shows the percentage point changes in the contributions of sectors and factors to value added growth between the year 2010 and the average in the 2020s.

In the benchmark simulation (with ICT), labor productivity grows at the 2.3

percent rate.[56] The contribution of the ICT sector is increasing during the simulation, while the contribution of traditional goods production is declining. MFP growth is the largest factor affecting economic growth. Importantly, the growth rate of the economy is not getting lower during the simulations between the years 2010-2030, which suggests that the influence of structural change to economic growth is not strong.[57]

In the second simulation, all sources of ICT -related productivity growth are removed in the manner described above. The results show that the growth rate of the economy declines during the period between the years 2010 and 2030 by 40.9 percent as a result of the removal. The growth contributions suggest that the change originates in the ICT sector, but also to some extent in a decline in productivity growth in the service sector. Both capital and MFP contribute less to economic growth. The results suggest that the growth rate of the economy is no longer stable. For example, the average growth rate of the economy falls by 0.20 percentage points between the 2010s and the 2020s.

In the third simulation, MFP growth in the Finnish ICT sector is replaced with MFP growth in the traditional goods production. This simulation aims to capture economic growth in Finland without the domestic ICT sector. The results now show a 33.4 percent fall in the growth rate of the economy over the years 2010-2030. The result seems to indicate, perhaps surprisingly (see, e.g., Oulton, 2012), that domestic ICT production plays a crucial role in ICT -related productivity growth. The growth rate is only moderately larger than in the scenario without

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[56] Comparable to US non-firm business sector long-run average 2.25 percent after 1889. (Byrne et al., 2013)

[57] In the scenarios, the real interest rate also remains stable. In the 2000s the average is 7.35; in the 2010s it is 7.41 and in the 2020s it is 7.94. The interest rate corresponds well to the usual real interest rate calibrated in long-term economic growth models (see, e.g., Acemoglu & Guerrieri, 2008).

ICT.

Table 8 : Growth projections

	ICT	No ICT	No ICT sector
VA/H growth:			
2010	2.32	1.60	1.65
2011-2020	2.28	1.45	1.57
2021-2030	2.33	1.25	1.44
Growth 2010 vs. 2020s:			
VA by sector:			
ICT	0.51	0	0.03
Goods	-0.18	0.01	0.02
Services	0.07	0.03	0.11
VA by factor:			
ICT cap.	0.03	0	0.01
Trad. cap.	-0.12	-0.16	-0.05
Labour	0.25	0.25	0.25
MFP	0.23	-0.05	-0.04

6 Conclusions

This paper studies structural changes and economic growth in the knowledge economy. Rapid technological change in ICT has given rise to an expanding high-tech sector and has facilitated wide-spread reorganization of production in sectors using the new technology. On the other hand, economic growth in advanced economies is still accompanied by an increasing role of the service sector, reflecting not just changes in the organization of production, but also changes in consumption demand and deindustrialization.

The paper uses an open economy general equilibrium model consisting of sectors producing ICT, traditional goods and traditional services calibrated for the Finnish economy. Based on long-run projections of economic growth and under different counterfactual scenarios, the paper finds that ICT has a large role in determining economic growth. In Finland, it accounts for 40.9 percent of long-run economic growth.

The paper finds that ICT does not generate structural changes that would decrease economic growth substantially. In scenarios with and without the productivity growth related to ICT, the structural change in consumption appears to remain very similar. If ever, the model suggests that its effect on the relative prices of consumption goods is growth-enhancing. The technology benefits growth in the service sector, where it has been historically difficult to improve productivity.

The paper also finds that drivers of structural changes in consumption, value added, and hours have different origins. Increasing the consumption share of services can be replicated with a model, where the sector-specific expenditure shares of production factors remain constant. Changing factor shares reflecting the substitution of labour by intermediate services and the increasing role of ICT as a factor of production are needed to account for the increasing share of services in value added and hours.

Appendix A : Data and quantification

Data and definitions

Sector shares in intermediate use: Source OECD input-output matrix. ICT sector is (C30-C33, C64, C72), traditional services are industries with the code C52T67 or higher excluding ICT industries, and traditional goods is the rest of the economy.

Cost components of production: Value added is defined as the sum of capital and labor compensation based on the Statistics Finland productivity database. Shares of nominal ICT and traditional capital are taken from the EU KLEMS data, version 2009 (ICT assets are office and computing equipment, communication equipment, and software; non-ICT assets are transport equipment, other machinery and equipment, residential buildings and nonresidential structures). In the Finnish data (based on TOL2008) ICT: 26, 61-63, Goods 1-43 excluding 26, Services: 43- excluding 61-63 . Intermediate goods: ICT: DL + 642 + 72, Goods A-F excluding DL. Services: G-P, excluding 642 and 72. In the EU KLEMS data ICT : 30t33, 64. Goods : A-F. Services : others.

Consumption: Annual national accounts series at current and reference year 2000 prices based on COICOP. ICT: (C0812+C0813 (Telecommunication equipment and services), C091 (Audio-visual, photographic, and data processing equipment)); Traditional goods (All goods CDP31S14, CSDP31S14, CNDP31S14 excluding ICT goods); traditional services: all private and public services excluding C0812+C0813.

Value added and employment shares: Annual national accounts series at current and reference year 2000 prices. ICT: industries 26 and J; Traditional services: Services excluding J; Traditional manufacturing: other sectors excluding 26.

Trade: see below for estimation. ICT and Goods imports and exports from National Accounts. ICT corrected for trade in services.

Quantifying the international trade model

The quantification of the trade model is based on the estimation of the bilateral trade equations. Their estimation closely follows Eaton and Kortum (2001). Let us denote the share country i has in country n's market π_{ni}. Furthermore, the share can be expressed as

$$\pi_{ni} = \frac{UC_{in}^{-\theta}}{\Phi_n}$$

The expression can be normalized by dividing the share with country n's share in its own market. After taking logs:

$$\begin{aligned} \ln(\frac{\pi_{ni}}{\pi_{nn}}) &= \ln(\frac{UC_i^{-\theta}}{UC_n^{-\theta}}) - \theta \ln(\tau_{ni}) \\ &= \theta \ln(UC_n) - \theta \ln(UC_i) - \theta \ln(\tau_{ni}) \end{aligned}$$

On the left-hand side, the variable is observable, and in a full dataset with N countries it corresponds to NxN bilateral trade observations. On the right-hand side, unit costs measuring the competitiveness of the country can be observed as the coefficients on export-country dummies.

To handle $\tau_{ni}-$terms, proxies for various geographic, cultural and tariff variables can be used. The dataset does not have any missing observation, and therefore the unit cost estimations are conducted with ordinary least squares. Variables of the equation are observable up to the parameter θ. A reasonable estimate in both sectors is 8.3. The estimated unit costs and barriers of trade can be straightforwardly used to estimate relative prices across countries. The set of variables to model trade barriers is based on the gravity dataset by Head et al. (2008) provided by CEPII. The variables include tariff levels, RTA dummies, distance (6 classes), common official language, border and colonial background, WTO and EU membership status as well as an importer fixed effect. The equations are estimated yearly for the years 1995 and 2001. Unit cost estimates are taken from the year 1995 while for trade costs 2001 (the end year of the dataset) is used.

In principle, trade data for the latter years could be used. However, the obvious caveat in the bilateral trade data is the fragmentation of production across countries. Yet these features have changed production style of the Finnish ICT sector, especially in the 2000s as Finland has specialized more and more in the production of R&D. The Finnish economy is currently exporting ideas rather than finalized goods. Industrial supply chains may obscure the country of origin concept as the value of a good may not originate in the "country of origin" stated in the trade data. For example, consider a good that is innovated and developed in country A and assembled in country B. The price of the good mostly consists of R&D in country A, but trade statistics still view B as the exporter. The reason is that the service trade flow in the form of R&D from A to B is typically not measured. Thus, B could be misleadingly considered to have the comparative advantage in production of the good. Under fragmented production, the productivities of individual countries should be measured from the observed outputs and inputs within countries and not rely on trade-based comparisons.

Instead, relative output prices across countries are used as proxies for competitiveness, as they provide a reasonably good approximation for the price the countries can provide in the foreign market when the possibilities to outsource production are similar.

Appendix B : Consumer's optimization problem

The corresponding Lagrangian with constraints for resources, balanced trade, and income are (' refers to next period, t+1):

$$\begin{aligned}
\mathcal{L} &= \sum_t \beta^{(t)} U(c_{IT}, c_G, c_S) \\
&\quad + \lambda \left(\sum_{j=IT,G,S} wL_j + p^a_{IT} a_{IT} + p^a_G a_G - \sum_{j=IT,G,S} [p_j(c_j + i_j)] \right) \mid i_S = 0 \\
&\quad + \gamma_1 (a^{'}_{IT} - (1 - \delta_{IT}) a_{IT} - i_{IT}) \\
&\quad + \gamma_2 (a^{'}_G - (1 - \delta_G) a_G - i_G)
\end{aligned}$$

Note that total household income is total output minus compensation for intermediate goods. Let us write down the FOCs for consumption

$$(c_j) : c_j : \beta^{(t)} U_{[c_j]} - p_j \lambda = 0 \; | j = IT, G, S$$

investment:

$$(i_j) : -p_j \lambda - \gamma_j = 0 \; | j = IT, G$$

future assets:

$$(a^{'}_j) : \lambda^{'}_j (p^a_j)' + \gamma_j - (1 - \delta_j) \gamma^{'}_j = 0 \; | j = IT, G$$

The Lagrange multipliers are then solved from $(c_j)'$s and (i_j)'s:

$$\begin{aligned}
\lambda &= \frac{\beta^{(t)} U_{[c_j]}}{p_j} \mid j = IT, G, S \\
\gamma_j &= -\lambda_2 p_j \mid j = IT, G
\end{aligned}$$

Static optimality conditions follow from (c_j)'s:

$$\frac{p_j}{p_k} = \frac{U_{[c_j]}}{U_{[c_k]}}$$

The dynamic optimality conditions are found by combining $(a_j^{'})$'s with (c_j)'s for $j = \; IT, G$:

$$\begin{aligned}
& \lambda^{'}(p_j^a)' + \gamma_j - (1-\delta_j)\gamma_j^{'} = 0 \\
\Leftrightarrow \; & \lambda^{'}(p_j^a)' - \lambda p_j + (1-\delta_j)\lambda^{'} p_j^{'} = 0 \\
\Leftrightarrow \; & \lambda^{'}(p_j^a)' - \lambda p_j + (1-\delta_j)\lambda^{'} p_j^{'} = 0 \\
& \overset{()}{\Leftrightarrow} \frac{\beta^{(t+1)} U^{'}_{[c_j^{'}]}}{p_j^{'}}(p_j^a)' - \frac{\beta^{(t)} U_{[c_j]}}{p_j} p_j + (1-\delta_j)\frac{\beta^{(t+1)} U^{'}_{[c_j]}}{p_j^{'}} p_j^{'} = 0 \\
\Leftrightarrow \; & \beta^{(t+1)} U^{'}_{[c_j^{'}]} \left(\frac{(p_j^a)'}{p_j^{'}} + (1-\delta_j) \right) - \beta^{(t)} U_{[c_j]} = 0 \\
\Leftrightarrow \; & \frac{U_{[c_j]}}{U^{'}_{[c_j^{'}]}} = \beta \left(\frac{(p_j^a)'}{p_j^{'}} + (1-\delta_j) \right)
\end{aligned}$$

Appendix C : Implications of factor share differences and economic openness

Differences in factor use

When factor shares in production are not symmetric, inpiut-specific technological change may affect structural change indirectly. Change in the relative price of an input-specific good can alter the relative prices of other goods when there are differences in the use of the input-specific good in their production. As other sectors have a more important role in final consumption, a change in their relative price alters the growth rate of the economy.

To illustrate this further, let us consider an example. In particular, the factor share of ICT in the service sector is assumed to be $\Delta\alpha$ higher than before, while the share of traditional manufacturing in the service sector is $\Delta\alpha$ lower. Otherwise the model is assumed to be same as in the previous subsection. After the change, the relative price of traditional goods and services is

$$\begin{aligned}\frac{p_s}{p_G} &= \frac{A_G}{A_s}(\frac{p_{IT}}{p_G})^{\Delta\alpha} \\ &= \frac{A_G^{1+\Delta\alpha}}{A_s A_{IT}^{\Delta\alpha}} \qquad (24)\end{aligned}$$

while the relative price of traditional goods and ICT remains governed by the ratio of their MFPs.

The difference in factor use has a direct effect on the real value added in Eq. (15). In the numerator weights are now different:

$$\begin{aligned}\frac{w}{p_G} &= A_G \prod_i (\frac{p_i}{p_j})^{-\frac{\alpha_i}{\alpha_w}} \\ &= A_G(\frac{A_G}{A_{IT}})^{-\frac{\alpha_{IT}}{\alpha_w}}(\frac{A_G}{A_{IT}})^{-\Delta\alpha\frac{\alpha_S}{\alpha_w}}(\frac{A_G}{A_s})^{-\frac{\alpha_S}{\alpha_w}} \\ &= A_S^{\frac{\alpha_S}{\alpha_w}} A_{IT}^{\frac{\alpha_{IT}}{\alpha_w}+\Delta\alpha\frac{\alpha_S}{\alpha_w}} A_G^{1-\frac{\alpha_{IT}}{\alpha_w}-(1+\Delta\alpha)\frac{\alpha_S}{\alpha_w}} \qquad (25)\end{aligned}$$

Then, after plucking in equations (24), (25), (14) and (17) to Eq. (15), the real value added can be expressed as follows.

$$\frac{w}{p}l = \frac{\frac{w}{p_G}}{\frac{p}{p_G}}l = \frac{A_S^{\frac{\alpha_S}{\alpha_w}} A_{IT}^{\frac{\alpha_{IT}}{\alpha_w}+\Delta\alpha\frac{\alpha_S}{\alpha_w}} A_G^{1-\frac{\alpha_{IT}}{\alpha_w}-(1+\Delta\alpha)\frac{\alpha_S}{\alpha_w}}}{\left(\omega_S^{\frac{1}{1-\rho}}\frac{A_G^{1+\Delta\alpha}}{A_s A_{IT}^{\Delta\alpha}})^{-\frac{\rho}{1-\rho}} + \omega_{IT}^{\frac{1}{1-\rho}}(\frac{A_G}{A_{IT}})^{-\frac{\rho}{1-\rho}} + \omega_G^{\frac{1}{1-\rho}}\right)^{\frac{1}{\rho}}}l$$

which shows that even when $\omega_{IT} \approx 0$, the growth rate of the economy does not remain constant, when $\Delta\alpha > 0$ and $\omega_S > 0$. A difference in factor share establishes a relationship between the relative price of ICT and the relative prices of the major consumption goods.

The labour share equations must also be augmented. In particular, Eq. (16) can be restated as

$$\begin{aligned} p_j m_j &= \sum_{i=1..3} \alpha_{ji} p_i f_i = \frac{\alpha_j}{\alpha_w} \sum_{i=1..3} w l_i + \frac{\Delta\alpha_j}{\alpha_w} w l_S \\ &= \frac{\alpha_j}{\alpha_w} \sum_{i=1..3} p_i c_i + \frac{\Delta\alpha_j}{\alpha_w} w l_S \end{aligned} \tag{26}$$

where α_j denotes the factor share of intermediate good j sectors other than services,

and $\Delta\alpha_j$ denotes the difference of factor use of j in the service sector: $\Delta\alpha_{IT} = \Delta\alpha$, $\Delta\alpha_G = -\Delta\alpha$. Labour shares can be now solved from the following system:

$$\begin{aligned} X_{IT} &= \overline{X}_{IT} + \Delta\alpha * X_S \\ X_G &= \overline{X}_G - \Delta\alpha * X_S \\ X_S &= \overline{X}_S \end{aligned}$$

where bars denote the labor share expressions in the symmetrical case, governed by Eq. (22). Labor share devoted in the intermediate production of ICT is increasing in $\Delta\alpha$. In addition, labor shares change as a result of changes in consumption shares reflecting changes in relative prices. In the example, the differences in factor use may support a higher labor share of traditional good production, as its price relative to services do not fall as rapidly as before.

Economic openness

Economic openness may also create a link between investment-specific technological change, structural change, and economic growth. Trade and specialization may change the relative prices beyond the input-specific good when it is exported in exchange for consumption goods. The implications of international trade are next considered in the simplified modeling framework. Distributional assumptions are the same as in the quantitative model, but focus is on two country cases where the home country (H) faces a single foreign market (F).

