European Commission

ISSN 1725-3187

Fellowship initiative
The future of EMU

EUROPEAN ECONOMY

Economic Papers 486 | April 2013

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Economic and Financial Affairs

European Commission
Directorate-General for Economic and Financial Affairs
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KC-AI-13-486-EN-N
ISBN 978-92-79-28568-4
doi: 10.2765/42751

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This paper starts by reviewing medium- to long-term growth prospects provided in recent academic and policy research. The paper argues that, owing to the ongoing advances in ICT, much higher growth is technologically feasible, but that a considerable amount of churn and reallocation across firms in the market sector. Next, the paper presents evidence on recent patterns of reallocation in EU countries. Based on theoretical findings from heterogeneous firm dynamics models, the paper will describe how various types of policy could affect the processes of allocation and selection and thereby growth prospects. Finally, the paper will combine empirical and theoretical insights to point towards promising policy directions. Conditional on the policy environment, labor productivity growth in the EU of 2.5 percent per year for the next 20-30 years appears attainable.

Keywords: Resource Allocation, Productivity Growth, Innovation, Framework policy

JEL Codes: E23, J63, L16, O40

ACKNOWLEDGEMENTS

This Economic Paper is published as part of DG ECFIN's Fellowship Initiative 2012-13.

The initiative was coordinated by a steering group comprising of Anne Bucher, Ines Drumond, Karl Pichelmann, Eric Ruscher and Michael Thiel.

Helpful comments and suggestions by Alfonso Arpaia, Narcissa Balta, Nicolas Carnot, Carlos Cuerpo Caballero, Stefan Ciobanu, Francesca D'Auria, Ombeline Gras, Isabel Grilo, Alexandr Hobza, Anton Jevcak, Robert Kuenzel, Staffan Linden, Alienor Margerit, Kieran McMorrow, Silvia Merler, Josefa Monteagudo, Plamen Nikolov, Peter Pontuch, Werner Roeger, Georges Tournemire, Geza Sapi, Hylke Vandenbussche and Stefan Zeugner are gratefully acknowledged, as is the very efficient administrative support provided by Filomena de Assis, Agnieszka Budzinska, Mariyana Ivanova, Nancy Saba and Kristine de Winter.

1. Introduction

This paper sketches an optimistic growth scenario for the EU, brought about by widespread adoption of new, ICT-related technologies that push out the productivity frontier. This scenario depends on an economic environment with the proper incentives for entrepreneurs and incumbent firms to commit resources to R&D and other knowledge-based capital investments.[1] Further, the environment must be accommodative to the processes of resource reallocation required for diffusion of new technology throughout the economy. Finally, the characteristics of current and prospective technology, with high fixed costs of creation and low marginal costs of use, may cause increases in income fluctuations and further skewing in income distribution. These outcomes could require renewed policy attention.

It is difficult to present an optimistic growth scenario at a time when so much of the news is pessimistic, or cautious at best. Five years after the onset of the crisis, growth remains sluggish, banks remain fragile, households worry about the adequacy of their savings, and government debt ratios are near or above the danger zone. Firms seem to be in a holding pattern, not investing in new capacity, let alone new technology, while the prospects for future demand remain unfavorable. Recent papers (Fernald 2012; Gordon 2012) provide projections of total factor productivity (TFP) growth and potential GDP growth for the USA that lie well below those experienced in the period 1995-2007.

Yet, productivity growth is the key to continued sustainable output growth over the long run. Especially in services productivity improvements in global value chains are required to enable countries in the EU to benefit from continuing expansion of income and consumption in other parts of the world (see Van Ark et al., 2012). The danger exists that only selected regions within the EU will have the policy environment conducive to firm-level investments in knowledge based capital that are required to deliver to global chains, especially for firms in business services (Foster et al., 2012). According to Hulten (2012), traditional policy aimed at growth remains important for knowledge based capital, but additionally it is necessary to consider the incentives for individual firms. Based on this view, Hulten mentions the importance of regulations aimed at improving flexibility in input and output markets, tax and accounting rules that broaden the definitions of investment and assets, and educational systems that mesh better with skill requirements.

This paper is focused on the firm-level perspective of growth, and is optimistic concerning growth if the incentives for knowledge-based capital investment are in place. Technologies that currently are in late stages of development could push out the productivity frontier if framework conditions are favorable to their adoption. Indeed, much of the momentum for future growth already is in place in innovative firms.[2] More speculatively, the paper argue that the nature of the relationship between reallocation, technology adoption and productivity growth may be changing, under influence of the increased use of new communications

[1] In this paper, the terms intangible investment and knowledge-based investment are used interchangeably, see footnote 2 of Hulten (2012).

[2] Bartelsman and Wolf (2013) provide empirical evidence that information derived from developments at the firm-level aid in typical macroeconometric productivity forecasting exercises. Their analysis of the patterns of technology adoption, reallocation, and productivity growth within and between firms shows that a considerable amount of potential growth already is in the pipeline.

technology. The need for flexible input markets and contestable output markets as an incentive for investments in knowledge based capital is increasing at the same time that such investments seem to be increasing the dispersion in productivity and market share changes.

The optimistic story about future growth does place requirements on the details of the policy environment. Mapping out policies that promote long-run growth, through the intervening process of allocation and selection in the market sector is not a straightforward task. Based on the theoretical literature on the links between firm-level dynamics and productivity the paper discusses the distortions that may harm productivity. The workhorse model of industry dynamics is provided by Hopenhayn (1992) or Pakes and Ericson (1998), depending on the structure of the industry. By adding policy frictions to these models, recent papers have shed light on a variety of policy and institutional problems. Hsieh and Klenow (2009), and Bartelsman et al. (2013) show how distortions to capital or product markets can lengthen the low tail of the distribution of productivity, can prevent markets from attracting productive entrants and can prevent resources from being allocated optimally among incumbents.

Policy that affects allocation also has indirect effects on productivity through changes in investment in new technology. Bartelsman et al. (2010) calibrate a model to show how firing costs can lower the adoption rates of ICT and reduce the share of resources allocated to high growth sectors. Recent work by Andrews and Serres (2012) provides a Schumpeterian framework for assessing the dynamic links between resource allocation, investments in intangible assets and growth.

Finally, especially in the light of the ongoing problems in the financial markets, the paper warns for the effects of credit constraints on allocation and productivity. This empirical path was first explored by Bernanke et al. (1996), placed into a firm dynamics context by Aghion et al. (2007), and finally explored in a general equilibrium heterogeneous agent model by Moll (2010) and Midrigan and Xu (2010). In short, frictions in the credit markets could result in resources not going to firms with the most promising projects, but to firms with lower agency costs in borrowing.

The paper is organized as follows: the first section contains a critical review of some recent productivity forecasts, followed by section 3 with the alternative optimistic scenario. In section 4 the paper provides evidence on the underlying process of reallocation of resources across firms in a large selection of EU member states. Next, section 5 will discuss the progress made in our theoretical understanding of the market dynamics of heterogeneous firms and how selection and allocation can be affected by policy distortions. Finally, in section 6 empirical and theoretical insights are combined to point towards promising policy directions. Section 7 concludes with a restatement of key points, some caveats in interpretation, and an agenda for future research.

2. Productivity Forecasts

In a provocative essay, Gordon (2012), suggests that growth in per <capita consumption for all but the wealthiest 1 percent may drop to 1/4 percent per year for the next generation, down from the nearly 2 percent per year in the previous 150 years. This implies a doubling in income per capita in a century or longer, instead of in a generation. In a growth accounting exercise using historical timeseries data, Fernald (2012), extrapolates a benchmark scenario with labor productivity growth slowing from the 2.8 percent per year seen post-1995 to 1.9 percent per year for the medium-term future. These two results are not directly

comparable, and the methodologies vary drastically. However, both are based on historically observed patterns and extrapolated judgment about future developments.

In this section we will review the methods, assumptions, and judgments made by Gordon and Fernald in their projections. There is, and likely will be, no econometric methodology that can provide accurate forecasts of productivity growth. In general, productivity forecasts perform horribly, with forecast standard errors being larger than ranges that would be useful for policy purposes. While a trend estimate may state 2.25 percent labor productivity growth on average for the next 4 years, the error bounds will be on the order of $\pm$ 3 percentage points (e.g. Bartelsman and Wolf (2013)). What would be useful for policy makers is to understand how and by how much policy programs, regulations, or tax rates, may affect long-run productivity growth. An increase in the long-run labor productivity growth rate of 1/4 percentage point, all else equal, will provide a considerable amount of fiscal leeway. By contrasting our own theoretical growth framework with the assumptions and methods of Gordon and Fernald, we will try to see where policy and technology may change their stories to be consistent with the optimism presented here.

To start, we assess the projections of Fernald. He carefully constructs a dataset of timeseries of prices and output, investment, capital stocks and labor for three sectors of the economy, namely equipment, buildings, and consumer goods. Next, TFP series are adjusted for cyclical influences (utilization), and aggregate labor productivity is decomposed into contributions of sectoral TFP, capital deepening and labor quality. Capital deepening itself is attributed to underlying sectoral TFP. In the benchmark scenario, Fernald assumes that equipment TFP moves forward at 3.6 percent per year, while consumption goods TFP only grows at 0.2 percent and structures TFP is at -0.3 percent, leading to overall TFP growth of 0.9 per year and labor productivity growth of 1.9 percent per year. The resulting overall TFP growth assumption lies halfway between those in the periods 1973-1995 and 1995-2007.

For a projection on which to base potential output growth for use in monetary policy, these cautious assumptions may be reasonable. However, going forward in time, say for a generation, it seems highly unlikely that TFP of structures production remains negative, especially given expected future improvements in scheduling/logistics and in materials. Further, as we will argue below, the improvements in areas such as health care, education, transportation, en leisure make the given growth rate for consumption goods seem quite low.

Besides implausibility of the underlying TFP assumptions, the theoretical model is not very useful for understanding the drivers of productivity. The theory of neoclassical growth, with representative agents and consumers underlying the projections, offer no links to policy other than typical R&D policy. In particular, the underlying model has no role for firm-level incentives for investing in intangible assets, no role for competition between firms that differ in their productivity level, and no role for the diffusion of frontier technology across firms. For example, as part of the analysis, Fernald shows contribution of computers and software peaking in 1999 at 0.9 percentage points, and then dropping to about 0.2 percentage points in 2012. These estimates do not reflect the stocks of intangible assets outside of software, for example in business organization and databases.

Turning to Gordon, he contrasts the underlying technology of three ’industrial revolutions’: i) the steam engines and railways, ii) the cluster of internal combustion engines and public utilities, and iii) the information and communications technologies (ICT). His main points are that the productivity implications of ICT do not compare in depth and breadth with the second industrial revolution, and that the main impact of ICT already is behind us. Gordon’s discussion of the enormous impact of the second revolution over an 80-year period, compared with the short-lived ICT boom of 1994-2004 is eloquent and interesting. Yet, the arguments he makes are fundamentally flawed because they do not appreciate the extent to which ICT is non-rival in production, while internal combustion engines and running water are rival. We turn to this below. Further, Gordon's view on the latest technologies not being able to rival the welfare benefits of those of the first and second revolution are not very convincing, despite his rhetorical gifts.

Gordon's Thought Experiment. In Gordon (2012), he presents a thought experiment to show why past inventions are much more important than the inventions that have come along since 2002.

"You are required to make a choice between option **A** and option **B**. With option **A** you are allowed to keep 2002 electronic technology, including your Windows 98 laptop accessing Amazon, and you can keep running water and indoor toilets; but you can't use anything invented since 2002. Option **B** is that you get everything invented in the past decade right up to Facebook, Twitter, and the iPad, but you have to give up running water and indoor toilets. You have to haul the water into your dwelling and carry out the waste. Even at 3am on a rainy night, your only toilet option is a wet and perhaps muddy walk to the outhouse. Which option do you choose?"

Gordon's audiences are purported to chuckle before choosing answer **A**, which obviously shows that the new stuff does not really add much. However, the example requires a bit of analysis to point out the fallacy.

To start, the thought experiment is related to the diamond-water paradox. Running water and indoor plumbing is ubiquitous and cheap, and depending on location costs less than 1/2 percent of GDP per year. So, at the margin, there is not much contribution, but the consumer surplus is enormous. When indoor plumbing was first being installed, embodied in public and private capital goods, the private investment depended on public infrastructure, otherwise the benefits would not outweigh the costs. Even then, the benefits at first were only high enough for the wealthy: the opportunity costs for most housewives of walking half a mile per day lugging 100 liters for the family was not high enough to warrant the investment. The reason consumer surplus now is so high, is because our productivity (and opportunity cost) became high through subsequent innovations.

Likewise, it seems obvious that in 2080, when we are all generating consumer surplus while playing/working on our tablet computers and social networks at the location of our choice, we would never want to give these up for option **B**, that is keeping the latest fads developed between 2070 and 2080. Option **B** of 2080 would entail driving to work to then spend eight hours doing repetitive, mentally draining tasks, without the ability to stay in touch with friends and family. This option is clearly even more onerous then today's option **B** of lugging water for 20 minutes a day.

A more direct way to favor Gordon's option **B**, is to realize that even if the plumbing, sewers, and water treatment plants are gone, we still have the knowledge about these things. We now know how backwards our public infrastructure really is. Using GIS systems with maps of infrastructure, LinkedIn networks of contractors and ditch diggers, smart procurement of infrastructure investment, new piping materials and waste management technology, we can rebuild a system with separate drinking, grey, and brown flows while at the same time burying electricity networks inside the large conduits whose bandwidth also can be auctioned off for fiber optics and automated package delivery. The present value of these combined features surely will outweigh the investment, thus making option **B** the obvious winner.

After describing the three technological revolutions and why he thinks the third one has already used up its benefits, Gordon goes on in the next part of his essay to subtract from the already lowered exogenous rate of TFP growth. He describes six growth reducing ’headwinds’ to arrive at a long-run growth of consumption per capita of 1/4 percent per year. Some of these headwinds provide useful pointers towards policy challenges and should be addressed, but others seem less valid.

Gordon starts with long-run growth of per capita GDP of 1.8 per year (equal to the 1987-2007 average, and similar to Fernald’s result). The first two headwinds subtract about 1/2 percentage points. First, labor force participation no longer contributes, owing to retirements of baby-boomers and leveling-off of female labor force participation. Next, Gordon expects labor quality increases to stop, as penetration in higher education already is high, but quality of high schools is declining and exorbitant costs of higher education are preventing further increases. Of course, this should be seen as a policy challenge: clearly the supply incentives in higher education at present do not seem to point towards improvements in productivity of educational delivery. With proper policy, investments in ICT and secondary market delivery of top-tier content (e.g. Coursera and EdX providing access to Ivy League courses), could change this market quickly.

Rising inequality is another headwind holding down per capita consumption growth, by another 1/2 percentage point according to Gordon. Indeed, we will later show how the nature of ICT may be worsening the distribution of income at the same time that high fixed-cost, low marginal-cost products require well distributed purchasing power in order to incentivize the necessary intangible investments.

Oddly, Gordon names globalization as a headwind. This may be the case in a constant returns world without rising knowledge: in this case factor price equalization would result in holding back per capita income in industrialized countries. But, in a world with non-rival technology and high fixed-cost cum low marginal-cost products, globalization should be considered a serious tailwind boosting growth world-wide.

Energy and environment are headwinds in the sense that they prevent scaling up current production methods. The extent that this will be a bottleneck depends on rapid policy adjustments to get the right price path to shift demand and elicit directed innovation (see e.g. Acemoglu et al. 2009). Further, developments of ICT may enable shifting consumers towards less energy intensive consumption, although the opposite could happen.

The last headwind, reductions in growth of disposable income owing to paying off debt, remains a problem but does not have a direct effect on productivity growth. However, it may reduce growth in per capita consumption if current debt levels are unsustainable in steady state.

After subtracting nominal growth penalties for each of the headwinds, Gordon ends up with growth in real per capita consumption of 0.2 percent per year. Some of the subtractions are more warnings to policy makers about issues that will harm growth, such as education, inequality, and energy. Globalization likely will be a positive, rather than a negative because intangibles become more valuable with scale. As long as debt is sustainable, and consumption is computed for steady-state debt levels, it will neither restrict nor boost consumption. With growing productivity, current debt levels will decline relative to GDP without attempts to reduce spending. The first subtraction, labor-force participation, is a red-herring: when people are able to make optimal labor-leisure tradeoffs any deviations, up or down, in per-capita consumption are welfare reducing. So, the lower labor force participation growth rates should not be cause for policy concern as long as the decisions were made by individuals facing proper price signals.

3. An Optimistic Productivity Forecast

The analyses of Fernald and Gordon leave us the question: so what is going to be the growth rate of output per hour, what policies are needed to achieve or increase this rate, and what policy challenges arise along the way? In this section we address the first question. To do this, we will expand the theoretical framework of the drivers of growth to include Schumpeterian processes of firm dynamics in an economy with intangible assets. Within this framework we will be able provide our own judgmental productivity forecast, using assessments of observed technological trends and conditioning on an appropriate policy environment.

Any analysis on future productivity growth driven by technology should start with Moore's Law, the rule of thumb that originated in Moore (1965), stating that the number of components on an integrated circuit was growing at a constant rate. At present, computational efficiency of computer processors is seen to be doubling every 18 months to 2 years, and even skeptical scientists expect this pace to continue for another decade (Kaku, 2012). After that, substrates other than silicon would <be needed to allow the progress of the devices to continue.

The economic corollary to Moore's Law is that the price of computing power is declining geometrically. While the price declines vary across different components, a single price index can be computed for ICT capital (EUKLEMS database). At present, ICT capital goods prices are declining 10-15 percent per year, relative to the average price level. This means that the price of ICT capital goods relative to other goods is cut in half every 5 to 7 years.

Technologists' visions can generate many different future scenarios based upon the staggering improvements in computing power of a single chip and the fast growth in the installed stock of available chips and computers. One such vision is presented by Ford (2009), a software engineer and entrepreneur with little training in economics. In his book, he extols the virtue of mass computing power, but worries about jobs and sustainability of the economy. His thesis is that within two generations no jobs will exist that can't be more cheaply done by computers. This process of replacing people with computers has some very serious implications for the continuity of the system. The innovators will collect much of the revenue of new varieties of goods, but most people lack jobs, and thus income with which to buy these goods. Ongoing replacement of educated workers by computers (to start, radiologists, legal researchers, but also software engineers) may reduce the wage premium to education and undermine incentives to become well educated. Finally, the lack of jobs, or impending loss of jobs will lead to pressure on government to protect jobs and slow the pace of innovation.

Economists also have been writing about the current and future economic impacts of ICT. In their book, ’Race against the Machine’, Brynjolfsson and McAfee (2011) call the current applications of ICT: “technology on the second half of the chessboard.” After 32 squares of doubling, the next doubling of ICT power will have very large effects, and the one after that even more. Many of the effects will no longer directly be tied to a particular firm’s investment in ICT, but will depend on the network infrastructure and on the large collections of data that are continuously being augmented. The growing investments in these intangible datasets however are not being measured as investment.

We take the Luddite scenario that Ford sketches with a grain of salt, but will turn to a descriptive analysis of the effects of Moore’s Law using available economic theory. Mainstream economics provides descriptions of mechanisms through which the ongoing advancement of ICT can affect output, the value of different skills, and the availability of jobs. The starting point is the growth accounting path through which ICT boosts output. Next, ICT may change the structure of markets and the economic environment facing firms. This opens up many links to policy on product and factor markets. The substitution of ICT for labor and the effect this can have on wages and employment for different types of workers requires further policy attention. Finally, there are the possible effects of ICT on labor share of income and on aggregate demand that are generating pressure on policy makers.

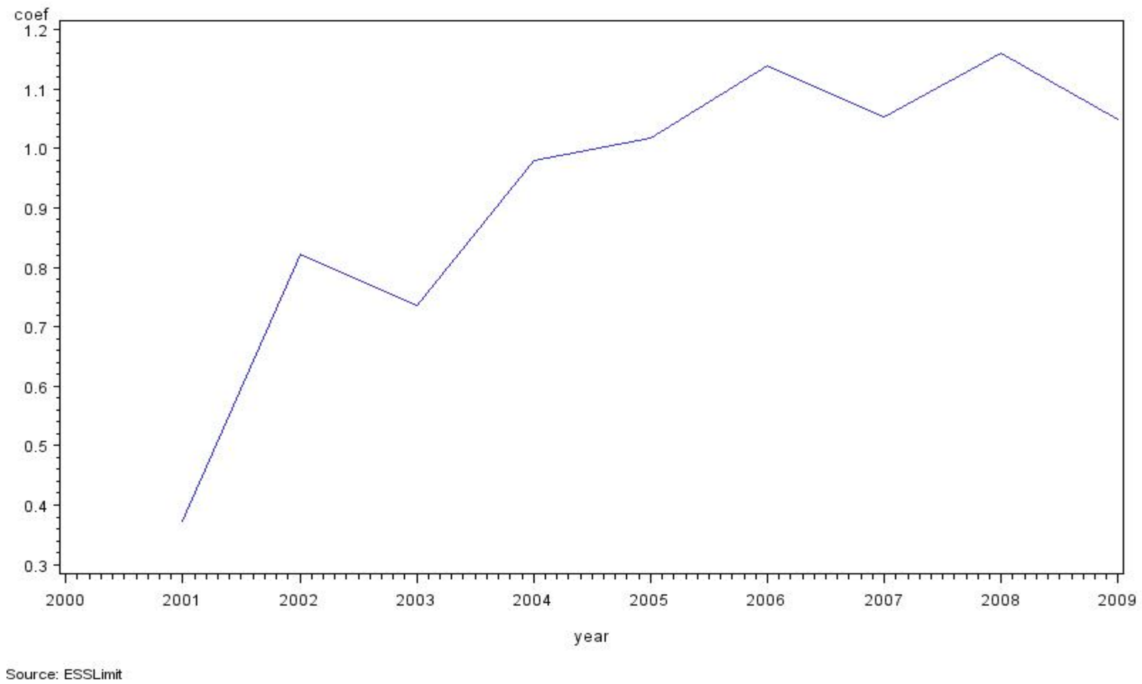
Computer technology is not new, nor is the convergence between computers and communications devices (Licklider and Taylor, 1968). Yet, Brynjolfsson and McAfee make clear why the economic effects we have seen so far are only the tip of the iceberg. When Solow stated his productivity paradox in 1978, computers had been doubling in capability for a mere generation and the stock of computers was small enough that the contribution of computer capital to output still was imperceptible. Using growth accounting methods (see e.g. Jorgenson et al. 2008), the contribution of a productive factor equals its expenditure share of income times the growth rate of the factor input. Unlike at the time of Solow’s quote, computers now actually are ’everywhere’, and the direct contribution of ICT capital to output growth in th past decade was 0.5 to 1 percent per year. With continued exponential decline in ICT prices, and increasing importance of ICT as an input into production, the contribution will increase over time. However, as the nature of the investments and the stock are becoming more intangible, official measures of ICT are seriously understating these effects (see Corrado and Hulten, (2010)).

Some evidence of this point is available from a Eurostat (2012) project, ESSLimit.[3] In Figure 1 we see results from a country/industry/time paneldata regression of labor productivity on the penetration of broadband in firms, as well as on the capital-labor ratio and country, industry and time fixed effects. The penetration of broadband is measured as the percentage of employees with access to broadband internet in firms in each industry. The coefficient on broadband penetration is estimated for each year from 2001 through 2009. The estimated impact of broadband penetration on productivity is seen to increase over time, and by 2008 implies that a 1 percentage point increase in broadband enabled workers increases productivity by slightly more than 1 percent. This does not necessarily mean that the rate of return on ICT is increasing over time. It likely is the case that each broadband enabled worker makes use of associated intangible assets, which are increasing over time. Because we only measure broadband enabled workers and not the service flow resulting from ICT capital, the impact of our proxy is seen to increase, even while the impact of the unmeasured capital service flows may be constant. The increasing coefficient would then be consistent with

[3] www.esslimit.eu.

rising intangibles, which would show up in growth accounting exercises if we had proper statistical measures of intangible investments, stocks, and service flows.

Figure 1. Estimated impact of Broadband on Labor Productivity, by year



Source: Eurostat ESSLimit. The chart shows the coefficients of a cross-country panel data regression of labor productivity on broadband intensity interacted with year dummies. The regression also includes country, industry, and time fixed effects.

The direct contribution of ICT to output through ICT capital deepening, is not the end of the story. Plausible statistical evidence exists that increases in total factor productivity are related to ICT use (Corrado et al, 2008). More convincing is the theoretical link between the use of ICT and the productivity of researchers. ICT can be used to improve productivity in difficult, high skilled tasks, such as research and innovation.