Prices of tradable goods are no longer governed solely by domestic unit costs. Given the distribution of the productivity, the domestic final good in sector j will have price

$$p_{Hj} = UC_{Hj}\left(1 + (\frac{\tau_{HFj}UC_{Fj}}{UC_{Hj}})^{-\theta}\right)^{-\frac{1}{\theta}} \tag{27}$$

as EK shows. The price of tradable goods will always be lower than the average unit cost of production as $\left(1+(\frac{\tau_{HFj}CU_{Fj}}{CU_{Hj}})^{-\theta}\right)^{-\frac{1}{\theta}} < 1$. Let us assume that country H has comparative advantage in the production of ICT, that is, the average cost of one unit is lower than in F ($\frac{UC_{HIT}}{UC_{FIT}} < 1$). Furthermore, H has comparative disadvantage in production of non-ICT ($\frac{UC_{HNIT}}{UC_{FNIT}} > 1$).

Let us then revisit relative prices. When production functions are symmetric, the comparative advantage ensures that the relative price of ICT will be higher in the open economy compared to autarky (with equal τ):

$$\frac{p_{HIT}}{p_{HNIT}} = \frac{A_{HNIT}}{A_{HIT}}\frac{\left(1+(\frac{UC_{HNIT}}{\tau_{HFNIT}UC_{FNIT}})^{\theta}\right)^{\frac{1}{\theta}}}{\left(1+(\frac{UC_{HIT}}{\tau_{HFIT}UC_{FIT}})^{\theta}\right)^{\frac{1}{\theta}}} > \frac{A_{HNIT}}{A_{HIT}}$$

Trade induces changes in the relative price of services and traditional manufacturing::

$$\frac{p_S}{p_{HNIT}} = \frac{A_{HNIT}}{A_S}\left(1+(\frac{UC_{HNIT}}{\tau_{HFNIT}UC_{FNIT}})^{\theta}\right)^{\frac{1}{\theta}} > \frac{A_{HNIT}}{A_S}$$

Let us further study the patterns of trade. The expenditure share of country F goods in country H (π_{HF}) in sector j is:

$$\pi_{HFj} = \frac{(\tau_{HFj}UC_{Fj})^{-\theta}}{(\tau_{HFj}UC_{Fj})^{-\theta} + UC_{Hj}^{-\theta}} = \frac{1}{1+\left(\frac{UC_{Hj}}{\tau_{HFj}UC_{Fj}}\right)^{-\theta}}$$

The lower average cost in production in F relative to H will translate into higher expenditure share. This information is useful in solving the labor shares. The home country's total sales of sector q goods are

$$\pi_{HHj}(p_{Hj}c_{Hj} + p_{Hj}m_{Hj}) + \pi_{FHj}pd,$$

where pd is the total demand in the foreign country. Total domestic factor expenditures equals total sales:

$$\begin{aligned}
& \sum_{i=1..3} [wl_i + p_i m_i] \\
= & \sum_{i=1..3} [\pi_{HHi}(p_i c_i + p_i m_i) + \pi_{FHi} pd] \\
= & \sum_{i=1..3} [p_i c_i + p_i m_i] - \sum_{i=1..3} [(1 - \pi_{HHi})(p_i c_i + p_i m_i) + \pi_{FHi} pd] \qquad (28)
\end{aligned}$$

The last sum in eq. (28) is total net exports. If balanced trade is assumed, the sum is zero, and as before

$$\begin{aligned}
\sum_{i=1..3} wl_i + \sum_{i=1..3} p_i m_i &= \sum_{i=1..3} p_i c_i + p_i m_i \qquad (29) \\
\sum_{i=1..3} wl_i &= \sum_{i=1..3} p_i c_i
\end{aligned}$$

Eq. (29) shows that value added can be defined as before. First, numerator in Eq. (18) is constructed, but this time using the zero-profit condition for the non-tradable service sector:

$$\begin{aligned}
\frac{w}{p_S} &= A_S \prod_i (\frac{P_i}{P_S})^{-\frac{\alpha_i}{\alpha_w}} \\
&= A_S \left(\frac{A_S}{A_{HNIT}} \left(1 + (\frac{UC_{HNIT}}{\tau_{HFNIT} UC_{FNIT}})^{\theta} \right)^{-\frac{1}{\theta}} \right)^{-\frac{\alpha_{NIT}}{\alpha_w}} \\
&\quad \times \left(\frac{A_S}{A_{HIT}} \left(1 + (\frac{UC_{HIT}}{\tau_{HFIT} UC_{FIT}})^{\theta} \right)^{-\frac{1}{\theta}} \right)^{-\frac{\alpha_{IT}}{\alpha_w}} \qquad (30) \\
&= A_S^{1-\frac{\alpha_{IT}}{\alpha_w}-\frac{\alpha_{NIT}}{\alpha_w}} \left(A_{HNIT} \left(1 + (\frac{UC_{HNIT}}{\tau_{HFNIT} UC_{FNIT}})^{\theta} \right)^{\frac{1}{\theta}} \right)^{\frac{\alpha_{NIT}}{\alpha_w}} \qquad (31) \\
&\quad \times \left(A_{HIT} \left(1 + (\frac{UC_{HIT}}{\tau_{HFIT} UC_{FIT}})^{\theta} \right)^{\frac{1}{\theta}} \right)^{\frac{\alpha_{IT}}{\alpha_w}} \qquad (32)
\end{aligned}$$

When service sector is used as numenaire, the denominator in Eq. (18) is

$$\frac{p}{p_S} = \left(\omega_S^{\frac{1}{1-\rho}} + \omega_{IT}^{\frac{1}{1-\rho}} (\frac{p_{IT}}{p_S})^{-\frac{\rho}{1-\rho}} + \omega_{NIT}^{\frac{1}{1-\rho}} (\frac{p_{NIT}}{p_S})^{-\frac{\rho}{1-\rho}} \right)^{\frac{1}{\rho}}$$

where in particular the relative price

$$\frac{p_{NIT}}{p_S} = \frac{A_S}{A_{HNIT}} \left(1 + (\frac{UC_{HNIT}}{\tau_{HFNIT} UC_{FNIT}})^{\theta} \right)^{-\frac{1}{\theta}}$$

depends on the unit cost relative to the foreign market. In particular, UC_{HNIT} is a function of productivity growth in the ICT sector, which renders a connection between consumption patterns and input-specific technological change.

The eq. (29) suggests that intermediate goods can be written as a function of consumption

$$p_j M_j = \frac{(1-\alpha)\alpha_j^M}{\alpha} \sum_{i=1..3} p_i c_i$$

and the corresponding open economy version for Eq. (21) is

$$\pi_{HHj}(p_j C_j + \frac{(1-\alpha)\alpha_j^M}{\alpha} \sum_{i=1..3} p_i C_i) + \pi_{FHi} p d.$$

The labor shares are now (a modified version of the open economy labor share equation in Yi and Chang (2010))

$$\begin{aligned} & X_j^C + \frac{\pi_{FHi} pd}{wL} - (1 - \pi_{HHj}) X_j^C \\ \equiv \;& X_j^C + N_j, \end{aligned}$$

where X_j^C is the sectorial expenditure share expression from the closed economy model and N_j is the net export share of total GDP. The net export share depends on the comparative advantage, employment shares, wages, and the relative sizes of the countries.

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Essay 3

Investment-led Growth in Crisis: The Finnish Great Depression Revisited

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Unpublished manuscript.

Investment-led Growth in Crisis: The Finnish Great Depression Revisited

Tero Kuusi[58]

Abstract

This paper considers the collapse of the Finnish investment-led growth policy as a contributing factor to the Finnish Great Depression in the early 1990s. The policy change is analyzed with a dynamic general equilibrium model as a lifting of an investment-tax credit. The paper finds that the constructed policy change helps the model to replicate the depth and the persistence of the Finnish crisis in terms of a fall in employment, output, and investment. A reasonably sized financial crisis alone cannot explain the contraction and largely fails to account for the following long slump.

Keywords: business cycles, depression, transition, industrial policy JEL classification: E32, F41, P2

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1 Introduction

The Finnish Great Depression of the early 1990s (one of the worst economic crises in an industrial country since World War II) has received much attention in economic literature. An established view regarding the depression is that both Finland and Sweden experienced very similar severe currency and banking crises resulting from financial liberalization, while the deeper contraction in Finland can be explained by the fact that the Finnish economy suffered more from the collapse of the Soviet Union. However, results of the recent paper by Gorodnichenko et al. (2012, 2009) show that neither the Soviet trade shock nor financial shock are fully consistent with the wide-spread and persistent nature of the crisis (Gorodnichenko et al., 2009, figure 5). Production and especially investments fell substantially in all sectors of the economy[59] and the economic contraction was very persistent, affecting the economy until the 2000s, while the Finnish export market recovered fairly rapidly. The findings suggest that other explanations may still be warranted to understand the anatomy of the crisis.

This paper considers the collapse of the Finnish investment-led growth policy as a contributing factor to the crisis. The policy had a marked effect on the Finnish economy both during and before the crisis (see Pohjola, 1996; Heikkinen and Kusterä, 2001). In the decades after World War II a high rate of investments was administratively maintained with tax subsidies and accommodative monetary policy. As a consequence, the country's production capacity was large at the onset of the crisis, while the marginal product of capital was low. The inefficiency problem escalated during the depression and the country faced a long-lasting restructuring of production. During the crisis the country's investment rate fell permanently to the rates of the US and Sweden.[60]

The policy change is analyzed with a dynamic general equilibrium model as a lifting of investment tax credit. The modeling choice is reasonable given that the main function of the policy (which consisted of a complex system of state

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[59] Aggregate production fell roughly 20 percent compared to the long-run trend, while for investments the contraction was almost 40 percent.

[60] The policy change was a unique feature of the Finnish crisis while in most other European countries, including Sweden, a similar transformation (albeit on a more modest scale) was already experienced in the 1970s. In Finland the investment rate was on average over 25 percent before the crisis, while during the crisis it permanently fell roughly 5 percentage points.

regulation) was to lower the price of investment. Indeed, the next section shows how the crisis coincided with a permanent increase in the price of investments relative to consumption. This paper finds that the constructed policy change helps the model to replicate the depth and the persistence of the Finnish crisis in terms of a fall in employment, output, and investment. A reasonably sized financial crisis alone cannot explain the contraction and largely fails to account for the following long slump. Furthermore, the paper finds that the contribution of the overcapacity problem corresponds roughly to the difference in the depth of the Finnish and Swedish crises.

Key features of the model are taken from the recent paper by Hall (2011). It builds on the Keynesian notion that during a crisis the real interest rate is above its market-clearing level and consequently the supply of current output exceeds demand. The collapse of the growth model, as well as the financial crisis, had a strong lowering effect on final demand, and thus the market-clearing real interest rate was low. The higher price of investments decreased investment spending and the real interest rate should have fallen in order to generate other forms of demand.

However, it appears that the real interest rate was not responsive to the slackness. In the liberalized financial markets the world real interest rates was exogenous, while the room for public policies to manipulate interest and exchange rates, and provide fiscal easing was limited by the financial crisis. Furthermore, the Finnish experience contrasts with the dynamics in a standard Walrasian model where firms respond to sudden demand shocks by lowering prices. In the standard model this generates inflation expectations, which lowers the real interest rate and returns equilibrium in goods markets. Rather than assuming price adjustments, a key feature of the current model is that inflation does not respond to slackness in product markets. To support the assumption, this paper reports evidence from Finnish industry-level prices showing that they were irresponsive to contraction in output.[61].

Instead of adjusting prices, firms are assumed to respond to falling demand conditions by adjusting the utilization rate of capital. When the utilization rate falls, fewer workers are needed in production and unemployment emerges. In the

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[61] Furthermore, the findings reflect well with those reported by Hall (2011) during the current US crisis..

model wages do not respond to lowering of the surplus that workers can provide in firms during downturns. As a result, demand for labor is procyclical. A reduced-form search model based on Hall's (2009) paper is used where the surplus depends on the slack in the use of capital, generating a tight relationship between the capital utilization rate and unemployment. Here the model also responds to downward wage rigidity during the depression, of which there is substantial evidence (see, e.g., Gorodnichenko et al., 2012).

When the price of installed capital starts to increase as a response to the policy change, the marginal product of capital must also increase in order to maintain the required return on investments. Consequently the capital stock starts to decline. However, increasing the marginal return on capital is costly, which forces the capital stock to react slowly to the overcapacity problem and the economy faces a long period of slackness.

To model the liberalized financial market, saving behavior is assumed to be governed by an exogenous return on investments in foreign assets. Households are the sole investors in the model and can invest in domestic and foreign bonds, as well as in capital and durable goods. Return on foreign assets becomes a binding constraint for domestic return on capital when assets can be traded across countries. However, domestic conditions are allowed to affect the household behavior. The consumption based real interest rate is partly affected by the changing price of domestic durable goods. Furthermore, during the financial crisis a fraction of households become credit constrained and are forced to save. Frictions in the financial markets affect investments in durable and capital goods, and are modeled as property taxes on holding the assets.

Similarly to Hall's (2011) work this paper focuses on the economic impact of the adverse forces during the recovery period. They consist of a combination of initial conditions and shocks which are calibrated to match the economic conditions at the end of 1993 and thereafter. As is common in the Great Depression literature, a perfect foresight model is considered where consumption's intertemporal elasticity of substitution governs behavior under uncertainty. Hall (2011) argues that a perfect foresight model gives a surprisingly good account of what happens in a dynamic model once a major surprise becomes known.

Investment tax credit governs the initial conditions of the simulation. It is calibrated based on the deviation of the actual capital stock from its subsequent growth path after the crisis. Using this measure, the total level shift in the capital stock series between the 1980s and the 2000s appears to be over 20 percent, while at the end of 1993 the remaining overcapacity is roughly 10 percent. Accordingly, the excess capacity is generated by initiating the simulations from a steady state that predicts a 10 percent decline in capital stock during the recovery period. Such transition is captured by starting simulations from a steady state with 7.5 percent investment tax credit while the tax credit is removed from the first period of the simulation.[62]

The financial crisis is modeled by solving the model as if the realization of financial shocks had just entered the initial steady state.[63] The first shock is captured by forcing 20 percent of the households to save an amount corresponding to 6.7 percent of GDP. Second, there is a two percent property tax on capital and durable goods. The financial conditions decay at a 10 percent quarterly rate and disappear by 1997. Finally, inflation remains constant at its steady state level, reflecting the central bank's inflation target, and the fiscal policy remains unresponsive to slackness.

In addition to its main results, the paper also shows that without the constrained real interest rate the economy can deal with the overcapacity problem while maintaining full employment by adjusting the domestic price level. The adjustment includes a rapid depreciation of the domestic price level followed by a slow recovery of the prices. A falling domestic price increases the share of domestic goods in final demand, while the recovery stimulates demand by increasing the expected real interest rate. While the Finnish Markka depreciated during the crisis, the observed adjustment of the capital stock is a clear indication that the overcapacity problem remained. The analysis indicates that the Finnish real exchange rate should have decreased by roughly 10 percent more than the Swedish real exchange rate given that only Finland had the overcapacity problem and the

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[62] It is noticeable that several other factors are omitted from the analysis, which include the Soviet fall and the multi-factor productivity (MFP) growth revival after the crisis. While abstracting them may hide the real size of the problem, focusing on the observed transition of the capital in a simplified model stock still gives a fairly good account of the size of the overcapacity problems given these features.

[63] That is, the shocks do not have an effect on the initial steady state which is used to benchmark the economic contraction.

financial crisis was similar in both countries. However, the actual depreciations of the currencies were very similar in the two countries. In any case, it is questionable whether such real depreciation would even have been feasible.

This paper relates to several other papers. First, this paper complements the view that the fall of Soviet trade was an important factor in the crisis, as Gorodnichenko et al. (2012) argue. However, it proposes a different channel instead of the trade shock. Soviet trade helped to maintain the growth policy until the 1980s, while its collapse generated a far greater and more persistent shock than the trade shock alone could have produced. The current model can generate a permanent and widespread fall in output, employment, and fixed capital investments, as well as explain change in the relative price of investment without resorting to rather strong assumptions regarding sectorial labor movement, substitutability of energy, and consumption – as made by Gorodnichenko et al. (2012).

The paper is also closely related to Conesa et al. (2007). The authors find that the Finnish crisis was mostly driven by multi-factor productivity (MFP) shock, which, however, their real business cycle model cannot easily explain. This paper proposes that the shock can be explained as the unmeasured lowering of the utilization rate of capital. Conesa et al. (2007) also argue that tightened fiscal policy during the crisis could be a partial explanation. This explanation is not discussed here, as evidence of a significant tightening of fiscal policy is not apparent in the data (Gorodnichenko et al., 2012).

Evidence of the real impacts of financial constraints during the crisis is ample. Honkapohja et al. (2009) discusses thoroughly their effect on both firm and household behavior. This paper quantifies their importance while not attempting to capture the underlying financial accelerator mechanism. Recently, Freystätter (2011) studied the Finnish crisis with a DSGE model based on the framework of Gerthler et al. (2007). Compared to Gorodnichenko et al. (2012), Freystätter (2011) shows that the model captures the effects and the magnitude of the collapse of Soviet trade more accurately by modeling it as a capital obsolescence shock and combining this shock with balance sheet constrained firms. In this paper the financial frictions are taken into account in a more reduced form, while the focus is on replacing the capital obsolescence shock with an alternative description of the factors affecting investments.