Besides the macroeconomic contributions of ICT capital to output growth, and the possible increase in the pace of innovation and TFP growth, ICT may change market structures. Brynjolfsson and McAfee (2011) stress the wonderful feature of digital technology that runs counter to the economists' favorite feature, scarcity. Information goods are non-rival in use: one person reading their e-book 'Race against the Machine' does not curtail anyone else's ability to read it as well. Even more so, the value of anyone reading the book may go up when others have read it as well. This feature generates markets that do not look like the 'constant returns to scale perfect competition' models used by growth accountants, and opens up the possibility that the invisible hand may not provide desirable outcomes. Income distribution, between capital and labor, and across workers, no longer needs to reflect marginal products, and may change in arbitrary and unexpected ways with changing technology.

To start, the non-rival nature of digital goods and possible network externalities create winner-take-all markets. In such settings, firms risk a fixed investment in return for a chance of winning the market and generating high returns. This type of market structure fits both evidence from specific industries (e.g. Pakes-Erikson 1995), but also the general pattern seen in country-wide firm-level datasets (e.g. Restuccia and Rogerson (2008), Bartelsman et al. (2013)). In these models, labor gets paid its marginal product, but capital receives quasi-rents. Overall, free entry will ensure that expected returns to capital equal the market rate, although successful firms will earn much more.

The widening of the distribution of profits across firms is taking place particularly in sectors that invest heavily in ICT (Brynjolfsson et al. 2009) or Bartelsman et al. (2010). Firms that invest heavily in ICT may arrive at a product/service quality that consumers like, and they can scale up production massively at relatively low costs. Firms that fail to please consumers must shrink and lose their investment. Further, high levels of ICT may increase transparency in markets, and in other ways reduce switching costs of consumers, allowing market shares between firms to be more volatile. However, as yet unexplored empirically, it may be that firms operating in sectors that are more prone to high idiosyncratic shocks invest heavily in ICT, in order to lower adjustment costs and smooth profit flows.

Labor markets also may be affected, especially if ICT is not just a complement to labor in production. In a fairly recent book, Levy and Murnane (2004) argue that only well specified routine tasks can be automated, and that "...computers cannot easily substitute for humans [in jobs like truck driving]". Just seven years later, Brynjolfsson and McAfee drily point to the annual advances in the DARPA Grand Challenge where driverless trucks navigate challenging courses and to the 1/2 million miles driven by Google's driverless cars without causing accidents. Moore's law is relentless: if it is too expensive to replace a taxi-plus-driver with a driverless Google Car today, just wait another few years.

Many more examples are given in the book, and more can be found in daily articles, ranging from IBM's Watson computer that won the Jeopardy game show to expert systems that outperform lawyers in legal research. Recent reports of robots used in shaver factories or restaurants, show that automation not only can replace routine manual work, but also non-routine manual/physical and routine cognitive tasks.

To understand the distributional effects of ICT on labor markets, the best framework now is provided by Acemoglu and Autor (2011). They posit a model with workers of differing skill levels that can undertake different tasks. The tasks that are undertaken in an economy generate the (differentiated) economic goods that are produced. In their framework, ICT can be modeled as complementary to certain types of skills, but also could be a perfect substitute for labor in performing certain tasks. Workers of each skill type perform tasks based on their comparative advantage. But, they also compete against ICT capital, which may undercut the cheapest type of labor available for the task. In this model, it seems clear that over time the range of tasks that can be substituted away will increase over time, along with Moore's law. However it is unlikely that humans will not continue to come up with demanded tasks that require human labor input.[4]

In Acemoglu and Autor, empirical exercises are conducted, mapping skill (education) and tasks, to labor quantity and wages. Their framework makes a plausible case that advancing ICT has increased demand for both high and low skilled workers, and reduced wages of medium skilled, through the pattern of tasks that were substituted over time. The important insight in this work is not that high-skilled win and medium-skilled lose, but that the pattern

[4]See the data appendix of Acemoglu and Autor (2011) for a list of work activities, aggregated into tasks ranked by substitutability.

of changes depends crucially on the tasks that are substituted by computers and the relative productivity of different types of workers in each task. One would need to carefully track ongoing advances in ICT to understand which tasks are next to be taken over by machines.

Finally, what does increasing ICT mean for aggregate productivity growth over the next 20-30 years? We can make a guess about the hours spent at present tasks that could be substituted away in the next generation, say 25 years, using technology currently in the pipeline. Take just three technologies: driverless cars, universal multi-jointed robots, and data-driven expert systems. Households in the USA drive 3 trillion miles per year, which for the 150 million drivers, driving at an average of 40 mph, leads to 500 hours, or ten hours per week, or about 25 percent of working time. Add to this half of the 8 million workers in transportation and materials moving occupations, or another 4 percent of the workforce, for 30 percent savings. Inexpensive industrial robots, flexible and trainable, are starting to come online. If they can provide in the next 25 years a 50 percent reduction in labor needed for todays tasks in food preparation (not cooks), janitorial services, and production lines, that is another 12 million workers, or 10 percent of the workforce. Finally, a mix of computers, databases, vehicles, and robots could shave 50 percent off the tasks for cashiers, office administrators and construction workers, for another 15 million workers saved, or 12 percent of the workforce. All told, a very conservative guess, with a limited set of occupations viewed and no future technologies assumed, can easily double productivity in 25 years.

The bottom line is that labor productivity growth of 2.5 percent per year is attainable. However, this achievement requires massive reallocation of workers. The improvements do not come through doubling the speed of every cashier, or doubling the efficiency of every taxi driver, but come through firing half the cashiers and all the taxi drivers. To convert the productivity advances into output growth, this needs to be accompanied by reallocating workers to other paid tasks, providing goods and services for which there is demand. And, demand is held back, unless disposable income is well enough distributed to generate the volume of sales needed to support the intangible-intensive products.

In the medium- to long-run, it is hard to predict how the expansion of the production possibilities afforded by ICT will affect hours worked. Over longer periods of history, the trend has been towards shorter work weeks in response to productivity growth. However, demographic trends point towards limited supply of available workers and increased demand by the elderly for what at present are labor-intensive services. This may put upward pressure on working hours. Further, the nature of ICT is changing the boundaries between work and leisure and the necessity for synchronization in time and space of labor input into production. It is unclear if social norms, centralized bargaining outcomes, or laws concerning the length and pattern of the standard work-week will be welfare improving or not. This issue is beyond the scope of this paper.

In the short-run, adoption of ICT will generate shifts in the demand for labor. The tasks for which computers are substitutes no longer will be needed, while tasks that are complementary to ICT will need to be staffed at higher levels. Sometimes, the shifts will be gradual and occur within firms or between tasks that require similarly skilled of schooled workers. For example, the shift to the self-driving vehicle may occur smoothly, as drivers become driver-seat ’caretakers’ because consumers may not be ready for driverless transport. Other times, sudden breaks may occur requiring reallocation of workers across firms, industries, and occupations. For example disruptive innovations may change complete production chains. In either case resources will need to be reallocated although the pace may vary.

In this section, we have considered how Moore's law will continue to affect the economy. We have expanded the growth accounting framework to allow for high fixed cost, low marginal cost production and considered what this may mean for firms and workers. Considering the adoption currently existing (but not yet market ready) technologies, we find it feasible that labor productivity can grow 2.5 percent per year over the next generation. However, to turn the productivity increase into output and welfare, considerable reallocation of labor needs to take place.

The next section turns to evidence on the current process of reallocation across firms in the business sector. For a selection of EU countries, various indicators describing the evolution of employment and productivity as well as the pace and direction of resource reallocation will be given. We will see how the indicators vary across sectors, but especially across countries in the EU.

4. Evidence on Reallocation

In order to enjoy the benefits of advances in productivity brought about by Moore's Law, workers will need to reallocate between tasks, jobs, and occupations. In this section, we will consider how the process of reallocation has taken place in different sectors in a selection of EU member countries.

The empirical evidence on the patterns of reallocation derives mainly from an ongoing Eurostat ESSnet project.[5] In this project, fifteen National Statistical Institutes collaborate to generate harmonized indicators of firm dynamics, reallocation, innovation, ICT use, and productivity from underlying linked-longitudinal firm-level surveys and registers. The data pertain to the period 2001 through 2009, and cover manufacturing, trade, and business service sectors of the economy.

The exhibits presented in this paper are selected from the ESSLimit (2012) Final Report.[6] A full description of the sources and methodology may be found in the Final Report as well.

We start with some tables describing firm demographics. The basic fact of sizable turnover of firms—entry and exit—and turnover of jobs—job creation and destruction—have by now been well documented for a wide range of countries. Eurostat publishes business dynamics indicators as part of the regular annual collection of structural business statistics and makes these available online (Eurostat-OECD, 2007).

Table 1 shows averages of firm turnover rates for 2003-2007, entry rates for 2003-2007, 2008 and 2009, and exit rates for 2003-2007 and 2008, for 3 industry subgroups and 15 countries.[7] For consistency with the earlier literature (e.g. Bartelsman et al. 2004), we define entrants, exiters, continuing firms, and one-year firms. Exiters in year t exist in year $t-1$ and year t, but not in year $t+1$, entrants in year t exist in year t and $t+1$, continuers exist in all three years, while one-year firms only exist in year t. The entry rate in year t divides the

[5] www.esslimit.eu

[6] A selection of the micro-aggregated indicators is available for researchers after completion of the ESSLimit project in November 2012.

[7] The demographics data are sourced from the ESSLimit project, for comparability with other firm-level indicators presented in this paper. For official published indicators of business demography, please refer to the Eurostat website instead.

number of entrants by all firms in existance in year t, except for the one-year firms. Likewise, definitions are made for exit rates and turnover rates.

Table 1. Firm Turnover, Entry Rates, Exit Rates

Industry	Country	Gross turnover	Entry Rate			Exit Rate	
		2003-2007	2003-2007	2008	2009	2003-2007	2008
Manufacturing	DE	6.9	2.9	3.1	3.4	4.0	3.6
excl.	DK	9.7	4.8	5.1	4.1	4.8	4.0
ICT	FR	7.5	2.7	4.7	3.4	4.7	5.4
	IE	16.3	7.3	8.9	3.0	9.1	7.3
	IT	13.3	6.0	5.8	1.0	7.3	7.6
	LU	6.8	3.9	3.1	2.6	2.9	2.6
	NL	15.0	8.5	9.2	7.5	6.5	.
	NO	7.3	4.6	3.6	3.5	2.7	2.2
	SE	7.1	3.7	4.1	4.1	3.4	3.2
	SI	7.3	3.8	5.1	5.1	3.5	3.0
	UK	16.6	7.2	9.8	4.0	9.3	8.6
Services	DE	10.9	6.0	6.5	7.1	4.9	4.2
excl.	DK	11.9	6.6	6.8	5.8	5.3	5.1
ICT	FI	17.0	9.6	10.5	11.3	7.3	7.2
	FR	8.5	4.0	6.5	4.8	4.5	5.4
	IE	39.6	27.9	11.4	8.5	11.7	21.9
	IT	16.1	8.4	7.7	1.6	7.7	7.9
	LU	11.9	7.7	8.2	7.8	4.2	4.0
	NL	22.0	13.9	13.2	20.7	8.1	.
	NO	11.7	8.4	6.0	5.6	3.3	2.6
	SE	11.2	6.8	7.6	7.7	4.4	4.2
	SI	11.4	7.2	9.6	11.1	4.1	3.9
	UK	22.2	11.8	14.9	7.2	10.3	11.4
ICT	DE	9.6	5.1	5.7	7.3	4.5	4.5
	DK	10.9	6.1	5.7	4.5	4.9	5.6
	FI	14.4	7.5	7.9	8.3	6.9	6.2
	FR	5.9	2.0	3.1	2.0	3.9	4.4
	IE	41.5	27.5	7.5	7.0	14.0	22.8
	IT	14.0	6.6	8.8	2.3	7.4	7.8
	LU	10.4	7.0	3.9	4.3	3.5	3.9
	NL	22.5	12.3	12.9	11.2	10.1	.
	NO	13.9	10.3	7.1	5.9	3.6	2.8
	SE	8.0	4.6	4.2	4.8	3.4	2.7
	SI	7.5	4.4	5.9	6.7	3.1	3.4
	UK	24.3	12.0	14.5	9.7	12.4	11.8

Source: ESSLimit.

The columns for 2008 and 2009 for firm entry and exit rates show that overall exit rates did not seem to rise in 2008. Unfortunately, the 2009 data do not provide information about exit in 2009 as it is an inferred indicator created by *not* observing the firm in the 2010 data. It seems reasonable to expect that exit rates will increase in 2009, as they have in earlier recessions. However, a worrisome possibility may be that firms with debt and poor productivity are being kept alive by banks so that no write-offs need to be taken (Caballero 2007). These ’zombie’ firms are preventing the economy from using resources that would be freed up by exit in more productive places.

Entry rates in some countries decline in 2008 and 2009, but in Germany and Sweden, for example, entry rates in 2009 are higher in all three sectors compared to the 2003-2007 average. However, in other countries, the entry rates in 2009 are generally down compared to the earlier average. It is to be expected that in countries with weak social safety nets, individuals will be ’pushed’ into entrepreneurship, thereby increasing entry.

Overall, we see that turnover varies across countries and across industries; the main observation is that all markets seem to be characterized by fairly high levels of such turnover. A naive view that well functioning economies are characterized by high turnover rates and sclerotic economies by low rates does not find confirmation in the data. Indeed, in early work, Caballero and Hammour (1998) discusses the problem of ’improper churn’, whereby turnover by itself is not an indicator of proper policy. In a recent paper, Cabral (2012) suggests that certain policies can create inefficient entry barriers, but others can create inefficient survival barriers. Turnover drops with one set of inefficient policies, but rises with the other. We will return to this issue in section 5.

Table 2 shows information about the size distribution of firms in each country for a selection of industries. In the first four columns we see the share of firms in each size class and in the second set of four columns we see the employment share by firm size class. As expected, most firms are small, while the highest share of employment is found in large firms, in all sectors and countries, except Italy. Conforming to earlier findings (Bartelsman et al. 2004), we see that Italy has a relatively high amount of employment in small firms.

Policy makers have often supported small firms, in the belief that they are the engines of job growth. However, Haltiwanger et al. (2013) show that after conditioning on firm age, no relationship exists between firm size and growth.[8] Nonetheless, the size distribution of firms may provide information on the role of policy barriers, for example by providing disincentive owing to regulations biting for firms above certain size thresholds.

[8] Unfortunately, the ESSLimit project has not yet been able to compile comparable indicators of firm age across countries, in order to provide tabulations related to the firm size distribution and the evolution of firms from birth onward.

Table 2. Size distributions of firms and employment

Industry	Country	Share of Firms by size class				Share of Employment by size class			
		1–19	20–49	50–249	250–>	1–19	20–49	50–249	250–>
Manufacturing	DE	80.1	10.3	7.7	2.0	12.1	9.4	24.2	54.3
excl.	DK	77.9	12.3	8.1	1.7	14.7	12.7	27.7	44.9
ICT	FI	90.7	5.0	3.4	0.9	16.6	11.0	24.7	47.7
	FR	78.3	12.9	7.0	1.8	15.8	13.1	23.4	47.8
	IE	63.1	20.3	13.5	3.1	12.5	15.0	32.7	39.8
	IT	93.0	4.8	2.0	0.3	41.4	16.1	21.0	21.4
	LU	73.3	12.3	10.6	3.7	8.4	7.9	21.9	61.8
	NL	87.8	6.8	4.3	1.1	17.4	12.2	26.0	44.4
	NO	83.2	9.8	5.8	1.2	18.5	14.3	27.5	39.7
	SE	84.6	8.5	5.5	1.4	16.2	10.7	23.0	50.1
	SI	90.9	4.3	3.8	1.0	18.9	9.2	28.5	43.4
	UK	86.4	7.5	4.8	1.2	17.8	11.4	24.5	46.4
Services	DE	93.1	4.3	2.2	0.4	30.4	12.1	20.5	37.1
excl.	DK	92.0	5.2	2.3	0.4	32.1	14.1	20.4	33.5
ICT	FI	97.2	1.8	0.8	0.2	38.5	11.1	15.4	35.0
	FR	88.8	7.5	3.1	0.7	27.6	13.8	18.7	39.8
	IE	88.8	7.1	3.5	0.6	31.0	14.3	21.0	33.7
	IT	98.8	0.8	0.3	0.1	62.9	7.1	9.5	20.5
	LU	92.0	4.7	2.7	0.7	26.7	12.1	23.0	38.2
	NL	96.6	2.2	1.0	0.2	35.4	10.1	15.0	39.5
	NO	94.1	4.0	1.5	0.3	39.1	13.6	17.6	29.8
	SE	94.7	3.5	1.5	0.3	38.0	12.8	17.3	31.9
	SI	97.4	1.7	0.8	0.1	48.6	10.9	15.9	24.6
	UK	95.5	2.8	1.3	0.3	28.9	8.3	12.9	49.9
ICT	DE	82.1	9.4	6.5	1.9	10.0	7.1	16.8	66.1
	DK	77.5	11.2	8.3	3.0	6.7	6.3	15.8	71.2
	FI	86.6	6.1	5.2	2.1	6.7	4.7	14.3	74.3
	FR	81.2	11.0	6.1	1.7	12.1	8.9	16.4	62.5
	IE	79.8	7.1	8.7	4.4	5.0	3.4	14.2	77.5
	IT	94.1	3.8	1.8	0.3	23.0	9.1	13.5	54.5
	LU	78.8	10.1	8.5	2.5	9.1	7.2	17.5	66.2
	NL	93.5	3.6	2.0	0.9	10.3	4.7	8.9	76.1
	NO	87.9	6.0	5.0	1.2	9.7	6.4	17.2	66.6
	SE	83.1	8.7	6.2	2.1	7.5	5.4	13.0	74.0
	SI	91.4	3.7	3.4	1.4	11.3	5.6	19.8	63.3
	UK	90.0	5.4	3.6	1.0	10.4	6.3	14.4	68.9

Source: ESSLimit.

The next set of tables looks at job reallocation, using the measures developed by Haltiwanger and Davis (1992). Similar to findings of Haltiwanger et al. (2008), gross job turnover is on the order of 25 percent. A significant part of the variation can be explained by size and industry effects. Indeed, job flows are seen to be much higher for small firms.[9] However,

[9]As discussed by Haltiwanger et al. (2013), the higher job flows mostly related to age of the

even when controlling for size and industry, the remaining variation can partly be explained by cross-country differences in regulation. Job turnover in countries with high employment protection and firing costs is relatively lower in those industries that require more job reallocation, where the latter is measured as turnover in the relevant industry in the USA.

The measures of Job creation, destruction and reallocation are defined as follows:

- Job creation (JC_{jt}) captures the amount of jobs created, as a fraction of total employment, in period t, in industry j of firms. It is defined as

$$JC_{jt} = \sum_{i \in j} w_{it} \, (\Delta L_{it}^{+} / \tilde{L}_{it}),$$

- for industry j, in year t, where i indexes firms, ΔL_{it}^{+} is positive employment change from the previous year, $\tilde{L}_{it}$ is average employment over year t and $t-1$: $\tilde{L}_{it} = 0.5(L_{it} + L_{it-1})$, and the weight is the ratio of mean-employment over total mean-employment in the firm-group: $w_{it} = \frac{\widetilde{L_{it}}}{\sum_{i \in j} \widetilde{L_{it}}}$.[10] This is the notation used below when not indicated otherwise.

- Job destruction (JD_{it}) measures the amount of jobs lost, as a fraction of total employment, from period $t-1$ to t:

$$JD_{jt} = \sum_{i \in j} w_{it} \, (\Delta L_{it}^{-} / \tilde{L}_{it}),$$

- where ΔL_{it}^{-} is negative employment change.

- Net employment growth is the differences between job creation and destruction, and shows the total employment change in the group j:

$$\Delta L_{jt} = JC_{jt} - JD_{jt}$$

- Excess job reallocation express the degree firm-level job creation or destruction (i.e. turnover) which comes on top of what would be necessary to generate the observed net employment change:

$$EJRA_{jt} = JC_{jt} + JD_{jt} - |\Delta L_{jt}|$$

This is our preferred measure of labor market turbulence, as this shows the amount of micro-economic adjustments which are hidden behind the aggregate patterns; it essentially controls for aggregate shocks and only focuses on micro-level phenomena.

These indicators are generated from te firm-level data for each detailed industry. In table 3 we show data on average excess job reallocation for 2003-2007, for 3 industry subgroups and

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firm, with age and size of firm being positively correlated.

[10]The advantage of using such two-period average wages is that the resulting firm-level employment change number is bounded by the interval $[-2,2]$, and it is equal to the log approximation to percentage change up to second order (Davis and Haltiwanger 1999).

14 countries. In general, excess job reallocation is higher in serices than in manufacturing. Also, the job creation rate is generally higher than the destruction rate in services, while the opposite is true, in the 2003-2007 period in manufacturing. Overall, we see that the job creation rate has declined in 2009 compared to the earlier average in most sectors and countries, except in Germany. The next columns show job destruction rates, with averages for 2003-2007 and annual rates for 2008 and 2009. The job destruction rates also seem to have gone up in 2009 in all countries, except in Germany. Some care needs to be taken, because the employment data are derived from 'business registers', and not from the typical employment source data available at statistical agencies. Often, information on employment in these business registers, which serve as the sample frame for surveys and as the 'backbone' for modern statistical processing of firm-level data, get updated over time as new information becomes available.

Table 3. Excess Job Reallocation, Job Creation and Destruction

Industry	Country	Excess JR	Job Creation			Job Destruction		
		2003-2007	2003-2007	2008	2009	2003-2007	2008	2009
Manufacturing	DE	12.6	6.3	6.1	6.7	8.0	6.9	5.1
excl.	DK	9.6	6.5	6.8	2.0	5.9	7.4	24.9
ICT	FI	16.0	8.6	7.9	4.9	9.0	8.7	16.5
	FR	8.8	4.4	5.4	6.0	6.3	8.4	7.4
	IE	28.8	19.0	6.4	8.7	23.5	11.5	15.9
	IT	16.9	8.8	8.7	4.8	9.1	9.3	12.4
	LU	0.6	1.4	1.6	0.1	0.5	0.9	2.4
	NL	10.4	6.1	9.3	7.6	8.4	2.8	.
	NO	11.8	6.1	5.9	3.6	7.9	5.9	12.4
	SE	12.5	7.6	6.1	4.0	6.6	6.1	15.2
	SI	11.1	6.3	4.9	3.1	6.3	8.7	17.7
	UK	16.9	8.4	10.4	7.6	13.3	11.3	16.6
Services	DE	19.9	10.5	11.4	11.5	10.5	7.6	7.3
excl.	DK	15.7	12.4	9.5	9.4	7.9	6.6	14.2
ICT	FI	17.3	11.3	12.1	10.8	8.9	10.1	12.5
	FR	14.8	8.9	9.1	9.8	7.7	8.6	7.3
	IE	34.0	29.3	19.6	9.5	27.7	27.7	22.0
	IT	19.3	12.5	12.5	7.9	9.6	9.9	12.8
	LU	7.2	7.2	8.8	7.1	3.6	3.2	4.2
	NL	20.8	13.5	14.0	20.6	11.6	4.5	.
	NO	16.3	14.2	15.1	12.1	8.2	5.9	14.5
	PL	18.0	13.3	16.7	16.6	9.0	7.8	8.3
	RO	25.5	19.0	17.8	12.1	12.8	11.6	17.1
	SE	18.4	13.7	14.1	12.2	9.2	8.4	11.7
	SI	12.8	9.8	10.3	7.8	6.4	6.5	9.7
	UK	24.8	14.3	15.3	11.5	13.2	16.5	11.1
ICT	DE	14.2	7.3	8.4	8.9	8.2	9.3	8.1
	DK	12.0	9.9	9.6	2.3	6.8	6.5	14.1
	FI	15.3	7.6	5.5	2.7	10.9	6.1	9.0
	FR	8.3	4.3	4.6	5.2	6.3	7.2	7.2
	IE	19.1	15.4	11.4	6.0	15.4	23.3	16.1
	IT	15.9	8.3	6.1	3.7	8.8	6.9	8.0

	LU	3.1	4.2	1.9	2.3	1.6	2.2	1.3
	NL	11.4	6.3	5.5	6.2	9.1	10.3	.
	NO	8.5	6.9	4.8	4.5	9.0	2.8	15.9
	SE	24.4	26.2	6.2	7.1	14.7	5.8	8.2
	SI	9.7	5.5	5.1	2.2	5.0	5.7	10.8
	UK	14.5	7.3	7.8	5.9	13.2	9.1	9.1

Source: ESSLimit. The table shows average values (over industries) for excess job reallocation, job creation, and job destruction for the periods shown. The definitions for the job flow measures are given in the text.