An extensive description of the overcapacity problem in Finland can be found in the work of Pohjola (1996). Landesmann (1992) discusses the Swedish experience in the 1970s. Discussions of the policy change in other European countries can be found in Eichengreen (2007). Recently, Karanassou et al. (2008) suggest that capital accumulation plays a fundamental role in shaping unemployment movements in Sweden and Finland and is related to the literature on the inverse relationship between the investment rate and unemployment. While the current paper agrees with their conclusion that the relationship follows from too few investments, the explanation based on overcapacity problem is more explicit.

This paper focuses on the overcapacity problem during the crisis, but it should be stressed that in the long run the policy change led to productivity enhancing structural transformations in the country. For example, Maliranta et al. (2009) show how the beginning of financial liberalization and deregulation in the mid-1980s coincided with a period of rapid productivity improvements and creative destruction. An illustrative framework to understand the long-run effects of the liberalization and the change in the technological paradigm is given by Acemoglu et al. (2006).

The paper is organized as follows. Section 2 discusses the economic environment and collects empirical facts on the crisis. Section 3 describes the model. In Section 4, calibration of the model is discussed. Section 5 reports quantitative results of the benchmark simulations. Section 6 discusses alternative specifications, while section 7 concludes.

2 The Economic Environment: Empirical Evidence

This section outlines the empirical evidence regarding the economic conditions during the crisis and the recovery period. The first subsection discusses the collapse of the investment-led growth policy. The second subsection considers other reasons for the crisis. The third subsection discusses Overcapacity as a distinctive Explanation for the Crisis. The last subsection considers price determination during the crisis period.

2.1 The Investment-led Growth Model

Finnish monetary and fiscal policies fostered economic growth by channeling resources towards industrialization in the decades after World War the II (see, e.g., Korkman, 1992; Pohjola, 1996; Heikkinen and Kuusterä, 2001). There was an implicit understanding between industry and the central bank that low and stable interest rates, as well as fixed exchange rates, should be maintained in order to ensure a supportive and stable investment environment. At the same time capital flows were tightly regulated and interest rates were set administratively below the market-clearing levels. While the exchange rate regime was fixed, large adjustments were made if that was necessary to ensure some minimum return on investment. Before the Finnish Great Depression of the early 1990s, sizable devaluations of the Finnish Markka were undertaken in 1949, 1957, 1967, 1977–1978 and 1982. Finally, the government intervened in the market by setting-up state-owned enterprises and by granting subsidies.

Many European countries resorted to similar policies after World War II. However, in most other countries the period of rapid catch-up ended with the oil crisis of the 1970s. In Sweden, for example, the 1970s was a time of major structural changes. Figure (6.2) shows how, after the investment boom in the early 1970s, the volume of investments in Sweden dropped substantially and the investment rate never returned to the old levels. Landesmann (1992) describes the period being difficult for the Swedish economy. Problems in the private sector forced the government to rescue ailing firms and support the restructuring of Swedish industry. However, by the early 1980s the restructuring proved to be successful and the Swedish economy gained a position as an exporter in high technology areas.

Unlike many other countries, Finland continued to rely on the extensive growth model until the late 1980s. This was partly because bilateral trade with the Soviet Union rescued the Finnish economy from a deeper recession in the 1970s. The rising oil price meant that Finland could export more industrial products to the Soviet Union due to the countries' bilateral barter trade agreement. Indeed, in the mid-1970s the Finnish economy experienced record high levels of investment (Heikkinen and Kuusterä, 2001).

However, by the early 1980s Finnish officials became increasingly aware of the destabilizing effect of the system. Resorting to devaluation from time to time was an inevitable consequence of conducting economic policies that bring about a rate of inflation that is higher than in the rest of the world. The resulting inflation/devaluation cycle gradually became deeply rooted in expectations and made its removal difficult. Furthermore, several indicators suggest that the Finnish economy was suffering from an overcapacity problem. Pohjola (1996) analyzes aggregate, industry-level, and firm-level data and concludes that the capital-output ratio in the country was high, while return on investments was low in the late 1980s and the early 1990s.

Modernization and liberalization of the financial market became topical in the early 1980s. The financial markets opened gradually in cycles of deregulation that included the abolition of the regulation of domestic bank lending rates and, later, the lifting of restrictions on private borrowing from abroad (Honkapohja et al., 2009). By the mid 1980s most of the regulations were removed. The development had a marked impact on the Finnish growth strategy. Institutional means of maintaining the low real interest rates through independent monetary policy and circulating domestic savings back to investments were reduced substantially. Furthermore, major reforms of the tax system were gradually carried out during the years 1987 - 1993[64]. The statutory corporate income tax rate was very high before the reform (on average 50 per cent in 1987), but generous inventory and investment reserves (up to 20% of profits) considerably reduced the corporate taxes collected. After the reform the corporate tax rate was the same for both distributed and for retained earnings (28 percent from 1996). (Valkonen, 1999)

The effect of the policy change is clearly seen in the data. Figure (6.1) shows that the gap in the price of investment relative to consumption compared to the US disappeared permanently during the liberalization and the crisis period. The relative price reflects both the high cost of consumption in regulated economy and the measures to lower the cost of investments given that the item prices provided

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[64] The motivations for the corporate and capital income tax reform were both external and internal. Domestically, the most compelling reasons were the need to improve the efficiency of the allocation of capital and to promote neutrality in taxation of industrial branches, types of capital, sources of financing and investing sectors. Also, opportunities for tax arbitrage had emerged as a result of the deregulation of credit markets. International pressures were generated by the deepening economic integration to other parts of Western Europe and the wave of tax reforms carried out there, which intensified tax competition. (for details, see Valkonen, 1999)

are final product prices including taxes and subsidies. It is noticeable that the relative price does not directly take into account the effect of low (or even negative) real interest rate in the decades before the crisis, and thus the relative price is likely to be a moderate proxy for the actual incentive to invest.

Figure (6.2) shows that while the Finnish investment share of GDP was significantly higher than in the US throughout the post World War II period, following the crisis the difference disappeared. It appears that the investment frenzy of the late 1980s maintained the high investment rate, while a permanent change was not seen before the early 1990s. Finally, Figures (6.3 and 4) show the estimates of Finnish non-residential and residential capital stocks based on the perpetual inventory method[65]. The former clearly indicates that the non-residential capital stock gradually declined towards a new, lower growth trajectory. It is interesting to notice that residential capital does not seem to have a major role in the structural change.

2.2 Other Factors Contributing to the Crisis

An extensive literature finds that the main factors contributing to the crisis were financial (see, e.g., Kalela et al., 2001; Jonung et al., 2008; Honkapohja et al., 2009). The financial crisis was preceded by an overheating, which resulted from poorly designed financial regulation. Due to the financial liberalization there was an explosion of domestic credit and capital inflows, a significant fraction denominated in foreign currency. Economic policies during the period were not sufficiently restrictive to counteract the boom. Furthermore, a sharp increase in the terms of trade resulted from a fall in energy prices and a rise in the world market prices of forest products that also contributed to the overheating.

The boom reached its peak in 1990 and rapid contraction of the economy began. The economic downturn was due to factors that can be classified as shocks and economic policy effects. The Finnish export market shrank significantly both because of slow growth in market economies and the collapse of a major trading partner, the Soviet Union. However, the Soviet trade shock should not be exaggerated. In 1991 exports to the Soviet Union were around 15 percent of total exports,

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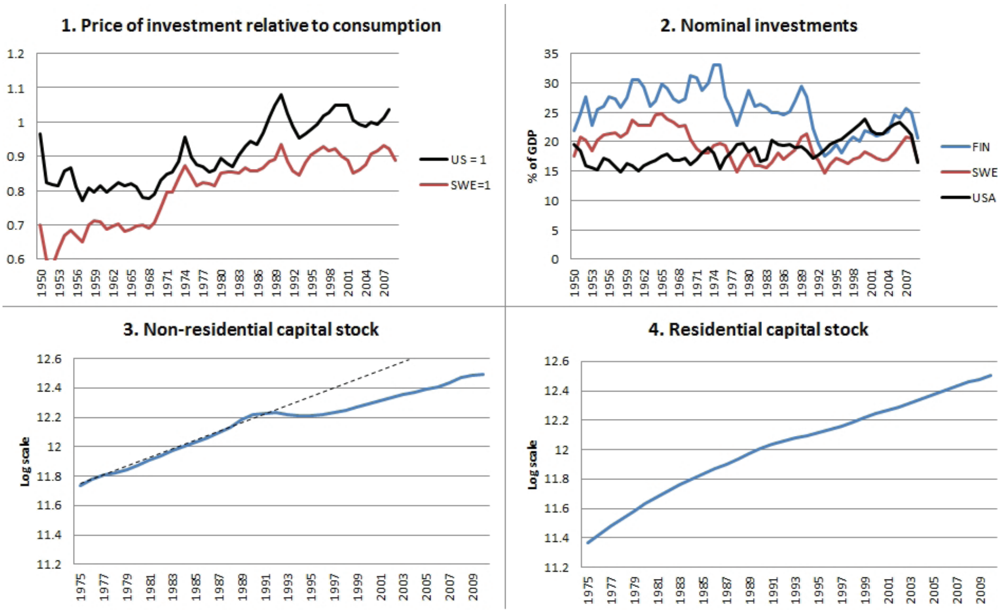
[65] Based on the calculations of Matti Pohjola.


1. Price of investment relative to consumption

2. Nominal investments

3. Non-residential capital stock

4. Residential capital stock

Figure 6: Investments

and the share of total exports in the GDP was 23 percent. After allowing for a multiplier, the 70 percent decline in this trade can account for three percentage points of the total decline of seven percent in 1991 (Honkapohja et al., 2009). At the same time, interest rates in Europe rose, reflecting the tightening of monetary policy after the German unification. Lastly, in defense of the fixed exchange rate, the Bank of Finland tightened monetary conditions in Finland significantly. As a result the interest rate increased even more and the Finnish Markka appreciated. The currency came later under a speculative attack that forced the central bank to leave the fixed currency regime and let the value of the Markka depreciate.

This paper follows Hall (2011) in considering various adverse economic conditions during a financial crisis. First, a large spread between lending and borrowing rates emerges, reflecting the agency relationship between investors and financial intermediates, as well as frictions in the banking system. Honkapohja et al. (2009), among others, show evidence that firms suffered from significant financial frictions caused by high leverage both in firms and in the financial system. The defense of the pegged exchange rate led to a period of high real interest rates that undermined the value of the assets of households and corporations, creating a process of falling asset prices.

Honkapohja et al. (2009) suggests that major signs of frictions disappear by 1997, at about the same time that the debt burden returns to a normal level. This paper calibrates the shocks to be equal to the ones used by Hall (2011) to describe the current US crisis, that is as equivalent to a two percent property and capital tax at the annual rate. The existing data on credit spreads presented in figure (7) suggests that the calibrated size is reasonable.

Second, the financial crisis generates a situation where a significant share of consumption is restricted by households' ability to borrow in the crisis period. Following Hall (2011), a household is considered credit constrained if its liquid assets (holdings in savings accounts and other liquid assets) minus the amount of outstanding consumption credit is less than two months income. Finnish consumer data suggests that in 1994 the income share of such households was roughly 20 percent of all household income. All income of the constrained households goes to consumption, which is restricted by their debt burden. Here, debt burden (s_t) is defined as interest payments and amortization minus the amount of new loans.

The figure (7) shows the total household debt burden as a share of GDP in Finland 1975–2010. It indicates that the debt burden reached 6.7 percent of GDP in 1992 and only reached a normal level in 1997. Following Hall (2011) deleveraging is assumed to restrict the consumption of constrained households.

The frictions and the debt burden are taken to follow an autoregressive process with the rate of decay set at 0.9, and to disappear in 1997.

Finally, Hall (2011) considers the overhang of consumer durables and housing as a source of falling consumption demand during the current economic crisis. While in the current crisis this may play an important role, based on the figure (6.4) it seems that the housing capital stock in Finland did not significantly exceed its long-run growth path.

Honkapohja (2009) discusses fiscal policies during the recovery period and concludes that during the Finnish economic crisis fiscal policy was not consistently designed for stabilizing aggregate demand. It is true that during the crisis the GDP share of the public sector increased dramatically. However, the expenditure increased mainly as a result of increased transfers, especially unemployment compensation. The crisis was accompanied by a large increase in the central government debt and, from the mid 1990s, the government adopted a program of fiscal consolidation reflecting the requirements for membership in the EMU. According to Honkapohja et al. (2009), government support for banks and the effect of automatic stabilizers were counteracted by cuts in government expenditures and increases in tax rates. Gorodnichenko et al. (2012), contrary to Conesa et al. (2007), find no evidence of significant tax hikes during the crisis. Based on these findings this paper abstracts from the role of fiscal policy in the crisis beyond the lifting of the tax credit discussed further in the next subsection.

2.3 Overcapacity as a Distinctive Explanation for the Crisis

This paper proposes that the permanent decline in the investment rates was largely due to the end of the investment-led growth policy. However, there are other possible explanations for the investment behavior, and this subsection compares

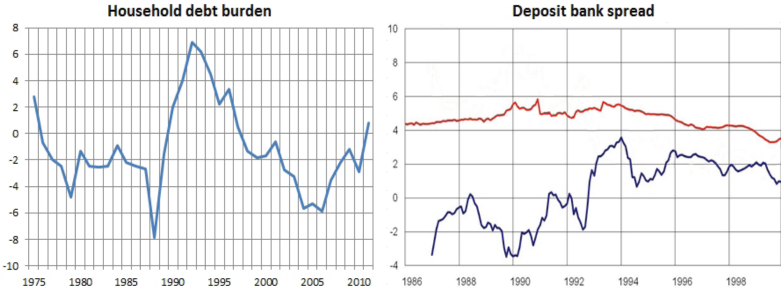


Figure 7: Debt burden as % of nom. GDP. Spreads: red = average loan rate - borrowing rate, blue = average loan rate - 12 mth Euribor

them with the current one. Gorodnichenko et al. (2012) emphasize the embodied nature of capital (physical and human) which limited the flow of resources from the Soviet sector to other sectors and thus limited new investments. In Freystätter (2011) the capital stock that was used in the production of Soviet goods became obsolete and resulted in adverse financial conditions in the economy. Technological change is yet another candidate to explain the changes in the investment behavior (Conesa et al., 2007).

There are a few reasons why the overcapacity explanation may still be warranted to understand the anatomy of the crisis. First, as the left-hand side of the figure (8) shows, the investment rate fell substantially in almost all sectors of the economy including many service industries (transportation, trade, and finance (part of the other services in the figure (8))). This fact is hard to reconcile with an external shock, in particular, because the crisis appears not to have a permanent effect on the country's ability to export. The figure (9) is a plot of the Finnish real exports versus an estimated linear trend (the dotted line) based on the observations for the years 1960 to 1989. The figure unambuously shows that the country returned to the old trend by the late 1990s. Even if business capital was lost during the crisis, as Freystätter (2011) suggests, it is hard to reconcile with the fact that investment demand never recovered. For the same reason it is unlikely that transitory financial frictions could explain permanent decline in the investment rates.

Technological change has affected greatly the relative price of investment and consumption goods during the last century. The resulting changes in production processes may have have led to the decline in the investment shares. However, this explanation is also hard to reconcile with the wide-spread and rapid transformation experienced in the Finnish economy during the late 1980s. It could be anticipated that the relative (to US) price of investment goods would fall as a result of the economic liberalization and increasing inflow of international technology in the 1980s. It is much harder to explain why technological change would have increased it. Furthermore, some of the largest changes in the investment shares were seen in the service sector which was not on the frontier of the technological change at the time of the crisis.

There are also direct facts that support this paper's view. Kari et al. (1995) reports the elimination of generous tax reserves during the crisis. [66] The reserves consisted of inventory reserves (deduction that is claimed on inventoried assets which have undergone some amount of depreciation or deterioration, or are considered obsolete in terms of the operation of the business), operational reserves (deduction that firms could make from wage income similarly to inventory reserves), and investment reserves (deductions based on current or expected investments). Almost all the reserves were removed either in 1992 (investment reserves) or 1993 (inventory and operation reserves), while sizable reductions to the system were already conducted since 1986. The timing of their complete removal (1992-1993) fits well with the timing of the collapse of the investment shares.

The reserves effectively subsidized a large production capacity in the Finnish firms. One way to see this is to relate the industry-level effective tax rates to the investment rates before and after the crisis. Prior to the tax reform tax burden varied considerably by the sectors of the economy. For example, the tax burden of capital-intensive industries was generally lower than labour-intensive industries. As the possibilities to adjust earnings were almost completely eliminated in the tax reform, the neutrality between industried increased. On the right-hand side of the figure (8) the sectorial (median) effective corporate tax rates in 1989 reported

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[66] As a result the corporate tax reform did not relaxe the effective taxation of companies despite the considerable decline in the statutory tax rate.. Indeed, it is noticeable, that the purpose of the reform was not to collect more corporate taxes, but rather make the tax system more efficient (Kari et al., 1995). Thus, the reform, initiated in 1986, was not a response to the crisis, per se.

by Kari et al. (1995, table 4.3) are compared with the changes in the investment shares. There is a positive correlation between low effective tax rate in 1989, and permanent decline in the investment share. The relation appears to be without apparent connection with the Soviet trade.

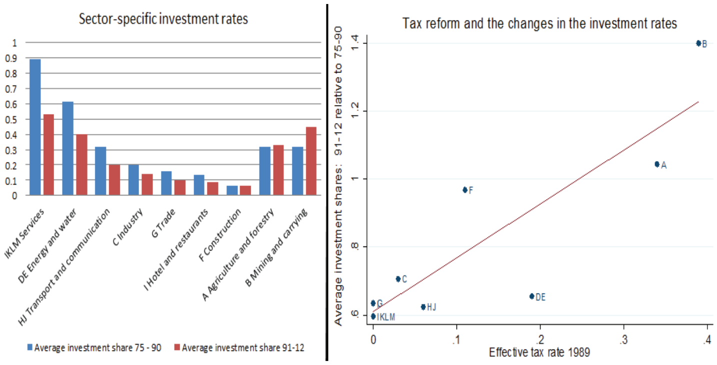

Figure 8: Investment shares in sector level

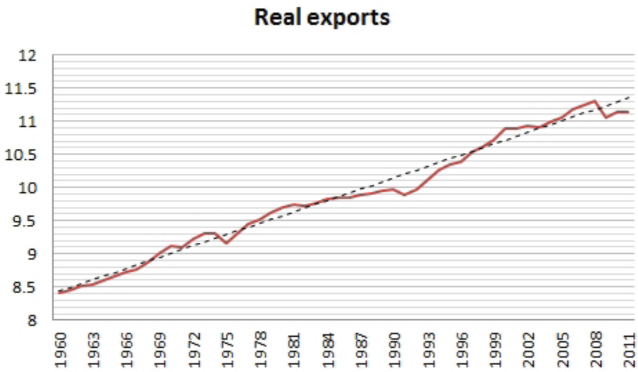

Figure 9: Persistence of the export shock

Furthermore, as a part of the the Business Tendency Survey conducted by the Confederation of Finnish Industries (EK), the Finnish firms have been asked whether they have excess capacity.[67] The left-hand side of the figure (10) shows the share of firms amongst roughly 500 firms from all manufacturing industries that reported a positive answer to the question. The share was large of firms prior to the crisis and it decreased substantially during the crisis. This suggests that there was a major change in the firms attitudes towards maintaining a large production capacity. The overcapacity problem escalated in the early 1990s when the percent of firms reporting excess capacity was as high as 90 percent, while the share fell to 20 percent during the 1990s. HP -filtered (lambda = 1600) series suggests that the new normal level was gradually reached. Finally, it should be noted that the comparison is not completely without problems, as the questioneer has slightly changed over the years[68].

This paper considers the Finnish crisis in aggregate level. A caveat of the aggregate approach is that it cannot directly address the limited flow of resources across sectors that may have considerable amplified the shock caused by the collapse of the Soviet trade, as Gorodnichenko et al. (2012) suggests. This may be a problem when the Soviet collapse explanation is compared with the overcapacity explanation. Already the changes in the investment shares suggests that the collapse of investment demand was wide-spread. The industry-level shares of the firms that reported overcapacity on the left-hand side of the figure indicates the same. In all industries the share exceeded 80 % in the early 1990s and it subsequently fell to the new low level relative uniformly.

Another sign of the limited flow of resources in the economy would be that during the crisis some firms have excess production capacity, while others would be in demand for more resources. This hypothesis can also be addressed using the survey data. In the survey the firms are asked whether they suffer from bottlenecks in production due to lack of different resources[69]. The survey suggests that lack

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[67] The referred series is BTEOLRPM:B3AP. Another source of information could be the capacity utilization series that the Finnish statistical agency regularly report as part of investment surveys. Unfortunately, the Statistics Finland currently reports capacity utilization rate only after 1995

[68] Until 1992q4 the question was: "Is there excessive capacity in our firm? yes / no". Afterwards the question was changed to "Is there too much capacity in your firm? Answer: too much / enough / too little". Prior to 1993 the share of firms answering "yes" is reported while thereafter the answer "too much" is used. Furthermore, there was a reported change in the industry classification in 1996.

[69] The referred series is BTEOLRPM:B10AP

of resources was not a particularly large problem during the crisis. For example, the share of firms reporting lack of educated labor was on average only 3.6 percent during the years 1991-1995.

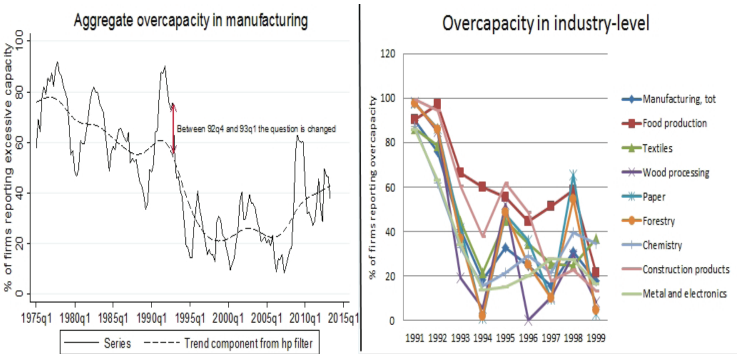


Figure 10: Reported Excess capacity in Finnish firms

Lastly, there are several ways to quantify the collapse of the investment-led growth model. First, the relative price of investments will increase if an investment tax credit is lifted. The size of the tax credit can be approximated by observing the change in the relative price of investment prior and after the crisis. The change is roughly 10 to 15 percent. Furthermore, the structural change in investment policy can be addressed by measuring the long-run level shift of the capital stock before and after the crisis. We find that the shift is roughly 20 percent. However, both measures are somewhat noisy and prone to be affected by the other explanations, changes of the export market and technology. Alternatively, it is possible to address the size of the investment tax credit based on the details of the tax reform. In the appendix the value of the reserves is measured relative to the value of investments, and it is found that the share of subsidies is roughly 15.8 percent in 1989.

2.4 The Near Exogeneity of Prices

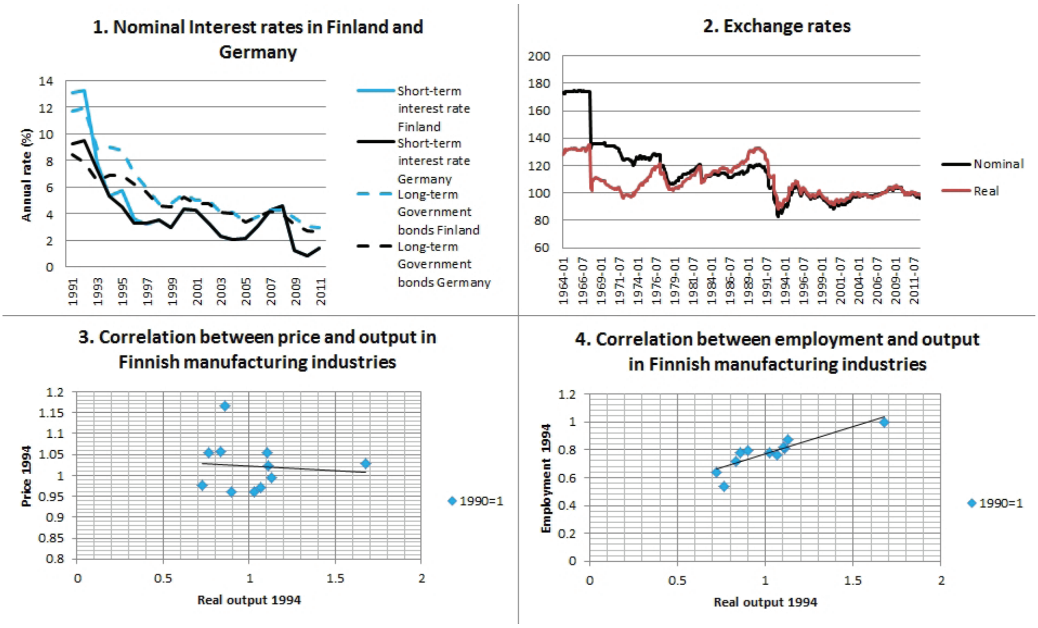
This subsection discusses the determination of prices in the Finnish economy during the recovery period. Hall (2011) shows that assuming the given, unresponsive real interest rate achieves a crucial simplification of macro modeling while providing intuition regarding the roots of economic crises . Next, evidence is presented which suggests that considering the nominal interest rate and prices of tradable goods as exogenous is a reasonable approximation after 1993.

First, from 1993 onwards the central bank implemented a two percent inflation target that it maintained until 1999, when monetary independence ended and the country joined the euro. The level was chosen because it was considered to be more or less equal to the implicit or the explicit target announced by other countries aiming at price stability. As figure (11) shows, the policy succeeded in maintaining substantially smaller fluctuations in the nominal exchange, and the nominal interest rate followed the German nominal interest rate closely during most of the recovery period.

There was limited room for the Bank of Finland to adjust the nominal exchange rate during the recovery period. According to Honkapohja and Koskela (1999) defending the value of the currency to prevent an outflow of foreign capital would have required a raise in domestic interest rates, which would have hurt the highly indebted private sector. Improving the weakened competitiveness of the export sector would have required a devalued exchange rate, which would have hurt those who had borrowed abroad. In the end, either a tightening of monetary policy or a depreciation would lead to bankruptcies and rising unemployment. The central bank also feared that the pass-through of the nominal adjustments to factor prices was strong, and thus they would only generate higher domestic inflation without improving external competitiveness (Suvanto, 2000). Nevertheless, at the onset of the crisis the Bank of Finland abandoned the fixed exchange rate, first by devaluating the currency in November 1991 and then by floating the currency in September 1992. The size of the depreciation was comparable to the Swedish depreciation at the same time.

Second, a look on the Finnish data shows that the adjustment of relative prices was weak. Figure (11.2) shows how the Finnish real exchange rate follows the nominal exchange rate tightly, despite major slackness in the economy (unemployment only peaked in 1995). While it could be argued that they might be connected because of common shocks, the volatility of the real exchange rate is connected to changes in the monetary policy regime, which is a sign of real price rigidity.

Furthermore, the Finnish industry level data suggests that industries did not respond to changing demand by adjusting prices. Rather, the firms adjusted their production by controlling capacity. Figure (11.3) reports a missing correlation between output change and price change in the Finnish manufacturing industries 1990–1994[70]. Figure (11.4) shows how there is a strong negative relationship between output changes and changes in the number of employed workers in Finnish manufacturing industries.


1. Nominal Interest rates in Finland and Germany

2. Exchange rates

3. Correlation between price and output in Finnish manufacturing industries

4. Correlation between employment and output in Finnish manufacturing industries

Figure 11: Price Rigidity

3 A Quantitative Model of the Finnish Crisis

This section introduces a general equilibrium model used in the quantitative exercise. In many key features the model corresponds with the Hall (2011) model . In

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[70] Data for major manufacturing industries from EU KLEMS, 2009 edition. Hall (2011) makes a similar finding for US industries during the current economic crisis.

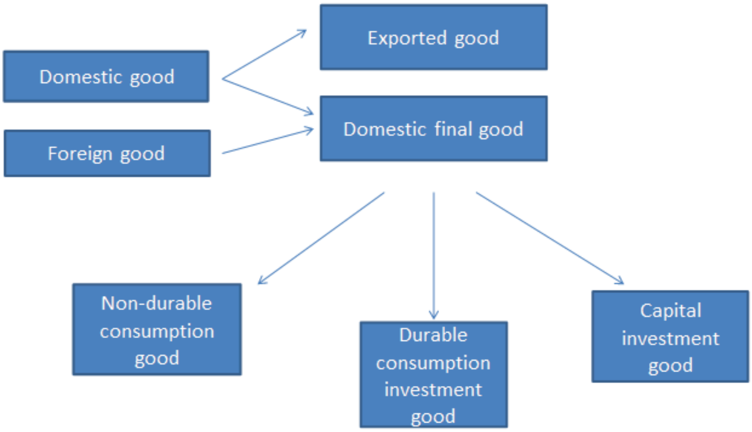

Figure 12: Model structure

particular, it illustrates how slackness may emerge, when the real interest rate is above its market clearing level. In contrast to a standard Walrasian model, prices do not settle the market, but rather the utilization rate of capital adjusts supply to meet the lowered demand. The main difference between the current model and Hall's (2011) is that in the current model a small open economy is considered.

Figure (12) outlines the model structure[71]. A representative firm operating in competitive markets produces a domestic good that is either exported or combined together with a foreign good into a domestic final good according to a CES aggregator. The domestic final good can be used as a non-durable consumption good, capital investment good, or durable consumption investment good. Final goods are fully substitutable and investment goods are transformed by capital producers into capital in the period following their creation.

In the model there are two types of households. A credit unconstrained household can invest in the capital goods or acquire bonds denominated in domestic or foreign currency. A constrained household does not have access to the financial markets. Both households provide labor and maximize intratemporal utility.

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[71] A more detailed figure is found in the appendix.

3.1 International Trade

Domestic and foreign goods are combined into domestic final good which is consumed or invested. The final good is a CES aggregate of domestic and foreign good, its price being

$$p_t = (p_{y,t}^{-\theta} + p_{w,t}^{-\theta})^{-\frac{1}{\theta}}$$

where θ is the elasticity of domestic and foreign goods in the production of the final good, p_y and p_w are domestic prices of the domestic and the foreign good, respectively. The cost share of the domestic good in the final product is also a function of relative prices.

$$\pi_t = \frac{p_y^{-\theta}}{p_w^{-\theta} + p_y^{-\theta}}$$

The size of the economy in the initial steady state is pinned down with an additional condition that governs the volume of the export market as a function of domestic and foreign prices:

$$ex_t = f(p_{y,t}, p_{w,t}).$$

Furthermore, trade is balanced[72].and the purchasing power parity (PPP) condition holds:

$$p_{y,t}^* = \xi \frac{p_{y,t}}{\epsilon_t} \tag{33}$$

where p_y^* is the price of the domestic good abroad, ξ is the cost of transportation and ϵ_t is the nominal exchange rate. The price p_y^* is given in the international commodity market.

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[72] The export condition is relaxed during the simulated transition, as prices are fixed and thus one less equation is needed to identify the equilibrium path. During the transition the balanced trade condition governs exports.

3.2 Households

To model household behavior during the crisis, two types of households, constrained and unconstrained, are assumed. The unconstrained household engage in saving and consumes according to the optimal consumption path. It can invest in domestic and foreign bonds as well as in the two types of capital. International financial markets are assumed to be incomplete. The foreign bond is denominated in terms of tradable goods in foreign markets with the gross nominal rate of return $(1+r_t^{n,*})$ and the domestic bond in terms of the tradable good in the domestic market yielding the nominal return $(1+r_t^n)$.

The constrained household is restricted from the financial markets and consumes all its income after payments for outstanding loans while maximizing utility with respect to the allocation of its intratemporal consumption.