A next set of indicators of reallocation are related to productivity. In the early literature documenting reallocation processes in industries, a set of statistical measures were collected that decomposed productivity growth into the contributions of entry, exit, reallocation and within-firm growth (Foster, Haltiwanger and Krizan 2001). Those so-called FHK measures have been subject to criticism, as they are sensitive to the length of the window used for differencing.

In most empirical exercises described in the literature, the growth contributions of each component was computed for a five-year or three-year window (see e.g. Bartelsman et al. 2004). In the ESSLimit projects, where the emphasis of the project was on the link between ICT indicators and productivity, the available time-spans of firm-level data were relatively short. For this reason, we do not find it informative to report on the FHK indicators.

In table 4 we turn to more recent measures of (mis)allocation. In a recent publication of Bartelsman et al. (2013) three different measures of (mis)allocation are compared and contrasted. The first column, labeled OP-Gap, was introduced by Olley and Pakes (1996) and measures the difference between weighted and unweighted (log) productivity or, equivalently, the covariance between the (log) of output per worker and firm size. Intuitively, if more productive firms are larger, aggregate productivity, which is the (employment) weighted average of firm-level productivity, will be larger. In Bartelsman et al. (2013), it is shown that in an equilibrium of a heterogeneous firm model, a the OP-gap moves monotonically with per capita consumption and is thus a proxy for welfare.

The next columns measure the dispersion of productivity (the standard deviation of the firm-level distribution of (log) output per worker, σ_{LP} and TFP, σ_{TFP}), as developed by Hsieh and Klenow (2008). Their story is that with ineffective competition, low productivity firms are able to remain in business, thus widening the dispersion of productivity. This may be the case, but the measure may be influenced by entry and exit, or firm selection, as emphasized by Bartelsman et al. (2013).

The timeseries of the three measures do not very systematically over this period, although the dispersion measure is more volatile than the covariance measure. Therefore, the measures are averaged over the available years. For comparison across countries, the indicators are averaged over the detailed industries comprising each of the three aggregate sectors.[11]

Overall, we see the Nordic countries with high levels of the OP-gap indicator, while the transition economies have low values. This is in accordance with the theoretical story in

[11]As described in Bartelsman et al. (2013), the sub-industry indicators are aggregated using the same weights for each country. The weights reflect the employment share of the industry for all countries considered.

Bartelsman et al. (2013) who related the indicator to policy induced distortions to profits. An odd finding is that Denmark has such a low level of this indicator. Also in very recent work by Andrews and Cingano (2012), using the publically available ORBIS database, Denmark has a substantially lower level of this measure of allocative efficiency. As yet, we have no explanation for this finding.

Table 4. Moments related to (Mis)allocation (avg 2003-2009)

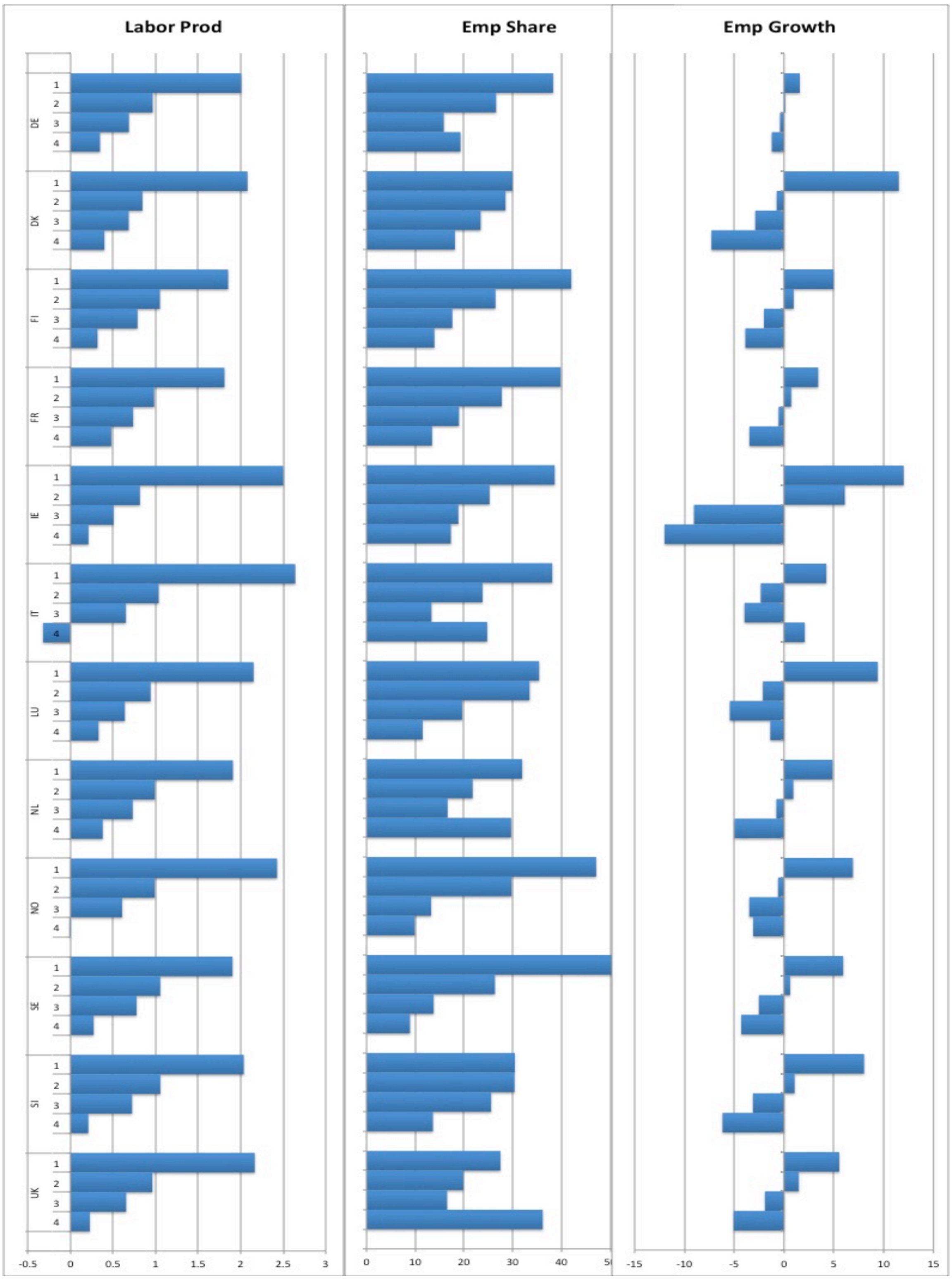
Industry	Country	OP-gap	σ_{LP}	σ_{TFP}	Churn	JD Exit	Sz En/Co
Manufacturing	DE	0.42	0.85	0.19	0.10	42	66
excl.	DK	0.08	0.72	0.24	0.17	24	30
ICT	FI	0.42	0.70	0.40	0.13	41	50
	FR	0.21	0.76	0.23	0.13	27	33
	IE	−0.12	0.82	.	0.23	40	48
	IT	0.42	1.00	0.38	0.16	33	33
	LU	0.41	0.89	.	0.12	24	8
	NL	0.38	0.83	0.21	0.13	46	75
	NO	0.58	0.97	0.38	0.18	30	30
	SE	0.49	0.85	0.38	0.18	23	34
	SI	0.40	0.91	.	0.16	11	29
	UK	0.32	0.84	0.43	0.13	55	37
Services	DE	0.05	1.03	0.26	0.19	33	43
excl.	DK	−0.18	0.89	0.32	0.25	31	44
ICT	FI	0.14	0.77	0.44	0.17	39	33
	FR	−0.10	0.78	0.34	0.15	27	43
	IE	−3.67	0.63	.	0.48	51	55
	IT	0.02	1.13	0.48	0.22	47	48
	LU	−0.16	1.07	.	0.25	13	10
	NL	0.32	1.03	0.29	0.11	44	75
	NO	0.29	0.94	0.43	0.19	35	36
	SE	0.19	0.88	0.56	0.26	31	41
	SI	0.06	0.99	.	0.29	19	32
	UK	0.10	1.12	0.65	0.12	56	39
ICT	DE	0.46	1.10	0.15	0.11	36	34
	DK	−0.15	0.83	0.35	0.22	15	25
	FI	0.38	0.82	0.53	0.16	35	11
	FR	0.34	0.99	0.46	0.12	24	27
	IE	−0.48	0.46	.	0.13	42	41
	IT	0.30	1.22	0.57	0.16	40	22
	LU	0.02	1.05	.	0.21	6	7
	NL	0.63	1.04	0.33	0.18	37	93
	NO	0.57	1.01	0.47	0.15	27	11
	SE	0.32	1.03	0.58	0.27	21	106
	SI	0.12	1.04	.	0.15	8	11
	UK	0.23	1.10	0.60	0.13	50	17

Source: ESSLimit. The moments are averaged over time and across industries. The OP-Gap measures the difference between the weighted and unweighted average of (log) labor productivity. The σ_{LP} and σ_{TFP} columns present the standard deviation of the distribution across firms of labor productivity and TFP. The column ’Churn’ measures the sum of the absolute value of market share changes of firms in an industry. ’JD Exit’ is the share of job destruction taking place through firm exit and the column labeled ’Sz EN/CO’ is the ratio of the size of entrants relative to continuing firms.

To the three moments discussed by Bartelsman et al. (2013), we add a measure of ’churn’, namely the sum of the absolute value of market share changes of firms in an industry. This indicator can pick up changes in firm composition inside an industry, for example because of disruptive innovation occurring in some firms. The column JD exit describes the share of job destruction that takes place through firm exit. In general, if a country has high firing costs, firms may hold on to workers and stay in the market until their productivity fails below a very low threshold. If the JD Exit indicator is high, it might be a sign that poorly performing firms stay in the market too long or that firms are not able to adjust their labor force without exiting. Finally, the column labeled ’SZ En/Co’, is the relative size of entrants compared to continuing firms. This indicator may be related to the types of financing available to entrants. With venture capital and angel investment, firms usually start small but with a wide variety of business strategies. With more reliance on bank financing, entrants are more similar to incumbents but generally utilize known technologies.