A tilde $\widetilde{()}$ denotes unconstrained and a bar $\overline{()}$ constrained consumption. Consumption is a Cobb-Douglas composite of non-durable consumption, $c_{y,t}$, and the services of durables, d_{t-1}, constructed at the end of period t-1:

$$\overline{c}_t = \overline{c}_{y,t}^{\phi}\overline{d}_{t-1}^{1-\phi},$$

and consumption is calculated similarly for unconstrained households. The price of composite consumption is

$$p_{c,t} = \phi^{-\phi}(1-\phi)^{-(1-\phi)}p_t^{\phi}p_{d,t}^{1-\phi},$$

a combination of the price of nondurable goods (imported and domestic) and the rental cost of durables, $p_{d,t}$.The constrained household's demand for the nondurable goods component of consumption satisfies

$$p_t\overline{c}_{y,t} = \phi p_{c,t}\overline{c}_t$$

and demand is calculated similarly for the unconstrained household. Combining the two yields the total nondurable consumption as

$$p_t c_{y,t} = \phi p_{c,t}(\widetilde{c}_t + \overline{c}_t)$$

while total consumption of durable services is

$$p_{d,t}d_{t-1} = (1-\phi)p_{c,t}(\widetilde{c}_t + \bar{c}_t).$$

The unconstrained households choose their paths of composite consumption according to the intertemporal utility function

$$\sum_{t=0}^{\infty}\beta^t \frac{\widetilde{c}_t^{\,1-1/\sigma}}{1-1/\sigma},$$

where σ is the intertemporal elasticity of substitution.[73] The unconstrained household price assets with returns measured in units of output by the discounter

$$\mu_t = \beta \frac{p_{c,t}}{p_{c,t+1}} \left(\frac{\tilde{c}_{t+1}}{\tilde{c}_t}\right)^{-\frac{1}{\sigma}}$$

In the optimum the consumption growth results in a discounter that discounts the market real interest rate to one:

$$1 + r_t^n = (1 + r_t^{n,*})\frac{\epsilon_{t+1}}{\epsilon_t} = \frac{1}{\mu_t}.$$

Furthermore, a zero arbitrage condition holds for the return on investment in durable and capital goods:

$$\begin{aligned} (1 + r_{t-1}^n)(1 + f_{d,t}) &= \frac{p_{d,t} + (1-\delta_k)q_{d,t}}{q_{d,t-1}}. \\ (1 + r_{t-1}^n)(1 + f_{k,t}) &= \frac{p_{k,t+1} + (1-\delta_k)q_{d,t}}{q_{d,t-1}} \end{aligned}$$

where q_t is the price of a newly installed good at the end of period t. For one unit of output the household can buy $\frac{1}{q_{t-1}}$ units of the investment good in the end of the period t-1. Its value in t consists of the rental price in t and the amount at which the good sells at t. In equilibrium, carrying one unit over time must yield the required return on investment, which is due to the financial frictions (f), higher

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[73] The static optimality conditions arises from standard utility maximization problem and are omitted here. The dynamic optimality conditions are derived in the Appendix.

than the gross nominal interest rate.

Constrained households' consumption is proportional to the size of the economy and depends on the financial constraint:

$$p_{c,t}\bar{c}_t = p_{y,t}(\omega y_t - s_t y_t)$$

where ω is the fraction of constrained households in total income and s_t is the burden of interest and debt payments of constrained households as a fraction of output.

Finally, the investment tax credit is financed with a lump-sum tax credit that is levied on the unconstrained households.[74]

3.3 Interest Rates and Prices

Consumer optimization suggests that the interest rate parity condition holds for the nominal interest rates:

$$1 + r_t^n = (1 + r_t^{n,*})\frac{\epsilon_{t+1}}{\epsilon_t},$$

where $1 + r_t^n$ and $1 + r_t^{n,*}$ are the domestic and foreign gross nominal interest rates, respectively. Domestic monetary policy is restricted to maintain a similar rate of inflation with other countries implying $\epsilon_t = \epsilon$ and thus $r_t^n = r_t^{n,*}$ consistently with the observed convergence of nominal interest rates with Germany. Furthermore, the international real interest rate, r_t is defined as the own rate of tradable goods in the foreign market which equals the domestic real interest rate (the own rate of domestic output in the domestic market) under the specified monetary policy:

$$1 + r_t^* \equiv (1 + r_t^{n,*})\frac{p_{y,t}^*}{p_{y,t+1}^*} = (1 + r_t^n)\frac{p_{y,t}}{p_{y,t+1}} \equiv 1 + r_t \qquad (34)$$

The model abstracts from further analysis of money and the prices are determined in relative terms. The nominal interest rate is set to 0 in which case $1 + r_t = \frac{p_{y,t}^*}{p_{y,t+1}^*} = \frac{p_{f,t}}{p_{f,t+1}} = 1 + r_t^*$.

---

[74] Notice that this assumption is equalent to a corporate tax levied on corporate profits (the production subsection), because in the model the corporate tax do not change the production decisions of the firm.

In the model prices are exogenous and their change corresponds with the rate of foreign inflation. In principle, economic slowdown could be expected to lower the rate of domestic inflation which generates the need to decrease the domestic nominal interest rate to maintain the targeted rate of inflation. However, sticky prices mean that the monetary policy does not generate such stimulation.[75]

3.4 Production

The domestic good is produced by a representative firm that chooses inputs to maximize its flow of profits:

$$\max_{n,k} p_{y,t} y(x_t k_{t-1}, n_t) - w_t n_t - p_{k,t} k_{t-1}$$

where y denotes the production function, x_t is the capital utilization rate, w_t is the per worker wage, n_t is the number of workers, $p_{k,t}$ is the rental cost of capital, and k_{t-1} is the available capital constructed at the end of period t-1. While the firm can adjust its current utilization of capital, it expects to fully utilize newly acquired capital, that is $\frac{\partial}{\partial k_t} y_{t+1} = \frac{\partial}{\partial (x_t k_t)} y_{t+1}$. The first order conditions with respect to k_t and n_t are the usual:

$$\begin{aligned} w_t &= p_{y,t} \frac{\partial}{\partial n_t} y_t, \\ p_{k,t} &= p_{y,t} \frac{\partial}{\partial k_{t-1}} y_t \end{aligned}$$

[76]

---

[75] A choice is made here to remain agnostic over the exact source of price exogeneity. Instead of considering exogenous prices, wages could as well be considered fixed in which case prices would be solved from the model. At face value there is evidence of both forms of rigidity. However, the model simulations presented later on suggest that both price measures are consistent with their observed patterns, when prices are fixed. Thus, fixing wages would not change the results.

[76] Notice that regardless of the level of the corporate tax rate ($\tau_{corp} < 1$), the same first order conditions would arise if the firm maximizes profits $\max_{n_t}(1 - \tau_{corp}) (p_{y,t} y(x_t k_{t-1}, n_t) - w_t n_t)$ under the assumptions of perfect competition and full input exhaustion. That is, it does not matter whether the tax credit is financed with lump-sum consumption tax, or levied on corporations.

Throughout the exercise Cobb-Douglas production function is assumed: $y_t = An_t^{\alpha}(x_t k_{t-1})^{1-\alpha}$, where α is the nominal cost share of labor in production and A is MFP. Then,

$$\begin{aligned} w_t &= p_{y,t} A\alpha(\frac{x_t k_{t-1}}{n_t})^{1-\alpha} \\ p_{k,t} &= p_{y,t} A(1-\alpha)(\frac{x_t k_{t-1}}{n_t})^{-\alpha} \end{aligned}$$

3.5 Capital and Durable Good Producers

Capital and durable goods are produced by combining old capital and investment goods to produce new capital. The task of capital producers in the model is to help firms to use capital efficiently and to maintain the durable stock. They operate competitively and use domestic resources to adjust the size of the capital stock and the need for resources increases with the size of adjustment.

The aggregate capital stock evolves according to

$$\begin{aligned} k_t &= i_{k,t} + (1-\delta_k)k_{t-1} \\ d_t &= i_{d,t} + (1-\delta_d)d_{t-1} \end{aligned}$$

The producers optimization problem is to maximize profits, subject to a quadratic adjustment cost:

$$\begin{aligned} &\max_{i_{k,t}} q_{k,t} i_{k,t} - (1-\tau)p_t i_{k,t} - p_{y,t}\frac{\chi_k}{2}\frac{(k_t - k_{t-1})^2}{k_{t-1}} \\ &\max_{i_{d,t}} q_{d,t} i_{d,t} - p_t i_{d,t} - p_{y,t}\frac{\chi_d}{2}\frac{(d_t - d_{t-1})^2}{d_{t-1}}, \end{aligned}$$

where τ is the investment tax credit. Under zero profits the maximization problems yield the following first order condition for $i_{k,t}$ and $i_{d,t}$:

$$
\begin{aligned}
q_{k,t} &= p_t(1-\tau) + p_{y,t}\chi_k \frac{(k_t - k_{t-1})}{k_{t-1}} \\
q_{d,t} &= p_t + p_{y,t}\chi_d \frac{(d_t - d_{t-1})}{d_{t-1}}
\end{aligned}
$$

where q_k (q_d) is Tobin's q, i.e., the shadow price of installed capital (durable good).

3.6 Employment

Employment is modeled with a reduced form search model following Hall (2009, 2011). In the original RBC model (Kydland and Prescott, 1982) implausibly high Frisch wage elasticity is required during recessions to equalize the marginal rate of substitution between consumption and time spent working. To overcome this problem, in the standard Diamond-Mortensen-Pissarides model the condition arises from unemployment rather than from the hours of work of those employed; but recently Shimer (2010) shows that the standard model still fails to generate enough labor fluctuation.

Hall (2009) replaces Mortensen and Pissarides's Nash wage bargaining by a generalization that allows the share of employment surplus captured by employers to decline in recessions, resulting in less recruitment effort and higher unemployment.

All workers desire to work a standard number of hours. The only source of variation in aggregate hours arises from unemployment. Employers post vacancies to fill jobs. The probability of finding a worker to fill the vacancy is q. Filling the job becomes harder when the job market is tight, i.e. the vacancy/unemployment ratio, θ, is high. With the job-finding rate: $\phi(\theta)$ (increasing and concave function of θ), vacancy-filling rate: $\frac{\phi(\theta)}{\theta}$ and the exogenous job destruction rate s, the equilibrium employment rate is

$$
1 - \frac{(\overline{n} - n)}{\overline{n}} = \frac{\phi(\theta)}{s + \phi(\theta)}^{77} \tag{35}
$$

---

[77] In the equilibrium the number of filled vacancies equals the number of destroyed jobs: $(\overline{n} - n)\phi = sn \Leftrightarrow \frac{(\overline{n}-n)}{\overline{n}} = \frac{s}{s+\phi} \Leftrightarrow 1 - \frac{(\overline{n}-n)}{\overline{n}} = \frac{\phi}{s+\phi}$.

In the equilibrium θ is (by inverting the equation 35) a function of n. Therefore, the equilibrium job-filling probability

$$q(n) = \frac{\phi(\theta(n))}{\theta(n)}$$

is also a function of n. In particular, it is assumed that higher employment leads into lower job-filling probability.

Employers pay workers wage w_t. However, without loss of generality, the wage paid to the worker can be decomposed into two parts, corresponding to a two-part pricing contract . The worker pays a present value J_t back to the employer for the privilege of holding the job. The payment is the difference between the net benefit of having the worker and the worker's actual compensation. In equilibrium, the expected payoff exactly offsets a constant recruitment cost, γ, which the firm has to pay:

$$q(n_t)J_t = \gamma \tag{36}$$

This is the employment function, which defines employment as a function of labor market tightness and the payment. In what follows, the payment is assumed to be an increasing function of slack in the economy:

$$J_t = J(x_t)$$

and a relationship between employment and x_t now follows from the equation (36). Following Hall (2011) the relationship is taken as constant-elastic:

$$n_t = \overline{n}x^{\psi}, \tag{37}$$

Empirical evidence is based on US data (see figure (13)) that suggests that unemployment closely follows capacity utilization rate. Similarly to Hall (2011) ψ is set to 1.When this is the case, the real wage is unresponsive to sudden changes in the utilization rate of capital as the effective capital labor ratio remains constant at $\frac{x_t k_t}{n_t} = \frac{k_t}{\overline{n}}$, where k_t is predetermined.

While the equation (37) that describes the equilibrium outcome in the labour market is the same as in Hall (2011), the interpretation is slightly different. Hall (2009, 2011) suggests that unemployment should be a monotonic function of the

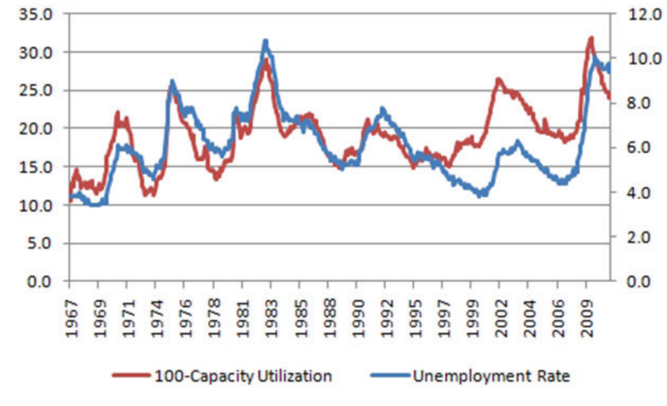

Figure 13: Capacity utilization rate and employment in US data

marginal revenue product of labor. He argues that the actual compensation to worker, $m_t - J_t$ (where m_t is the marginal revenue product of labour to the worker), does not respond to changes in m_t, thus leaving the payoff J_t to be highly responsive to cyclical movements in m_t. Procyclical changes in the marginal product leads into procyclical movement in the firms' recruitment efforts and thus to procyclical employment. The Finnish labour market was rigid during the time period and thus the mechanism seems reasonable (Gorodnichenko et al., 2012).

This paper links unemployment directly to slackness, x_t; the assumption is made that unemployment returns to a normal level when the slack disappears. In the exercise this is important, as lifting of investment tax credit is associated with a permanent fall in real wages (compared to the trend). Eventually full employment (full capital utilization) is reached in the model, while the transition may include a long period of unemployment (a low utilization rate of capital), because of the capital adjustment costs.

Finally, it should be noted that employment in the late 1980s may have been above the equilibrium level and thus employment may have decreased permanently during the crisis. While the focus of this paper is mainly on modeling the fall in labor demand, the supply side reason for the rising unemployment is also shortly analyzed.

3.7 General equilibrium

In general equilibrium the household consumes according to the optimal consumption path, and firms produce and invest to meet the profitability requirement. The economy is subjected to two constraints governing the aggregate use of resources and international trade. First, trade is balanced

$$ex_t = p_t * (1 - \pi_t) * (i_{k,t} + i_{d,t} + c_{y,t})$$

where ex_t denotes the value of exports and the left hand side collects all sources of imports. It is noticeable, that the balanced trade condition does not take into account trade surplus that emerged after the crisis. The next section discusses the issue further.

The aggregate resource constraint is

$$y_t = \frac{p_t \pi_t (i_{k,t} + i_{d,t} + c_{y,t}) + ex_t}{p_{y,t}} + \frac{\kappa_k}{2} \frac{(k_t - k_{t-1})^2}{k_t} + \frac{\kappa_d}{2} \frac{(d_t - d_{t-1})^2}{d_t} + v \frac{\gamma}{q(n_t)} n_t.$$

In the first term the domestic cost share of the final goods used in Finland and the cost of exports divided by the unit cost of the domestic good equals the required resources for these uses. The last three terms are the domestic resources that are required for adjustments of capital and durables, and recruitment, respectively.[78]

All equations required to solve the dynamic model are collected in the Appendix and the dynamics are further illustrated in a diagram.

4 Data and Calibration

Similarly to Gorodnichenko et al. (2012), this paper studies macroeconomic variables after filtering out the long-run trends from the data. The behavior of the model is compared with the detrended variables. For real investment, real consumption, and real GDP (Penn World Tables) a common trend is imposed. The trend growth rate is allowed to gradually fall in order to capture the apparent fall in

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[78] Notice that the tax type financial frictions as well as the investment tax credit have purely distributional effects in the model and thus do not appear in the aggregate resource constraint.

the long-term growth rate resulting from structural change towards post-industrial economy.

The common growth rate is estimated with the following model

$$\Delta \log(var) = \beta_{cons} + \beta_{year} year_t + Dummy_{1985-2000} + \varepsilon_t$$

where β_{cons} and β_{year} are constant and common to the three variables, while the dummy variable for the crisis period (1985-2000) is included in order to capture the potential variable-specific level shifts during the crisis. The trend is obtained by adding the series average to detrended cumulative growth without the estimated crisis effect. Seemingly unrelated regression in STATA was used.

For the non-residential investment series (Statistics Finland) the common estimated trend (β_{cons} and β_{year}) was imposed, while using the same approach in finding the effect of the crisis was otherwise used. The labor input series is the total hours engaged in the EU-KLEMS 2009 revision and the trendline is the average between 1970-1989. The real export series is from the World Bank and the trendline is the linear log trend over the years 1960 and 2010. A list of data sources is found in the Appendix.

Calibration of the model is mostly based on earlier literature while elements which can be calibrated based on the Finnish data are taken to match the data during the crisis period.

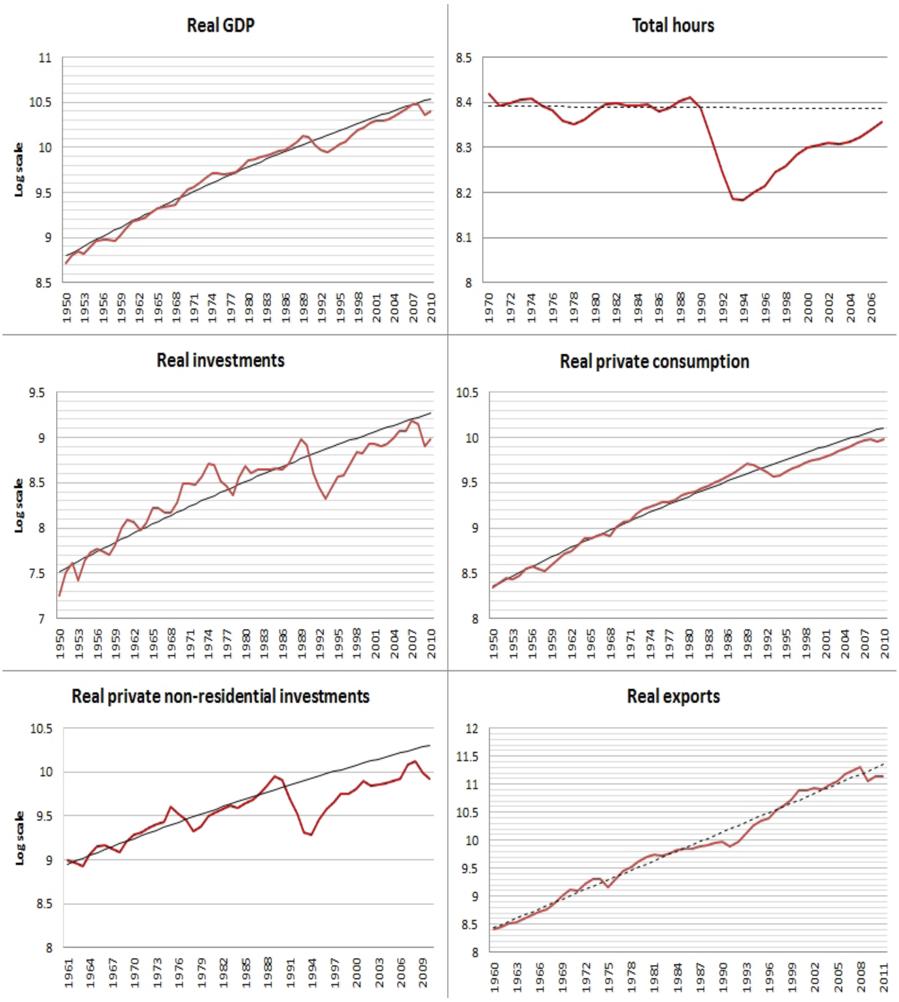

Figure 14: Fluctuations and long-run growth

Parameter	Description	Value	Source
α	Nominal labor share in production	0.649	National Accounts 90-00
κ_k	Capital adjustment cost	8	Hall (2011)
κ_d	Durables adjustment cost	8	Hall (2011)
δ_k	Capital depreciation rate	0.0188	Hall (2011)
δ_d	Durables depreciation rate	0.0129	Hall (2011)
ϕ	Nondurables consumption share	0.65	National Accounts 90-00
β	Utility discount factor	0.99	Gorodnichenko et al. (2012)
σ	Intertemporal elasticity of substitution	0.5	Gorodnichenko et al. (2012)
ω	Fraction of constrained consumption	0.2	National Accounts 90-00
$\overline{n}$	Normal employment rate		Based on 1975-1989 trend
ψ	Elasticity of employment function	1	
γ/q	Job-filling cost	0.14 of quarterly wage	Hall (2011)
υ	Separation rate	0.12	Hall (2011)
θ	Elasticity of foreign demand	8.3	Eaton and Kortum (2002)

5 Benchmark Scenarios

In the benchmark scenarios the simulation is initiated from a steady state in period 0, which corresponds to 1993q4 in the data. The latter date is chosen as it validates the use of model a, where the central bank is committed to the inflation target while recovery was just beginning. At the end of period 0 several adverse economic forces hit the economy, and the economy starts to recover from period 1 onwards. Deviations from period 0 levels in the endogenous variables are compared with the deviations of the actual economy from the long-run growth paths.

Transition dynamics are solved using the non-linear deterministic simulation algorithm in Matlab/Dynare. Errors in the model equations are smaller than the default accuracy requirements of the simulation algorithm. While the theoretical problem has an infinite horizon, in practice Dynare requires a terminal date when the numerical solution algorithm assumes that the steady state is reached. In the benchmark simulations the simulation interval is 902 quarters. To check the robustness of the results, the simulation is repeated with 1902 quarters. The maximum difference in the simulated variables with different horizons is (1.1×10^{-9}). Thus, the choice of the horizon seems not to affect the results[79].

In the initial steady state the government is committed to an investment tax credit, which is lifted at the end of period 0. To quantify the size of the credit, figure (6.3) is used. It suggests that capital stock in the year 1993 was still over 10 percent above the growth path in the late 1990s and 2000s.[80] Thus the size of the tax credit is chosen so that the artificial economy generates a fall in the capital stock of the same magnitude . The size of the tax credit is calibrated to be 7.5 percent, which incidentally is relatively close to the rise in the relative price in figure (6.4). The credit is financed with a lump-sum consumption tax. Finally, in the initial steady state, 20 percent of GDP is consumed by households that do

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[79] The numerical method also requires to insert a final steady state for the algorithm. It is solved similarly to the initial steady state without the tax-credit. However, the final steady state should be considered as an initial guess for the true final state that is dependent on the transition dynamics. In practice, the difference in the simulated variables between the initial guess and the true state is found to be few percentages. However, the similarity of results with different horizons suggests that the choice of the initial guess does not affect the results.

[80] This suggests that the overcapacity problem still existed. An alternative simulation where the initial state is 1991 is considered in the next section.

not have access to the credit market later in the crisis. Numerical values for the initial steady state are reported in the Appendix.

Naturally the question arises; how much the transition is governed by the assumptions of the model. The first potential problem is that the parameters of international trade are taken to reflect the year 1995 in all periods of the simulation. This means that the relative price of the Finnish goods and the international market already include the effect of devaluation and the fall of Soviet trade. Honkapohja et. al (2009) argue that the fall of Soviet trade reduced the size of the economy by roughly -2.5 percent. Thus the choice of the benchmark year underestimates the size of the initial economy by 2.5 percent. On the other hand, trade is balanced in the model, whereas in reality the country's current account turned positive soon after the fixed exchange rate regime was abandoned. Due to the omission of a positive current account the model is likely to underestimate the size of the economy after the shocks. [81]

As the overcapacity problem is calibrated based on the observed transition path of the capital stock, this should not be a major problem. The observed transformation would have been larger without the positive current account in the late 1990s, while it would have been smaller if the Soviet Union had not collapsed. Focusing on the observed path controls these features in terms of aggregate demand , while this paper makes no attempt to match the actual pattern of the current account.

When the investment tax credit is lifted in period 1, a transition from the initial steady state towards a final steady state without the tax credit begins. The financial crisis provides another negative force in the economy. The constrained households face debt service commitments of 6.7 percent of GDP from period 1 onwards that declines by 10 percent per quarter and is removed in 1997. There is a financial friction equivalent to a property tax on both types of capital of 2 percent per year that declines at the same rate as the debt service commitment. Unlike in Hall's work (2011), excess housing capital is not considered. Finally, the real interest rate is fixed which captures the fixed inflation target of the monetary

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[81] Discussing the current account requires that a stand is taken on the question of technological change , because a major contributor to the export performance was the Nokia-led information technology cluster. A priori it is not clear how this export-specific technological change affected the unemployment problem in the model and considering its role is left for future research.

policy. In practice, in the simulations the real interest rate stays at the steady state level, $\frac{1}{\beta}$.

5.1 Results

Figure (15) shows the simulated paths of key endogenous variables in the simulation where only the lift of the investment-tax credit (Overcapacity) is considered and the simulation where the financial conditions are also included (Frictions & overcapacity). The simulated variables in the latter simulation seem to capture fairly well economic contraction during the crisis. Overcapacity helps the model to capture both the depth and the persistence of the slump in terms of GDP, employment, and investments. It contributes approximately 10 percentage points of the total contraction in GDP and employment. As expected, the model does best in explaining the behavior of investments and captures the deep and persistent fall in investment activity. The difference between the simulation outcomes reflects the effect of financial frictions. The effect on GDP and employment disappears by 1998. The fall in consumption is mainly due to financial frictions and the model fails to generate enough persistence in its contraction.

Further details of the simulation with frictions and overcapacity are presented in the Appendix. Let us first consider prices. The results show a marked drop in the price of consumption during the crisis, which is solely due to a fall in the rental cost of durables. The rental cost drops almost 12 percent from the initial steady state level. Wages fall gradually. The rate, 3 percent in seven years, is roughly in line with the trend reported in Gorodnichenko et al. (2012) for real wages. After the investment tax credit is removed, the rental cost of capital as well as Tobin's q for capital start to gradually increase towards the new steady state levels.

Let us then consider quantities. After the initial fall in the price of consumption, the prices start to recover. This induces a fall in the consumption-based real interest rate due to the expected rise in CPI that generates a positive shock to the consumption of unconstrained households despite the financial frictions on durable consumption. However, this increase is too small to overcome the negative impacts of financial shocks to the consumption of credit constrained households[82].

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[82] It is noticeable that a simulation with only overcapacity was made and it shows that it alone

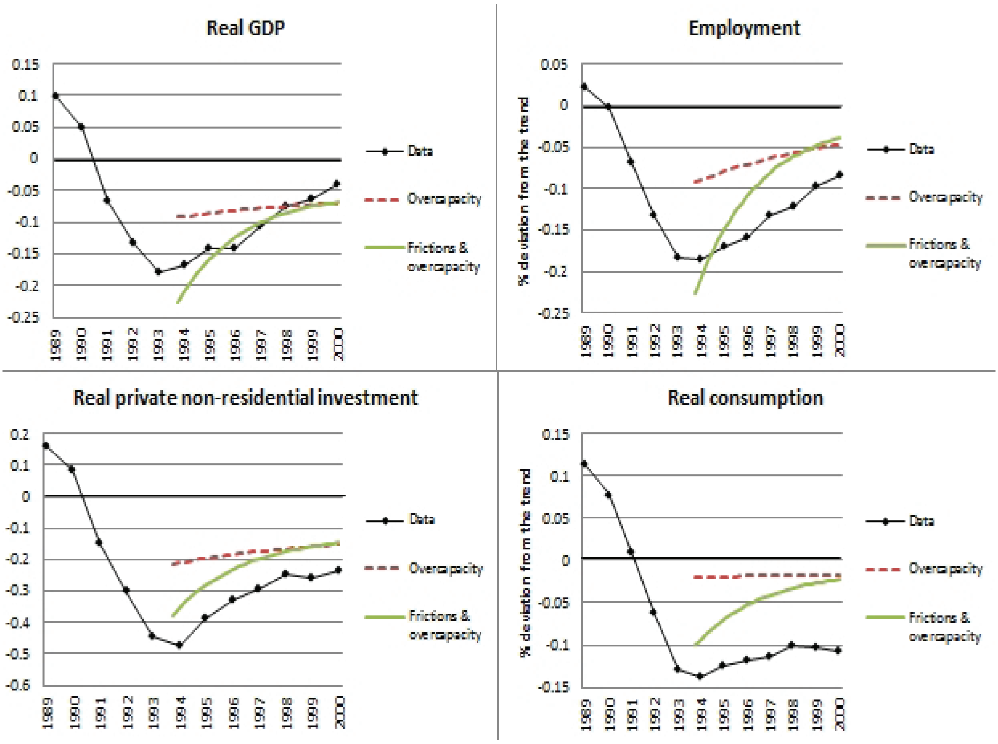

Figure 15: Benchmark outcomes

Having said that, the model has little means to replicate the persistence in the fall of consumption.

Finally, as a result of the calibration the model generates a roughly 10 percent fall in the capital stock in the long run.

5.2 Revisiting Other Explanations for the Finnish Crisis

Gorodnichenko et al. (2012) provide an interesting framework for understanding the implications of major trade shocks. By resorting to a multisector model they show how wage rigidity, together with the introduction of the service sector, provide a sizable fall in output following the permanent loss of a trading partner (the Soviet Union).

As one of the arguments for the validity of their explanation, Gorodnichenko et al. (2012) compare the depth of the crises in Sweden and Finland. In Sweden the crisis was not as severe as in Finland although the financial conditions in both countries were quite similar. As Sweden was not exposed to trade with Soviet Union, it is reasonable to believe that the depth of the Finnish crisis was contributed to by the fall of the Soviet Union. However, this paper suggests that overcapacity may explain the difference. While Sweden resorted to a very similar investment-led growth policy after the World War II, the country had already abandoned the policy by the late 1970s. According to Gorodnichenko et al. (2012) the fall below trend in the Finnish value added was 21 percent, while it was eight percent in Sweden, whereas in this paper overcapacity provides a roughly 10 percent larger contraction.

In an earlier work, Conesa et al. (2007) study the crisis with an RBC model and finds that a MFP shock was the main driving force for the crisis. However, with a standard RBC model it is hard to explain its behavior. With their methodology the lowered utilization rate of capital is accounted for as an MFP shock. While they find that, at its lowest point, MFP was roughly eight percent below the trend, in this paper the percentual deviation is

$$MFP_{\min} = 1 - \min(x_t^{1-\alpha})$$

---

has relatively small effect on consumption.

In the scenario with overcapacity and frictions this number is 8.6 percent.

6 Alternative Specifications

Any attempt to capture an event as complex as the Finnish Great Depression with a simplified economic model raises the question; what has been left out and what could have been modeled differently? This section discusses several issues.

6.1 Overcapacity and Flexible Prices

In the benchmark simulations prices are fixed. The following example illustrates how the overcapacity problem can be resolved while maintaining full employment when the domestic prices (and thus the real interest rate) are flexible. It also gives an impression of the magnitude of the corrective measure required to deal with the problem.

The model is solved by fixing full employment and taking domestic price as an endogenous variable. In the simulation (figure 16) the real exchange rate falls by almost 11 percent and then very gradually recovers. It is enough to induce more demand through several channels. The expected inflation increases the willingness of the unconstrained household to consume. The required return on investment is lower, which allows the investment to not fall as dramatically as in the baseline scenario. Finally, the domestic share of final goods also increases due to the improved competitiveness of domestic products. It is also noticeable that the capital stock also declines in this scenario, almost as much as in the benchmark scenarios.

Soon after the fixed exchange rate regime was abandoned, a corrective movement in the real exchange rate was indeed experienced. However, while it helped to solve the problem to some extent, the observed adjustment of the capital stock is a clear indication that it was not enough. The analysis above, combined with the comparison between Sweden and Finland, suggest that the depreciation should have been very large. Given that only the Finnish economy suffered from the overcapacity problem and financial crises in Finland and Sweden were fairly similar, the Finnish real exchange rate should have depreciated over 10 percent more than the

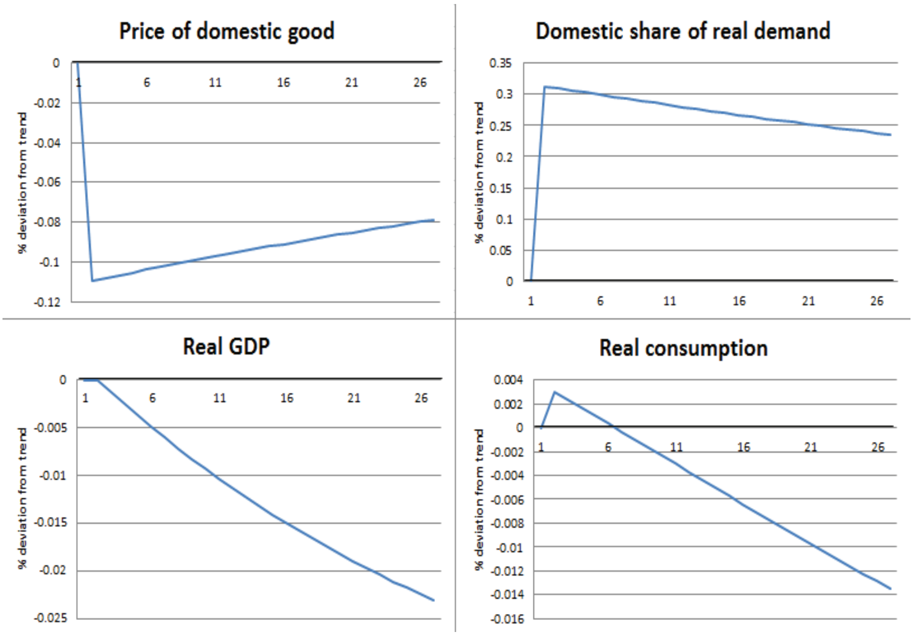

Figure 16: Flexible price

Swedish real exchange rate to resolve the problem. However, the depreciation of the Swedish Krona remained stronger than the Finnish Markka in the mid-1990s.