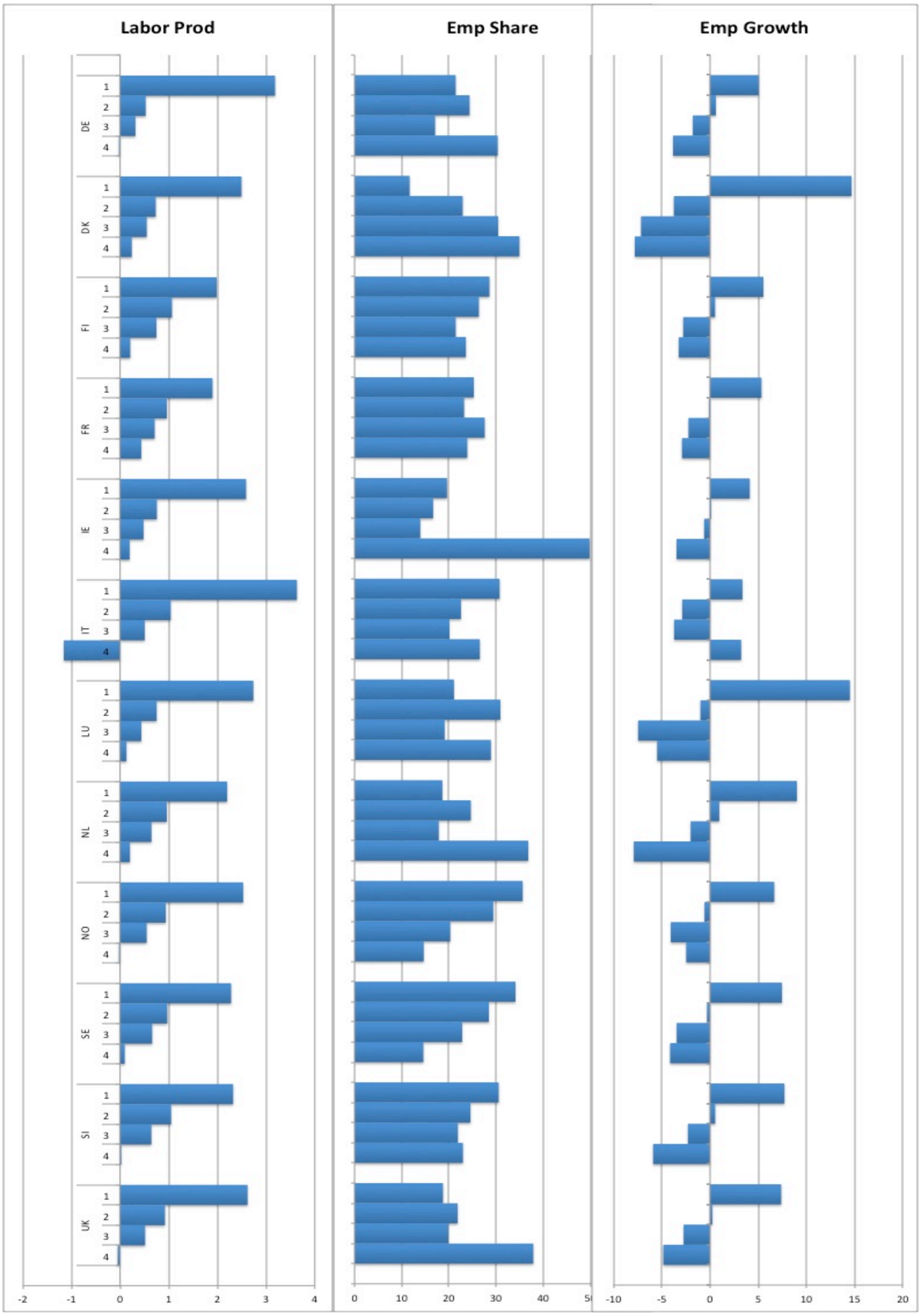
The OP-gap measure is static, in the sense that it only looks at whether more productive firms are larger at a particular point in time. Intuitively, economies should exhibit the tendency for more productive firms to grow larger, and less productive firms to shrink or exit. Or, if there are impediments to reallocation, this pattern may not occur. To get a more dynamic view of business sector developments, we refer to chart 2 through chart 4. These charts show the productivity differences across quartiles of the productivity distribution, market shares by productivity quartile, but also growth rates of firms by quartile of productivity. A positive correlation between productivity and firm size, as captured by the OP-gap, would be a sign that resources are not seriously misallocated. A positive correlation between (lagged) productivity and firm size growth is a sign that allocation is moving in a direction to boost aggregate productivity.

Figure 2. (Re)Allocation by quartile, Manufacturing excl. ICT (2002-2009)



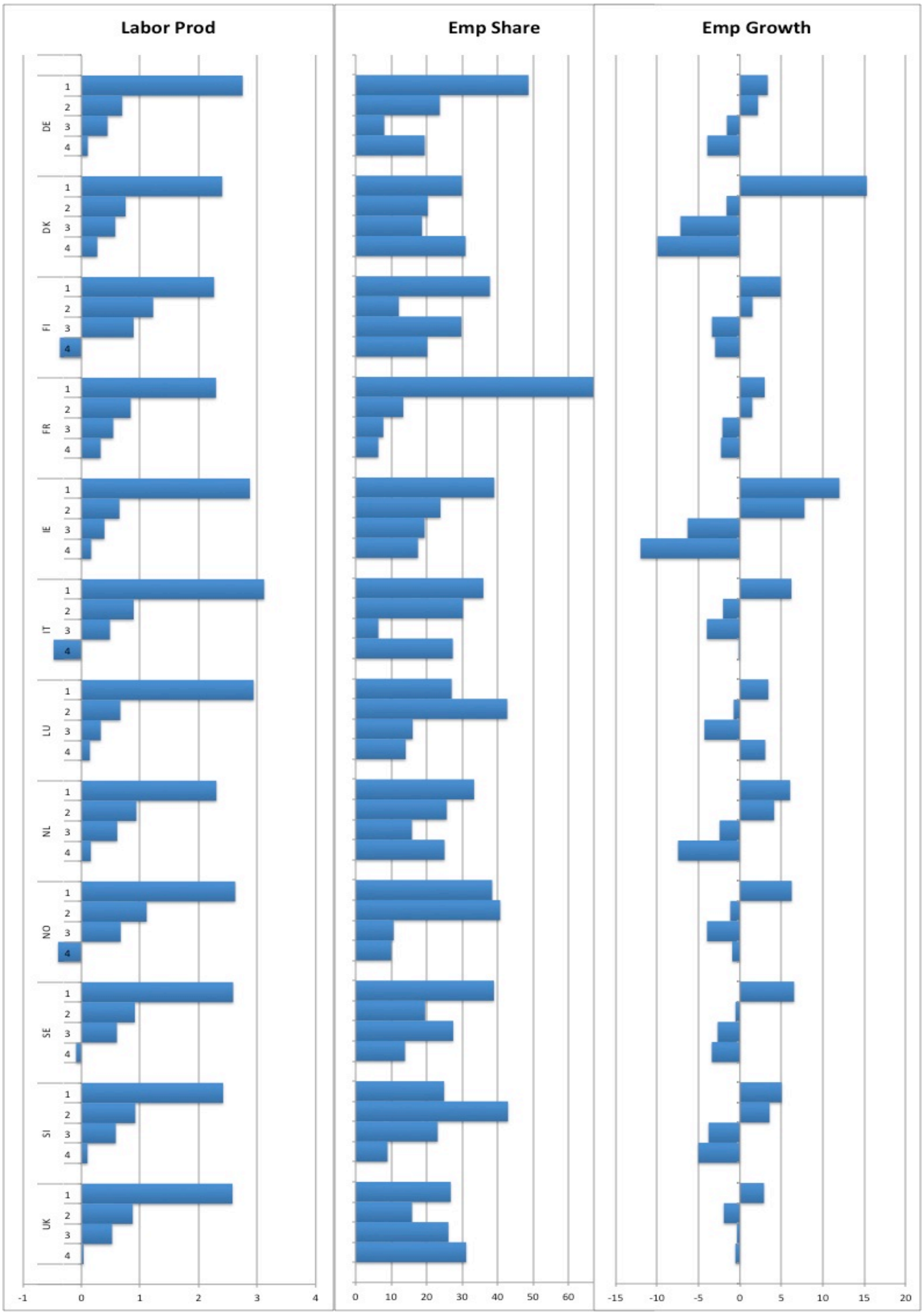
Source: ESSLimit. Quartiles are defined on the level of labor productivity of firms within an industry (or lagged level, for the last column). The highest productivity quartile is labeled with ’1’, the lowest with ’4’. The horizontal axis for labor productivity measures the average level of productivity for firms within each quartile in the industry relative to the industry mean. The horizontal axis for employment share measures the share of employment in firms in each labor productivity quartile. The horizontal axis for employment growth measures the average employment growth of firms in each quartile (of lagged productivity) minus the industry employment growth rate. The indicators for each industry and year are averaged across years and then a weighted average over industries is taken using the same weights for each country.

Figure 3. (Re)Allocation by quartile, Market Services excl. ICT (2002-2009)



Source: ESSLimit. See description of figure 2 for details.

Figure 4. (Re)Allocation by quartile, Electrical and Communications Eqpt. ICT (2002-2009)



Source: ESSLimit. See description of figure 2 for details.

Looking at the manufacturing (excluding ICT) sector, we see wide productivity distributions in Ireland and Italy. The bar, for each quartile of the productivity distribution, shows the average productivity of firms in that quartile, relative to the unweighted average firm-level productivity in the industry. The productivity measure is based on the relative productivity in the quartile for each of the underlying 2-digit NACE industries. For each aggregate sector we take a weighted average across the component 2-digit industries, where the weights are weighted-averages for the industries across our 15 countries. The next column of charts shows the share of employment in the firms in each productivity quartile. In ten of the fifteen countries, the employment shares are monotonic in productivity quartile, but many are not very strongly correlated. In Norway and Sweden the relationship is quite strong (as we already saw with the OP-gap). Interestingly, in the UK, the lowest productivity quartile employs the highest share of workers. In policy circles in the UK this often is referred to as the problem of the long-tail of productivity. The final column of charts shows the growth of employment in firms in each quartile of lagged productivity (averaged across 2-digit industries), relative to industry employment growth. Denmark and Ireland have particularly strong correlation between growth and (lagged) productivity quartile. The relation is non-monotonic in only three countries, but the differences across quartiles are very small in Germany and France. This indicates that the pace of reallocation towards more productive firms is not very high. Interestingly, the churn measure shown earlier is lowest for Germany and among the lowest for France.

In the service sector (excluding ICT), chart 3, we see a wider distribution in productivity than in Manufacturing. The best quartile of firms are three times as productive as the average firm (compared to a ratio of 2.5 in manufacturing). In contrast to manufacturing, the employment distribution is monotonic with productivity quartile in only two countries, Norway and Sweden. Again, in the UK, but also in Ireland, the quartile of low productivity firms has the highest share of employment. The dynamic reallocation column shows monotonicity with productivity in all but three countries. The strongest effects are visible in Denmark and Slovenia, while again, Germany and France do not show much differential movement in employment across quartiles.

Finally, in chart 4, we see the indicators for the electric equipment and communications industries. We notice that the relative productivity of the top quartile is quite far ahead of the other quartiles, much more so than in the other sectors. The static allocation of employment is monotonic with productivity quartile in only two countries, France and Ireland. In France, more than sixty percent of the workforce is employed with the best firms in this sector. Dynamic reallocation is non-monotonic in three countries, and the rates are small in France and the UK, while they are very differentiated in Denmark.

Closing the section on reallocation indicators, we explore the possibility that firm turnover, job reallocation, and cross sectional dispersion in productivity systematically vary with ongoing use of technology. As suggested in section 3, adoption of ICT may be associated with the need for reallocation. Further, ICT technology may be associated with winner-take-all markets, so that firm size correlates more strongly with productivity. On the other hand, it may be that firms in industries subject to frequent and large shocks to supply and demand conditions, may adopt ICT to reduce costs associated with response to shocks. Regardless of the direction of causality, the stories suggest a positive correlation between ICT and measures of reallocation.

To investigate this, we use data from productivity surveys (with firm-level input and output measures) linked to data from the EU ICT Usage survey (with firm-level information on various types of ICT). This excercise is conducted for a subset of six EU countries for which firm-level data are available for a long time span, roughly 1995-2009. We look at the timeseries and cross-sectional distribution of employment growth and output growth for ICT intensive firms and non-ICT intensive firms. At the firm-level, we determine which firms are ICT intensive and which are not, based upon the share of workers in a firm with access to broadband internet in the period 2002-2009.[12]

As seen in table 5, the dispersion measures are higher for ICT intensive firms, except in France. In the first two columns we see the average standard deviation of the firm-level timeseries of labor productivity growth. This is measured at the firm-level using a 5-year moving window. The firm-level dispersion is averaged into an industry series, using firm-size weights. Finally, the industry dispersion is averaged over the period 2003-2007 (thus using underlying firm-level data from 2001-2009). The first column uses data from those firms that we label non-ICT intensive. This is done through linking of the firm level production data with firm-level ICT data. If a firm has more than 50 percent of its workers broadband enabled in any of the years, it is labeled ICT intensive.[13] Both for productivity (deflated sales per worker) and output (deflated sales) the dispersion is larger for ICT intensive firms.

We also have dispersion measures from the firm-level cross sectional distribution, both for productivity growth and output growth. In computing the dispersion, observations are weighted by firm size. In this exercise, the ESSLimit project did not collect the measure for non-ICT intensive firms, only for intensive firms and the industry as a whole. In all countries, except France, the ICT intensive firms have a higher standard deviation of the cross-sectional distribution of firm-level output and productivity growth.