6.2 Labor Supply

The second issue concerns modeling of the labor market. The used model gives a demand side explanation for the unemployment problem. Yet, it has been argued that in the late 1980s employment was over its equilibrium level and structural problems relating to long-term unemployment in the late 1990s were demand driven (Honkapohja and Koskela, 1999). Using standard Greenwood, Hercowitz, and Huffman (1988) preferences, it is shown next that the demand side explanation can add persistence to the unemployment problem when overcapacity exists. In particular, the felicity function is now

$$\frac{1}{1-\sigma}(c_t - \frac{\chi}{1+\eta} n_t^{1+\eta})^{1-\sigma}$$

The model dynamics are solved while assuming that all consumers are unconstrained in order to avoid issues concerning corner solutions of utility maximization problem. The reduced form labor elasticity equation ($n = x\bar{n}$) is replaced with the first order condition

$$\chi n^{\eta} = \frac{w}{p_c}$$

that equates the ratio of marginal consumption and marginal disutility from labor with the relative price of work and consumption. Following Gorodnichenko et al. (2012), the inverse of the Frisch elasticity η is 1 , while χ is calibrated so that in the steady state the labor supply equals the full supply in the benchmark case. Wages are taken to be an exogenous state variable and decline two percentage points per quarter from the original steady state towards the new steady state.

The results suggest that, under wage rigidity, a sharp increase in unemployment is crucially dependent on the choice of labor model. In a model with the new features wages are still declining and the price of consumption is increasing but only at a very gradual pace so that the compensation for work, and thus labor supply, decreases at a very low rate. Even if the tax credit is lifted, a high real wage continue to motivate work and therefore the supply based explanation for unemployment is not a good starting point for understanding the unemployment. In contrast, in the benchmark model the capital utilization rate governs the rate of unemployment and overcapacity leads into a rapid fall in unemployment. The same is true when wages are allowed to vary in the GHH specification. In this case wages respond to the fall in the utilization rate of capital while the price of consumption remains almost constant. As the disutility of labor stays the same while the payoff of work falls, the supply of labor now falls. However, a rapid adjustment of wages was not observed during the crisis.

6.3 The Timing of the Overcapacity Problem

Until now the overcapacity problem is studied with the assumption that the simulation starts from the beginning of 1994. The latter year is preferred as the monetary policy is assumed to follow an inflation target, which was not the case before 1993. Furthermore, in the first years of the 1990s there were several other factors affecting the economy: an asset bubble in the late 1980s, the fall of Soviet trade, and the devaluation of the Finnish Markka. Considering a later starting date helps to better address the structural nature of the crisis. Nevertheless, data clearly shows that the fall in investments started from 1991, and therefore it is natural to ask whether the overcapacity problem can explain the persistence of the crisis, even if the economy is allowed to already start adjustment of the capital stock in 1991.

Thus a scenario is considered where there is a 12.5 percent investment tax credit instead of the 7.5 percent considered before. Due to the tax credit the capital stock is now 22.5 percent higher in the initial steady state, which corresponds fairly well to the overall adjustment of the capital stock during the crisis. The simulation otherwise follows parameterization in the benchmark simulation without the financial frictions. It gives a rough estimate on the full adjustment path of the capital stock when wages and prices are rigid and in the absence of other shocks.

The result suggests that the problem may indeed have a persistent effect on the economy. The overcapacity problem alone generates a 12 percentage point increase in unemployment in the starting period (1991q1). In three years time the effect is still 7.8 percentage points, 5 years later 5.5 percentage points and 10 years later 2.1 percentage points.

6.4 The Balanced Trade Condition

While the balanced trade assumption is necessary to maintain the long-run external balance of the model economy, the assumption may not be fully appropriate in the short-run and may lead to exaggerate the impact of other economic shocks. That is, because the condition governs not only domestic demand, but also exports. Thus, whenever there is fall in domestic demand, exports will fall, too. The effect of the export demand is roughly equal to the export share of GDP, as the contraction of the export market follows contraction in the domestic demand almost one to one. However, even if its effect is fully removed, the results still suggest that the economic contraction caused by the removal of the tax credit is large (roughly 7 percent of GDP, or one third of the total contraction in 1994).[83]

7 Conclusions

This paper constructs a general equilibrium model to quantify the collapse of the Finnish investment-led growth model of the early 1990s and investigates its role in the Finnish Great Depression. It reports a permanent fall in the country's investment rate and an increase in the relative price of investment. The paper shows that with reasonable parameterization and financial frictions, the lifting of an investment tax credit in the crisis conditions can explain a sizable fraction of the depression and the following long slump. In particular, it can explain the difference in the depth of the Swedish and Finnish crises, as well as the technology shock identified by Conesa et al. (2007). The findings are consistent with Karanassou et al. (2008) who also consider investments as an important factor in the Finnish crisis. Similarly to Pohjola (1996), this paper argues that the rapid fall in investments is an indication of competitiveness problems, and unemployment arises when firms face conditions that prevent them from rapidly adjusting use of capital and labor.

The first and foremost lesson of this paper is to avoid situations where rapid and large restructuring of production is needed. In this respect the Finnish experience shows how overcapacity can threaten the stability of the economy when steps are taken to reform the system. In hindsight, more progress in reorganizing production and improving the efficiency of the financial system may have been needed before beginning financial liberalization. The economy responded sluggishly to the opening financial and good markets, which later contributed to the escalation of

---

[83] A model with fully exogenous exports was also considered. The model was re-calibrated to match the level shift of the capital stock after 1993. In the model the country runs small trade surplus in the final steady state, because domestic demand falls more than exports. The results are found to be consistent with the corrected estimate.

the crisis.

While this paper considers financial frictions and the overcapacity problem separately, further research on their relationship is warranted to provide more exact policy recommendations. Nevertheless, it appears that there was not much room for action by the monetary authority during the recovery. A lower nominal interest rate would have led to depreciation of the currency and the increasing cost of the foreign denominated debt. Fräystätter (2011) illustrates this relationship for the Finnish economy. Indeed, recent literature suggests that, under binding constraints for the monetary policy, the fiscal multiplier can increase substantially. However, facing the need for structural transformation, the government was reluctant to support ailing industries. While preventing spillovers from weaker economic activity into financial markets would have been necessary, as Blanchard et al. (2009) notes, the fiscal situation rapidly deteriorated to the point where the focus of attention shifted from counter-cyclical fiscal policies to fiscal sustainability.

Another interesting avenue for future research is to consider models with endogenous technological change and financial liberalization (see, e.g., Song et al., 2011) in the crisis context. In Finland the supply-side policies were used to support the transformation, as the Finnish government fostered R&D activities and education during the crisis. The strategy proved to be successful and transformed the country's relative advantage towards exporting high-tech goods. Indeed, it is only according to the most traditional Schumpeterian thinking that recessions are times for productivity enhancing restructuring and a necessary part of the process of economic growth. More recent literature on creative destruction suggests that financial constraints during the recessions tend to be harmful for creative processes in firms, as they are forced to cut back on their long-term R&D spending (Aghion and Marinescu, 2008).

Appendix

Measuring the Size of the Reserves

Next, the size of the reserves is measured and compared to the value of the total investments to estimate the rate at which investments are supported. The next table collects definitions and parameter values. The definitions and values of effective tax rates are taken from Kari et al. (1995, section 4, table 4.1), while capital income and nominal investment shares are based on the estimates of the Statistics Finland.

Parameter	Description	1989	1980-1989 ave.
TR^1_{eff}	Eff. tax rate with reserves (TR_{leg}-ATR1-ATR2)	0.142	0.171
TR^2_{eff}	Eff. tax rate without reserves (TR_{leg}-ATR1)	0.204	0.291
TR_{leg}	Statutory tax rate	0.5	0.56
CAP	Capital income (private sector) = VA - Labor cost	.	.
CAPs	Capital income share (private sector) = $\frac{CAP}{pY}$	0.302	0.302
DD_{inv}	Investment reserves	.	.
DD_{oth}	Other tax deductions	.	.
TAX_{icred}	Investment tax credit	.	.
TAX_{corp}	Total corporate taxes	.	.
INV	Nominal investments	.	.
INVs	Nominal investments over GDP	0.29	0.26
τ	TC / Nominal investments	?	?

To quantify τ, let us first note that the effective tax rate without investment tax credit is the ratio of total corporate taxes, and the sum of the capital income and the other deductions (the effect of the difference between accounting earnings and taxable income) that the corporation aqcuires during the year:

$$TR^2_{eff} = \frac{TAX_{corp}}{CAP + DD_{oth}}$$

After using the definition of statutory tax rate ($TR_{leg} = \frac{TAX_{corp}}{CAP}$), the effective tax rate becomes

$$TR^2_{eff} = \frac{TR_{leg} CAP}{CAP + DD_{oth}}$$

Therefore, the sum of the capital income and the other deductions becomes

$$CAP + DD_{oth} = \frac{TR_{leg}}{TR^2_{eff}} CAP$$

If information on the effective tax rate with the reserves ($TR^1_{eff} = \frac{TR_{leg}CAP}{CAP+DD_{oth}+DD_{res}}$) is also available, the investment tax credit ($TR^1_{eff}DD_{res}$) can then be solved after rearranging the expression for TR^1_{eff} :

$$\begin{aligned} TR^1_{eff}CAP &= TR_{leg}CAP - TR^1_{eff}DD_{res} - TR^1_{eff}DD_{oth} \Leftrightarrow \\ TR^1_{eff}DD_{res} &= TR_{leg}CAP - TR^1_{eff}(CAP + DD_{oth}) \\ &= TR_{leg}CAP - TR^1_{eff}\frac{TR_{leg}}{TR^2_{eff}}CAP \\ &= (TR_{leg} - TR^1_{eff}\frac{TR_{leg}}{TR^2_{eff}})CAP \end{aligned}$$

Finally, the rate at which investment are subsidized can be solved:

$$\tau = \frac{TR^1_{eff}DD_{inv}}{INV} = \frac{(TR_{leg} - TR^1_{eff}\frac{TR_{leg}}{TR^2_{eff}})CAPs}{INVs}$$

Meanwhile, the effective corporate tax rate is TR^2_{eff} before the reform and falls to TR^1_{eff} after the reform.

After plucking in the parameters for the year 1989, τ is found to be 15.8 percent.[84] The average over the years 1980-1989 is 17.7 percent.

Utility Maximization of the Unconstrained Consumer

This appendix lays out the utility maximization problem for the unconstrained consumer. Let us write the Lagrangian.

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[84] It is noticeable that the estimated size of the tax subsidy depends on how broad effective tax rate is used in the comparison. If the 1989 broadest effective tax rate (10.1 percent) in Kari et al. (1995, table 4.1) is used, the estimated subsidy is roughly 19 percent.

$$
\begin{aligned}
\mathcal{L} \;=\; & \sum_t \beta^{(t)} U(c,l) \\
& +\lambda \begin{pmatrix} wl + p_d a_d + p_k a_k - p_c c - q_d i_d - q_k i_k \\ +DP^* - \epsilon D^* + DP - D \\ -\tau_k (p_k + (1-\delta_k) q_k) a_k \\ -\tau_d (p_d + (1-\delta_d) q_d) a_d \\ +T_t \end{pmatrix} \\
& +\gamma_1 (a_d^{'} - (1-\delta_d) a_d - i_d) \\
& +\gamma_2 (a_k^{'} - (1-\delta_k) a_k - i_k)
\end{aligned}
$$

where (') denotes the next period, D denotes domestic riskless bond, and DP return on bond, so that $DP' = (1+r_t^n)D$. $\overline{D}^*$ denotes the amount of bonds invested in foreign currency yielding the asset position D^* in foreign currency, where ϵ is the exchange rate $\frac{p}{p^*}$, where p is the price of domestic final good, and p^* is the price of the foreign final good. In exchange the household receives back $DP^{*\prime} = \frac{\epsilon(1+r_t^{*,n})}{\epsilon'} D^*$ units of domestic currency in the next period, where $(1 + r_t^{*,n})$ is the return on bond in foreign currency. Finally, there are financial frictions equivalent to property taxes (τ_k and τ_d) on both types of capital. The property taxes are returned in lump-sum transfer, T, to households. T also includes the cost of the tax credit that is levied on the household.

Let us write down the FOCs for consumption

$$(c) : \beta^{(t)} U_{[c]} - p_c \lambda = 0$$

investment:

$$(i_j) : -q_j \lambda - \gamma_j = 0 \; | j = d, k$$

future assets:

$$
\begin{aligned}
(a'_j): \qquad & 0 = \lambda'(p'_j - \tau'_j(p'_j + (1-\delta_j)q'_j) + \\
& +\gamma_j - (1-\delta_j)\gamma'_j \;|j = d,k
\end{aligned}
$$

and labor (in model specification, where the representative household optimizes the supply of labor):

$$-\beta^{(t)}U_{[l_j]} = \lambda w$$

Lagrange multipliers are then solved from (c) and (i_j)'s:

$$
\begin{aligned}
\lambda &= \frac{\beta^{(t)}U_{[c]}}{p_c} \\
\gamma_j &= -\lambda q_j \mid j = d,k
\end{aligned}
$$

Next, the FOCs are solved for D and D^* :

$$
\begin{aligned}
\lambda &= \frac{\epsilon(1+r_t^{*,n})}{\epsilon'}\lambda^{'} \\
\lambda &= (1+r_t^n)\lambda^{'} \\
&\Leftrightarrow \frac{U_{[c]}}{U^{'}_{[c]}} = \beta\frac{p_c}{p^{'}_c}(1+r_t^n), \\
& (1+r_t^n) = \frac{\epsilon}{\epsilon'}(1+r_t^{*,n})
\end{aligned}
$$

The dynamic optimality conditions are found by combining $(a^{'}_j)^{'}$s with (c)'s for $j = \; d,k$:

$$\begin{aligned}
0 &= \lambda'(p'_j + \tau'_j(p'_d + (1-\delta_d)q'_d) + \\
&\quad +\gamma_j - (1-\delta_j)\gamma'_j \\
&\Leftrightarrow\ 0 = \lambda'(p'_j + \tau'_j(p'_d + (1-\delta_d)q'_d) + \\
&\quad -q_j\lambda + (1-\delta_j)q'_j\lambda' \\
&\Leftrightarrow\ \frac{\lambda}{\lambda'} = \frac{p'_j + (1-\delta_j)q'_j - \tau'_j(p'_d + (1-\delta_d)q'_d)}{q_j} \\
&\Leftrightarrow\ \frac{1}{1-\tau'_j}\frac{\lambda}{\lambda'} = \frac{p'_j + (1-\delta_j)q'_j}{q_j} \\
&\Leftrightarrow\ (1+\frac{\tau'_j}{1-\tau'_j})(1+r^n_t) = \frac{p'_j + (1-\delta_j)q'_j}{q_j}
\end{aligned}$$

Let us denote $\frac{\tau_j}{1-\tau_j}$ $(\approx \tau_j)$ by f_j.

Furthermore, the optimality conditions are expressed in terms of relative prices and using the definition of the real interest rate, $(1+r^n_t)\frac{p_y}{p'_y} = 1 + r_t$, they become

$$\begin{aligned}
(1+f_j)(1+r^n_t)\frac{p_y}{p'_y} &= \frac{\frac{p'_j}{p'_y} + (1-\delta_j)\frac{q'_j}{p'_y}}{\frac{q_j}{p_y}} \\
(1+f_j)(1+r_t) &= \frac{\frac{p'_j}{p'_y} + (1-\delta_j)\frac{q'_j}{p'_y}}{\frac{q_j}{p_y}} \\
(1+r^n_t)\frac{p_y}{p'_y} &= \beta\frac{\frac{p_c}{p_y}}{\frac{p'_c}{p'_y}}\frac{U_{[c'_j]}}{U_{[c_j]}} \\
1+r_t &= \beta\frac{\frac{p_c}{p_y}}{\frac{p'_c}{p'_y}}\frac{U_{[c'_j]}}{U_{[c_j]}}
\end{aligned}$$

Lastly, this paper abstracts from further analysis of money and r^n_t is set to zero $(1 + r_t = \frac{p_y}{p'_y})$.

Further Characterization of the Model

This appendix illustrates further the structure of the model. First, equations of the model are collected. Second, a diagram of the model dynamics is presented.

7.0.1 Equations

Let us write down the whole model, while prices are expressed as relative to the price of the domestic good ($p_{y,t} = 1$). On the supply side the following five equations govern production and prices of production factors:

$$\begin{aligned} x_t &= \frac{n_t}{\overline{n}_t} \\ y_t &= An_t^{\alpha}(x_t k_{t-1})^{1-\alpha} \\ w_t &= A\alpha(\frac{x_t k_{t-1}}{n_t})^{1-\alpha} \\ p_{k,t} &= A(1-\alpha)(\frac{x_t k_{t-1}}{n_t})^{-\alpha} \\ q_{k,t} &= p_t(1-\tau) + \chi_k \frac{(k_t - k_{t-1})}{k_{t-1}} \end{aligned}$$

In the last three equations $p_{y,t}$ is omitted from the expression. When flexible prices are considered, $x_t = 1$.