Table 5. Measures of Growth Dispersion by ICT Intensity

	Productivity Growth		Output Growth		Productivity Growth		Output Growth	
	Time Series				Cross Section			
Country	ICT=0	ICT=1	ICT=0	ICT=1	ALL	ICT=1	ALL	ICT=1
DK	.037	.044	.057	.068	.23	.24	.29	.32
FI	.036	.079	.043	.097	.25	.27	.30	.33
FR	.040	.034	.047	.031	.21	.18	.21	.19
NL	.016	.019	.012	.017	.22	.24	.20	.21
NO	.031	.070	.043	.082	.32	.35	.33	.35
SE	.039	.067	.101	.141	.33	.37	.49	.52

Source: ESSLimit. The table measures the averaged standard deviation of labor productivity growth and output growth. In the time series columns, the standard deviation of growth is measured at the firm level for a 5-year moving window and averaged across ICT intensive and non-intensive firms in the industry (ICT=1 and ICT=0). The industry and time dispersion measures are then averaged over time and across industries with fixed industry weights. In the columns labeled cross section, the standard deviation of growth for the cross-section of firms in an industry is computed, for ICT intensive firms (ICT=1) and for all firms (ALL). The industry and time dispersion measures are then averaged over time and across industries with fixed industry weights.

[12]Broadband internet started diffusing early in the period 2002-2009, and reached full saturation in some industries in Sweden and Finland by the end of the period. This feature makes the technology a good proxy for willingness of a firm to invest in new technologies.
[13]In the ESSLimit project we experimented with multivariate definitions of ICT intensity. For the purposes of this table, the results appear robust.

It should be noted that the magnitude of the dispersion facing firms is quite large. The standard deviation of detrended real GDP growth in the US since 1983 is about .011 and it is even smaller since the late 1990s up throughout the crisis. On average, the standard deviation of real output growth in ICT intensive firms in our sample of countries is about 0.075. In the cross section, the standard deviation of output growth is on the order of .3, even when weighting with employment, giving more signal to growth of the more stable large firms. This high degree of uncertainty at the firm level should be taken into account when theorizing about the effects of increased macro-level uncertainty on firm behavior.

Similarly, in an industry/country/time panel dataset, there is a positive correlation between the standard deviation of the productivity distribution and ICT intensity, both in levels and first differences. In table 6 we show the results of a regression of the standard deviation of the cross sectional productivity distribution in a country/industry/time panel dataset on the average broadband intensity as well as on country, industry, and time fixed effects. As seen, higher ICT usage is associated with increased productivity dispersion.

Table 6. Std. Dev. of firm-level productivity distribution regressed on Broadband intensity

	Levels	First-differences
γ	0.47	0.28
t-stat R^2	(5.02) 0.52	(2.59) 0.03
D.F.	1180	1021
Fixed effects	ctry, ind, time	ctry, ind, time

Source: ESSLimit. Coefficients γ from a regression: $\sigma_{c,i,t} = \alpha + \gamma BBI_{c,i,t} + FE + \varepsilon_{c,i,t}$, with fixed effects FE: country, industry, time fixed effects, where σ is the standard deviation of the cross-sectional distribution of labor productivity in country c, industry i and time t, and BBI is the broadband intensity. The regression is run in levels and in first differences.

In this section, we have discussed a selection of industry indicators related to the evolution of output, employment and productivity developments at the firm level. The indicators are collected through a network using harmonized code running on linked firm-level panels available at national statistical offices. While the indicators are most useful in empirical exercises for evaluating the economic effects of policy, some of the findings stand out. Finland and Sweden have the highest OP-gap and churn measures. Also in terms of employment growth by productivity quartile these two countries stand out. Other findings that stand out relate to the relatively large size of less productivity firms in the UK and low levels or dynamic reallocation in France and Germany.

More interesting is the finding that ICT use at the firm level is associated with higher dispersion of output and productivity growth and that higher intensity at the industry level also is correlated with a higher productivity dispersion. In the following section we will discuss theoretical models that may link ICT to such measures of dispersion and to the role that can be played by policy.

5. Models with Frictions and Distortions

The previous section showed the considerable amount of reallocation of jobs, market shares, and firms, in all countries, industries and years under study. While earlier we stated that reallocation would be needed in order for the economy to enjoy the future benefits of adoption of technology, it is unclear what type of reallocation is needed, how much reallocation is enough, and what policies may result in proper reallocation. In this section, we will look at models of heterogeneous firms, in order to learn about links between policy, reallocation, ICT and productivity.

An aggregate representative agent growth model that captures the insights of the problem of optimal reallocation is that of Jones and Williams (1996). In their endogenous growth model, various market failures result in the possibility of either under- or overinvestment in R&D. To start, there could be spillovers from the stock of knowledge which may not be appropriable by private firms, leading to underinvestment. Next, multiple firms could be competing for a winner-take-all innovation, so that the R&D done by the losing parties does not get remunerated at all. Finally, the business stealing effect, whereby a cluster of existing technologies suffers untimely obsolescence through new innovations, may cause sub-optimally high R&D in a decentralized equilibrium. The business stealing externality is similar to innovators not taking into account the social losses they cause when they drive less efficient competitors, who themselves have made sunk intangible investments, out of the market.

The link between reallocation and policy is however not straightforward. While it may seem intuitive that evidence of a high contribution of reallocation to productivity is a good thing, a small contribution of reallocation to aggregate productivity alone may not be indicative of a poor policy environment. Consider a well functioning economy where allocation of resources is optimal. Shocks to tastes or to technology will generate only a small contribution of reallocation to aggregate productivity, because resources already are well allocated.[14] Next, consider an economy with considerable misallocation (e.g., the transition economies in 1990). If the economy suffers from policy-induced rigidities, the contribution of reallocation to aggregate productivity may be small, or even negative (in case distortions are correlated with productivity, see Bartelsman et al. (2009)), because firms cannot respond much to taste and technology shocks.

Further, even if reallocation is seen to contribute to aggregate productivity, it is difficult to draw welfare conclusions. Reallocation induces costs: entry costs, costs of adopting technology, costs associated with adjusting employment levels, costs of administering bankruptcy. Not all of these costs are policy induced, many are inherently associated with physical and technological features of a market economy. The costs induced by reallocation may not outweigh the productivity benefits, if policy distortions are present.

In order to understand the role played by policy and to assess the welfare consequences of firm-level dynamics associated with policy changes, it is necessary to interact theory and data. The workhorse model of industry dynamics is provided by Hopenhayn (1992) or Pakes and Ericson (1998), depending on the structure of the industry. By adding policy frictions to these models, recent papers have shed light on a variety of policy and institutional problems.

In the benchmark industry dynamics models, firms pay a fixed fee to enter an industry upon which they receive a productivity draw. In endogenous growth versions of these models, the productivity draw itself may depend on resources spent on R&D. In Pakes and Ericson, firms are involved in strategic interaction with competitors in the market, and the entry and

[14]More strongly, if no frictions to allocation exist and resources are optimally allocated, the envelope theory ensures that the contribution of reallocation is zero.

investment decisions will be the outcome of a strategic game. These models soon become too complex to solve, but recent advances in equilibrium concepts have allowed progress in this area (see e.g. Ackerberg et al. 2007, or Weintraub et al. 2011). Overall, these industry dynamics models allow entry decisions, investments in capital but also in intangible knowledge or product quality, as well as exit decisions. These features allow fairly rich modeling of policy effects.

Recent models can be calibrated using indicators from firm-level datasets and policy effects can then be simulation with the calibrated model. Hsieh and Klenow (2009), show how misallocation of capital can distort the observed distribution of productivity and capital-output ratios. In particular, they find that in India and China, the distribution of productivity is wider than in the U.S., which they attribute to unproductive firms staying in the market because of subsidized access to capital.

Bartelsman et al. (2013) point towards the importance of a level playing field in output markets to attract the proper entrants and keep allocation of resources among incumbents optimal. They show how the empirical covariance between productivity and size (the OP-gap displayed in the previous section) tracks welfare effects of policy induced distortions to revenue. Overall, the covariance between productivity and firm size turns out be be a very robust measure for such misallocation. However, the policy distortions can also have effects on the truncation of the productivity distribution, on rates of entry and efficiency of the process of market selection. In this model, increases in the policy distortions to firm level revenue actually will increase entry and exit rates, and increase the social losses owing to excessive entry.

What are the types of policies that may be related to the distortions modeled above? In general, these are conditions where the marginal revenue product received by the firm do not coincide with that which would prevail given firm technology and preferences of customers. One could think of preferential access to resources needed for production, such as stable energy, unfair or unequal tax treatment, barriers to shifts in market shares (switching costs) or other output market regulations that are not evenly applied or enforced.

In a model built to understand the links between exit costs and allocation of resources to emerging risky technology, Bartelsman et al. (2010) use a two-sector labor search model. They calibrate this model to show how firing costs can lower the adoption rates of ICT and reduce the share of resources allocated to high growth sectors. In the model, firms can choose to open a vacancy in a safe sector with a known technology, or they can open a vacancy in a risky sector where they face a hazard of receiving a productivity shock. Opening a vacancy in either sector requires an entry fee, which is calibrated using various micro data sources. However, the model assumes that opening a vacancy in the risky sector is more costly. Based on calibration, the mean productivity of the risky sector is higher than in the safe sector. The model further assumes that there will be an exogenous exit hazard in both sectors; jobs are destroyed at an ongoing rate unrelated to productivity. However, firms may also decide to terminate jobs if the productivity draw is below an endogenous threshold, but then have to pay an exit fee. All else equal, the exit fee will lower the exit threshold and thereby increase the variance of productivity observed across firms while also lowering the average productivity. More important for aggregate productivity, the exit fee acts as a barrier to choosing the risky sector. Indeed, in model simulations, under high enough variance of productivity shocks, increasing exit costs will lower the number of jobs in the high productivity risky sector, and thereby lower aggregate productivity and welfare.

The above model provides a clear view on how experimentation may increase the dispersion of productivity across firms while selection will reduce dispersion. As with reallocation, observed indicators of dispersion need to be assessed in the context of a model in order to draw policy conclusions. Another model used to assess the implications of labor market policies looks at the joint distribution of firm size and productivity in France. Garicano et al. (2012) can back-out the welfare losses associated with misallocation of labor that results from a discontinuity in firing costs for firms at 50 employees.

We have looked at models that can evaluate the effects of entry barriers, exit barriers, non-level playing fields, and other idiosyncratic output and factor market distortions. Coming out of the financial crisis, a policy issue is how credit constraints may affect allocation of resources, investment in intangibles and productivity growth. Midrigan and Xu (2010) use a calibrated model of heterogeneous firms to place bounds on the productivity losses owing to malfunctioning financial markets. In a cross-country setting, they estimate that credit constraint could explain up to 10 percent of differences in per capita income. Moll (2010) explicitly looks at transition dynamics in an economy with financial frictions. While financial frictions may not have large steady state consequences, they may hamper transition to the steady state, thus generating large welfare losses.

With the mechanisms of these models in mind, it becomes possible to find links between features of firm-level data, such as the moments described in section 4, and cross-country policy indicators. In a recent paper, Andrews and Cingano (2012) conduct some empirical exercises using cross-country firm-level public source data, to find links between various policy indicators and measures of reallocation. They start by showing a set of cross-country bivariate correlations between policy indicators and the OP-gap allocative efficiency measure. Next, they use the Rajan and Zingales (1998) method to interact the policy indicator with an industry-level indicator of the potential importance of the policy. They find clear results for policies such as employment protection, burdens of starting a business, or stringency of bankruptcy rules.

In a companion paper, Andrews and de Serres (2012) further try to link the policy and resource reallocation to incentives for investment in intangible assets. Here they also review some of the special characteristics of intangible assets that require policy attention, similar to the ideas presented in Hulten (2012). Based upon these thoughts, the work of Brynjolfsson and McAfee, and our own reflections, we continue in the next paragraph to discuss the required policy direction to boost investment in knowledge based capital and thereby boost productivity growth.

6. Policy Directions

Before turning to policy options, I will discuss the challenges faced by firms and workers in a future with improving ICT technology and reallocation.

From the point of view of existing businesses and potential entrepreneurs, these are interesting times. As stated by Brynjolfsson and McAfee, “There never has been a worse time to be competing with machines, but there never has been a better time to be a talented entrepreneur.” The goal of firms is to make profits for the owner, which requires a balancing of possibly conflicting goals of customers, suppliers, workers and community stakeholders. While considerable heterogeneity exists across firms, in productivity but also in innovation strategies, output growth, and development of employment and profitability, we will summarize the policy challenges for three types of firms. We start with innovators, or firms attempting to be at the global technology frontier, the variance of profitability can be exceedingly high, but so can payoffs when successful. Besides issues of intellectual property, which is outside the scope of this essay, these firms require a supply of appropriately skilled workers. Evidence shows local agglomerations of firms in specific technology areas, which likely increases technological spillovers and supply-chain spillovers, and also reduces income uncertainty of the skilled workers (Ellison et al., 2010).

For the second type, firms that attempt to keep up by adopting new ICT technology, the main issue is to have the flexibility to gain the scale required to make the technology pay off, and the flexibility to be able to reorganize operations to best fit the technology. As described in Bartelsman et al. (2010), firing costs reduce the incentive for firms to attempt adopting risky technology. Using technology and outsourcing, these firms do appear intent on shifting labor from being a quasi-fixed cost of production to being a variable cost. This is the case for risky, disruptive technologies. However, there are production technologies that require more incremental productivity improvements, for example through machines and complementary worker training, increase the value of a more stable workforce. For production using these technologies, firms could offer workers contracts with high termination penalties to elicit training effort, even if the country has no mandated firing costs.

Half of the firms reside in the bottom half of the productivity distribution. This type of firm may attempt to catch up, may be busy enough just trying to survive, or may be on a path towards exit. Indeed, the exit hazard is much higher for these laggard firms than for more productive firms. Further, these firms tend to be small and young. Other than that, the opportunities and hurdles these firms face are quite diverse.

Finally, policy often overlooks the group of potential entrants. These not yet existing firms are crucial in an environment with rapidly evolving ICT. As new market niches open up, entry is driven by enthusiastic entrepreneurs with appropriate business skills, a financial system with enough knowledge, insight and foresight to support the entrants, and a regulatory and tax system that does not favor incumbents.

From the point of view of a worker, the most worrisome aspect of the rapidly changing technology and concomitant reallocation is the unpredictability of the future value of one’s skills and the uncertainty about the longevity of chosen career paths. A good student investing many years and considerable sums (of own or societal money) on becoming a radiologist will not be pleased to discover that an expert system costs a fraction of their expected salary and also produces better results.

As a result of the rapidly advancing technology, the distribution of income, incidence of job-losses and chances of finding new work are likely to change drastically. It is unclear how the workforce can call the outcome fair, given the current ingrained experience with the value of education, work time and effort, responsibility and supervision, hazardousness, etc. Wages, of course, will remain a reflection of supply and demand, but more and more, it will be the sudden supply of the substitute computer that affects the wage, rather than the relative scarcity or abundance of workers competing to perform the task. Similar problems are occurring in winner-take-all situations, driven by the non-rival feature of products, where fractional differences in effort or quality of performance provide extreme differences in payoff. At least in these cases, pay and performance are still positively correlated. By contrast, technology has made it quite possible that more or less arbitrary shifts in consumer tastes, amplified by network externalities, provide windfalls to certain individuals. For example, a video clip could go viral and generate significant income streams, without much correlation to an objective quality ranking of the competing supply.

In short, workers will find it more difficult to make educational investment decisions, will face increasing variance in pay, higher incidence of job displacement, and more uncertainty in life-cycle planning. The possibility exists that workers will no longer perceive a positive link between their effort or performance and their pay.

Finally, we turn to the implications of Moore's law for policy, taking into account the implications of ICT for business and labor. The paper does not directly consider inherent policy tradeoffs, but makes suggestions that could help increase output per hour, maintain employment, reduce income inequality, reduce worker anxiety, and generate a sustainable path of government finance. However, given the complexity of the economic problems arriving together with advancing ICT, these policy suggestions should be considered preliminary.

To start, policy should keep the engine of innovation going. While mostly this is a global issue, the rents to be earned by a national firm contributing at the frontier are high. Countries should attempt to host a few world-class universities, fed by a schooling system that scouts talent at a young age and continues with rigorous cycles of training and selection are required. Facilitating immigration of high skilled workers and attracting subsidiaries of world-class firms complement the stimulation of home-grown champions. While picking winners is a risky business, supporting already existing agglomerations of successful technological areas provides the focal points to allow the private sector to make necessary investment in an otherwise uncertain environment. However, care should be taken that incumbents are not favored over potential entrants.

To stimulate the uptake of new ICT technologies, policy should encourage the flexibility needed for private sector firms, and improve the incentives for change in the public and quasi-public sector. To start with the former, firms will need access to workers and other resources if their adoption strategies are successful. Mismatches between skills and location of available workers and available jobs must be reduced. Geographical mismatch could be mitigated by reducing costs of labor migration or by temporarily subsidizing transport between home and work. Labor migration presently is held back by cultural and language barriers, non-portability of social insurance, health care and pensions, and local rigidities, such as waiting lists for public schools or parking permits. Skills mismatch is more difficult to solve. Workers whose tasks have been replaced in previous jobs need to have the foresight and resources to acquire the skills desired by employers with newly adopted technology. Some form of entrepreneurial employment agency would have the proper incentives. We will return to this later.

Firms that turn out to be unsuccessful in adopting new risky technologies will need to be able to avoid deep losses, otherwise the incentive for adoption is lost. This is the main reason to reduce firing costs. Another reason is that firing costs increase the labor resources tied up in marginal firms, when they could be allocated to entrants or successful firms. Further government policy could help to reduce transactions costs in hiring by making available a knowledge base of employment contracts that could serve as default options for various types of jobs or industries, depending on characteristics. Some of these standard contracts could include high firing costs, if these would be beneficial to both parties.

Entrepreneurs starting firms to fill new niches that open up owing to technology deserve support, or at least should not be set back relative to incumbent firms. Likewise, the decision of a worker to start on their own should not depend on tax considerations but on economic prospects. The same holds for taxes across legal forms of firm organization. In particular, governments should stop their promotion of small firms. Recent research has made clear that small businesses are not the job creators or innovators, but that *young* businesses are (Haltiwanger et al. 2013). Any tax benefits for non-employer firms (self-employed) would better be limited to a few years for each taxpayer. In this way, there is an incentive to either take on employees and grow, or find a job if earnings potential as a self-employed worker fall short. The benefit for unincorporated firms (SMEs) also could be limited in duration, as an incentive to grow. In any case, regulations that become more burdensome at some size threshold have been shown to generate significant welfare losses from misallocation (see Garicano et al. 2012).

A problem exists with adoption of technology in the public sector and publicly funded sectors such as education and health care. For example, owing to high firing costs and cost-based budgeting universities have been slow to adopt labor-replacing technology. The technology that is used, often is adopted under pressure of the customers, although the pressure would be higher if the customer knew how much they were paying for their education. Some of the new educational delivery methods have the potential to be quite disruptive. For example, world-class lectures, available on-line and for free, will open up new market niches, such as for coaching small groups of students who are taking online courses, for providing learning paths for traditional students and life-long learners, or for issuing certificates to document online students' progress. However, as long as the fees actually paid by students does not reflect costs of the incumbent universities, it will be difficult for entrants to create the industry that is necessary to improve efficiency in education delivery.

A similar logic holds for health care. Unless costs are transparent and entrepreneurs can find ways to lower prices, inefficient provision of the services will prevail. This is unfortunate because, as mentioned earlier, health care is a great place to spend our future income and a great industry to employ workers with interpersonal skills that are hard to substitute by machines.

We close this essay by attempting to give suggestions on policy to mitigate negative side-effects of advancing ICT. To start, firms and entrepreneurs are the engine needed to implement increases in output per hour, but they accomplish this by shedding workers, or at least by firing with subsequent hiring of different workers. Who will provide the new jobs following displacement? Brynjolfsson and McAfee put much faith in entrepreneurs coming up with ideas to generate profits by employing the displaced workers. But, scarce entrepreneurial talent is busy figuring out the best ways to use new technology, and likely is less drawn to the challenges of finding profitable opportunities by hiring thousands of unemployed taxi, truck, and bus drivers. These drivers had all been working for thousands of firms, who in turn were busy finding ways to shed the workers in order to buy the new cost-efficient driverless vehicles. Legal firing restriction, or firing costs may slow down the shedding of workers, but society loses because hours are being wasted doing unnecessary jobs and time is lost by not preparing for the inevitable. Without firing costs society has a potential gain, because workers are being freed up to do useful tasks.

Likely, solutions to this problem will require an institutional innovation in labor markets. What is needed is an actor with incentives to take care of the long-run wellbeing of a group of workers, without also being responsible for the return on capital. Unemployment agencies would have the proper incentive for training and placement, but only after the taxi driving jobs are lost. Unions might be able anticipate the impending job loss, but do not have much power other than delaying the firing of the drivers at firms with deep pockets (such as the public sector bus drivers.) However, an actor that has the drivers on their own payrolls and has rented them to transportation firms may provide the proper incentives. These actors would have the ability to find other customers for their workers before the driverless technology has become cost efficient, or as soon as the frontier firms have adopted the technology. Also, they can provide the training that is needed to maintain marketable worker skills.

Such actors may also be a solution to the increased uncertainty about relative wages. Members could form their own mutual funds, participating in each others potential windfalls and shielding each other from rapid declines in wages for certain tasks. Because these workers are together on a day to day basis (although their workplaces and colleagues will shift over a career), moral hazard can be mitigated and wage distributions can be negotiated that are considered fair, despite what market outcomes are. It remains to be worked out whether the best pooling format for these actors is based on homogeneous skills (to reduce information asymmetry and thereby moral hazard), or heterogeneous skills and tasks (to reduce aggregate shocks) or based on cultural/religious background (to increase solidarity). Possibly the actors could be private sector employment agencies that compete against each other in the output market (in renting out better skilled, harder working labor force), but also in the input market (offering different forms of insurance, solidarity, worker training). There should not be much harm in requiring these actors to offer contracts to their workers with high firing penalties, as long as the length of the contract in their output market is freely negotiable.

7. Conclusions

The paper posits that Moore’s Law and improvements in ICT provide a potential for labor productivity growth at 2.5 percent per year for the next 20-30 years. However, in order to live up to this potential, economies need to accommodate the dynamic behavior of firms required in implementing these technologies, and must be able to reallocate the workers that have been substituted away by the new technologies to tasks that are complementary to the technology.

The paper discusses productivity projections by Fernald (2012) and by Gordon (2012). These forecasts essentially have exogenous assumptions about the underlying pace of TFP growth. Gordon argues that the economy faces many headwinds in the coming decades. We argue that Gordon misses the main point of ICT progress, namely continuation of Moore’s Law and the non-rival nature of ICT capital in production. Based on these characteristics, we consider much higher feasible growth rates.

The difficulty in achieving the high growth rates lies in the aligning the incentives for adoption of ICT-related innovations and in re-employing workers that are substituted by ICT. Both of these depend on the ability of the economy to reallocate resources to the most productive uses. We discuss evidence from firm-level linked datasets on production, inputs, and ICT use, related to resource allocation. The OP-gap is a robust measure that can identify whether an economy has problems in moving resources to the most productive firms. Also, other measures such as the standard deviation of the productivity distribution, or the churn of market share may be indicative of the flexibility of the economy. Further, evidence is shown on the correlation between ICT use and the dispersion of productivity growth and output growth at both the firm and industry level. Increases in ICT usage are seen to move together with increases in volatility.

The paper next provides a discussion of the literature on heterogeneous firms to see how the firm-level evidence can be used to evaluate the effects of policy. Increases in measures of churn or higher contributions of reallocation to productivity may not in and of themselves be indicative of a proper policy stance. Instead, these models show how incentives for investment in innovative activities and knowledge based capital interact with frictions and the policy environment. Using these models, it may become possible to evaluate particular policies.

Given the nature of ICT, and the changes it brings to the production technology of firms and to the interaction of firms in markets, the paper presents arguments for appropriate policy. First, policy suggestions are provided that would improve incentives to adopt ICT and increase productivity for innovative firms, technology adopters, and less productive firms. Next, a discussion is provided for problems on the labor market, related to reallocation, but also to incentives for schooling and considerations of wage inequality and possibilities that rewards may no longer be tightly related to effort. Finally, the paper argues that policy related to adoption incentives in public services, such as health care and education, may not only increase aggregate productivity directly, but may aid in providing new areas in which to absorb displaced workers.

This paper opened up the discussion of how economies can become ready to embrace the technological changes that are available to increase productivity and welfare in the coming decades. The paper further has presented puzzle pieces needed for researchers to complete the picture of how to evaluate the efficacy of labor and product market policies. These pieces include cross-country indicators derived from firm-level data as well as theoretical advances in heterogeneous agent models. Future research will be needed to put these together, starting with simple cross-country panel data regressions, but going on with more recent methods of taking the models to the data, such as indirect inference and simulated method of moments.

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