Let us then write down the domestic real interest rate as a function of the real exchange rate, $\frac{1}{p_{w,t}}$ (the relative price of domestic good when $p_{y,t} = 1$), and the foreign real interest rate ($1 + r_t^* = \frac{1}{\beta}$):

$$1 + r_{t-1} = \frac{p_{w,t}}{p_{w,t-1}} \frac{1}{\beta}$$

When the domestic real interest rate (and thus intertemporal prices) is flexible, the relative price of domestic good varies over time. Instead of this, when the real interest rate is fixed at the level, $\frac{1}{\beta}$, the real exchange rate stays constant, as $1 + r^*$ is also the growth rate of the foreign good's price. The latter assumption is made when the exogenous real interest rate is considered, while the former assumption describes the model behavior under flexible prices.

The next set of equations governs the domestic price, the share of domestic goods, and exports:

$$
\begin{aligned}
p_t &= (cons * p_{w,t}^{-\theta} + 1)^{-\frac{1}{\theta}} \\
\pi_t &= \frac{1}{cons * p_w^{-\theta} + 1} \\
ex_t &= p_t * (1 - \pi_t) * (i_{k,t} + i_{d,t} + c_{y,t}),
\end{aligned}
$$

respectively. As mentioned before, solving the initial price level requires an additional equation that governs the size of the foreign market in the steady state. A constant (cons) is used to calibrate the model to match relative prices to the data.

The pricing kernel consists of the Euler equation and the two zero arbitrage conditions arising from the household utility maximization

$$
\begin{aligned}
\frac{1}{1 + r_t} &= \beta \frac{p_{c,t}/p_t}{p_{c,t+1}/p_{t+1}} \left(\frac{\tilde{c}_{t+1}}{\tilde{c}_t} \right)^{-\frac{1}{\sigma}} \\
(1 + r_{t-1})(1 + f_{d,t}) &= \frac{p_{d,t} + (1 - \delta_k) q_{d,t}}{q_{d,t-1}} \\
(1 + r_{t-1})(1 + f_{k,t}) &= \frac{p_{k,t} + (1 - \delta_k) q_{d,t}}{q_{d,t-1}}
\end{aligned}
$$

Consumption is further governed by the following static conditions and relative prices:

$$
\begin{aligned}
p_{c,t} \overline{c}_t &= p_{y,t} (\omega y_t - s_t y_t) \\
p_t \widetilde{c}_{y,t} &= \phi p_{c,t} \widetilde{c}_t \\
p_{d,t} d_{t-1} &= (1 - \phi) p_{c,t} (\widetilde{c}_t + \overline{c}_t) \\
p_{c,t} &= \phi^{-\phi} (1 - \phi)^{-(1-\phi)} p_t^{\phi} p_{d,t}^{1-\phi} \\
q_{d,t} &= p_t + \chi_d \frac{(d_t - d_{t-1})}{d_{t-1}}
\end{aligned}
$$

Finally, the model is closed by imposing the aggregate resource constraint:

$$y_t = \frac{p_t \pi_t (i_{k,t} + i_{d,t} + c_{y,t}) + ex_t}{p_{y,t}} + \frac{\kappa_k}{2} \frac{(k_t - k_{t-1})^2}{k_t} + \frac{\kappa_d}{2} \frac{(d_t - d_{t-1})^2}{d_t} + v \frac{\gamma}{q(n_t)} n$$

7.0.2 Diagram

This subsection describes the dynamics of the model with a stylized diagram (see, figure (17)). Arrows indicate the relationship between two variables. Variables inside solid rectangles are predetermined endogenous variables (in period t on the left hand side, or in period t+1, on the right hand side). Variables inside dashed squares are exogenous variables, while variables inside circles are endogenous.

In the diagram all prices are measured relative to the price of the domestic final good. In addition, for the sake of simplicity, the labor force ($\overline{n}$) and multifactor productivity (A) (which both remain constant during the simulations) are omitted. It is, however, noticeable that both affect the level of potential output, wage, and marginal product of capital.

The main effects of the real interest rate (R) are marked with bold lines. First, it governs changes in the relative price of the foreign good, and thus changes in the domestic share of final good. In the baseline simulation with constant prices this price change is taken to equal the price change of the foreign good (p_w) so that the share of domestic production remains constant.

The other three bold lines represent the consumption Euler equation and the zero arbitrage conditions of investment in durable and capital goods. The diagram illustrates how the general equilibrium does not necessarily generate full employment of the economy's resources. In particular, without adjustment to the real interest rate there is no direct link from low investment demand to other forms of final demand. Rather, the fall in investment does not affect international competitiveness or consumption.

Quantifying International Trade Patterns

While the model only discusses only the aggregate domestic and foreign production, it is calibrated based on a model where the tradable sector output is heteroge-

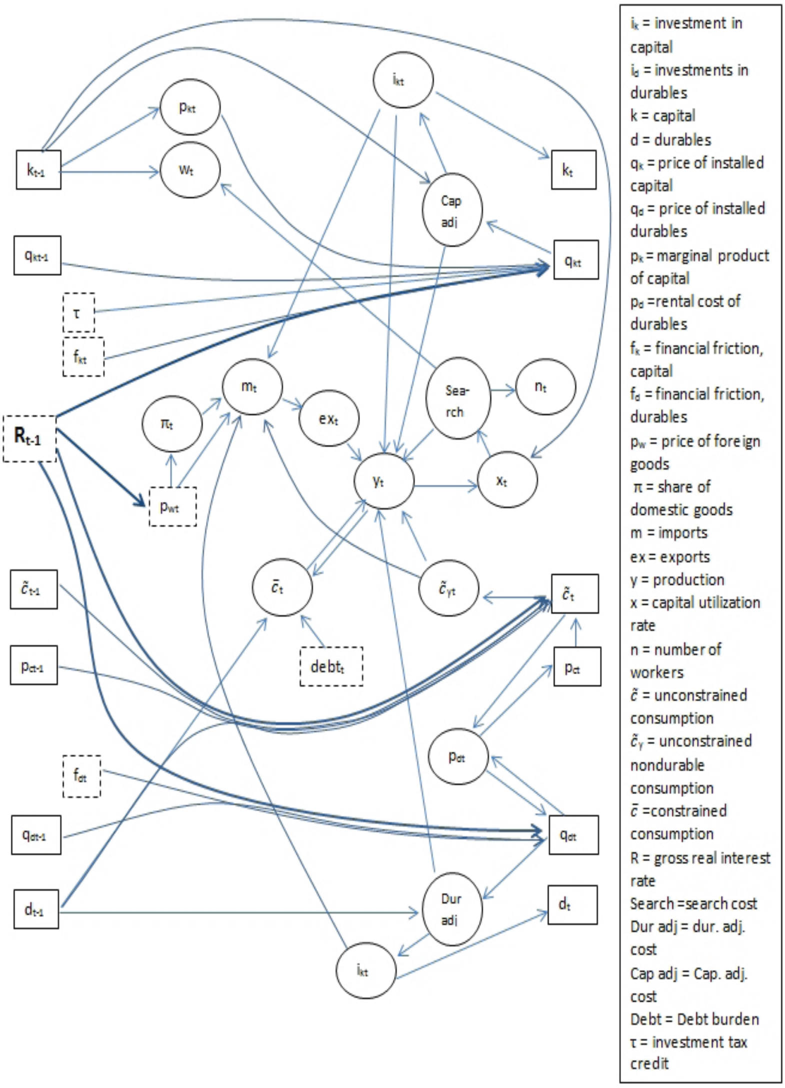


Figure 17: Model Dynamics in a Diagram

nous. The derived functional forms are standard in open economy macromodels and leads into reasonable parameterization of the model, and thus further details of the estimation are omitted from the actual model description. Nevertheless, the estimation is discussed next in some more detail.

Let the goods be indexed by their type, $z_q \in [0, 1]$. The domestic production function is Cobb-Douglas and identical for each type expect for the MFP term which captures differences in the domestic and foreign ability to produce a particular type. Due to differences in MFP, some goods are produced in Finland and exported, while others are imported. The goods are combined symmetrically to a composite final good ($\eta_q < 1$)

$$f_q = \left(\int_0^1 f_{z_q}^{\eta_q} dz \right)^{\frac{1}{\eta_q}},$$

which is then used for consumption or investments purposes.

The model is based on the Eaton and Kortum (2002) framework in which the MFP distributions across countries are realizations of random variables. It is assumed that productivity $\mathrm{A}_q(z)$ is drawn in each time period from a cumulative distribution function $\Phi_{iq}(z) = \Pr(Z_{iq} \leq A)$. When the distribution is chosen to be Frechet $\Phi_q(z) = e^{-T_q A^{-\theta_q}}$, where $T_{iq} > 0, \theta_q > 1$. The randomization has a clear economic interpretation. The draw is the maximum of a set of productivity draws that represents the best new idea from an underlying distribution of ideas. Being proportional to the mean draw from the F distribution, T measures the absolute advantage of the country in production. However, each country will have some production, as good productivity outcomes will be realized in each country. Their frequency is governed by θ, which can be interpreted as relative advantage.

Production of each class z is fully competitive and the similarity of the production makes it possible to obtain an aggregate unit cost function. It can be expressed by integration as

$$\log(UC_t) = MFP_t + (1 - \alpha)\log(R_t) + \alpha \log(W_t)$$

where MFP is the inverse of aggregate mean multi-factor productivity, given by $MFP = \gamma^{-1}T^{\frac{1}{\theta}}, \gamma = (\Gamma(1-\frac{\eta_q}{1-\eta_q})\frac{1}{\theta_q})^{\frac{1-\eta_q}{\eta_q}}$. It is noticeable that the higher the variance, θ, becomes, the less the fundamental drivers of unit costs, T, and the factor prices matters for the allocation of production. Thus, θ is one of the key parameters of the model.

In the EK framework the behavior of the price minimizing purchasers can be described with tractable analytical expressions. Given the distribution of the MFP, Eaton & Kortum (2002) show how the composite good q's relative price in Finland is

$$p_t = \gamma \Phi_t^{-\frac{1}{\theta}} \tag{38}$$

where $\Phi = \sum\limits_{k \in CN} \tau_{FIN,k}^{-\theta} UC_k^{-\theta}$, (CK being the) as EK shows. Similarly, trade patterns can be expressed as a function of wages and relative productivities. Under Fréchet distribution, the probability that the lowest price in the country is offered by the vendors in other countries can be derived from the distribution of prices. In the EK model this probability is also the expenditure share of goods bought from other countries. The share of Finnish goods in the domestic expenditure is

$$\pi_t = \frac{UC_t^{-\theta}}{\Phi_t} \tag{39}$$

In this paper the unit costs in other countries are taken as given and thus their aggregation is reasonable. The expressions for prices and domestic shares follows, after noticing that in competitive markets unit cost equals price and defining

$$p_f^{-\theta} = \sum_{k \in \{CN \setminus FIN\}} \tau_{FIN,k}^{-\theta} UC_k^{-\theta}.$$

The quantification of the trade model is based on the estimation of bilateral trade equations. Their estimation closely follows that of Eaton & Kortum (2001) and thus its details are omitted here. It is however noticeable, that the MFP terms are measured in relative terms, in which case θ is the only calibrated variable, which is set at 8.3 based on Eaton & Kortum (2002). The set of variables used to model trade barriers is based on the gravity dataset by Head et al. (2008), provided by CEPII. The variables include tariff levels, RTA dummies, distance (six classes), common official language, border and colonial background, WTO and EU membership status as well as an importer fixed effect. The equations are estimated for the year 1995 for all manufactures. Production and bilateral trade data are taken from the TradeProd dataset, also available on the CEPII homepage.

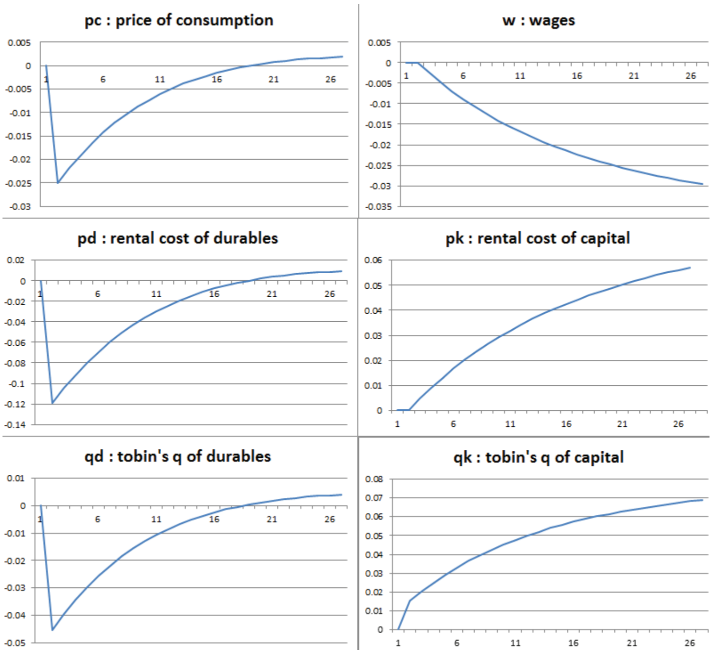
Data sources

Variable	Source
Real GDP	Penn World Table 7.2
Total hours	EU-KLEMS, 2009 edition (H_EMP)
Real Investments	Penn World Table 7.2
Real private consumption	Penn World Table 7.2
Real private non-res. investments	Finnish National accounts
Real exports	World Bank
Relative price of investments	Penn World Table 7.2 (pi/pc)
Nominal investment share	Penn World Table 7.2 (ki)
Non-residential capital stock	Based on PIM, Matti Pohjola (2012)
Residential capital stock	Based on PIM, Matti Pohjola (2012)
Short-term nominal interest rate	OECD country tables
Long-term government interest rate	OECD country tables
Industry-level prices, employment, output	EU-KLEMS ,2009 edition
Industry-level investment shares	Finnish National accounts
EK survey data	ETLA database
Exchange rates	BIS
Household debt burden	Finnish National accounts
US capacity utilization rate	FED
Deposit bank spreads	Bank of Finland historical series

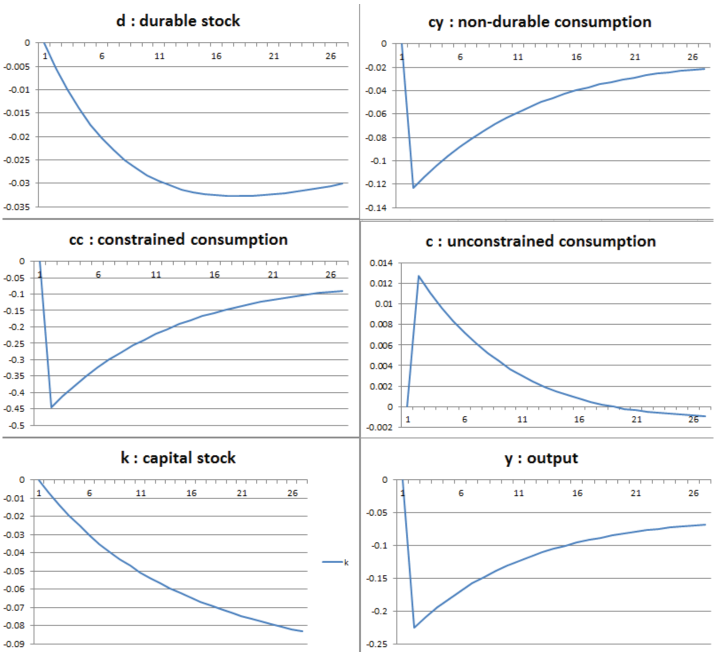
Initial Steady State

Variable	Description	Initial ss
py	price (output)	0.943
p/py	price (final good)	1.545
pc/py	price (consumption)	0.731
pd/py	rental price (durables)	0.022
pk/py	rental price (capital)	0.025
qd/py	Tobin's q (durables)	0.025
qk/py	Tobin's q (capital)	0.943
w/py	Wage	0.872
y	Output	49912
$\frac{ex}{py}$	Real exports	29184
i_k	investment (capital)	13065
i_d	investment (durables)	6966
k	Capital stock	694936
d	Stock (Durable goods)	370529
cy	Consumption (nondurables)	34090
c	Tot. consumption (unconstained)	41290
cc	Tot. consumption(constrained)	13647
π	Domestic share in final use	0.614

Details of the Simulation With Overcapacity and Financial Frictions:



Simulated prices in the quarters following 1993q4 (relative to py)



Simulated quantities in quarters following 1993q4

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Over the past few decades technology has been a source of profound economic transformation. This dissertation is a collection of essays concerning the key features of the process. The work extends traditional macroeconomic growth models to better describe and quantify the reorganization of production associated with the information and communications technology (ICT) revolution and the structural change accompanied by technological progress. Furthermore, it seeks new ways to analyze the economic impact of the policy changes involved in the transformation.

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