General purpose technology diffusion and labour market dynamics

A spatio-temporal perspective

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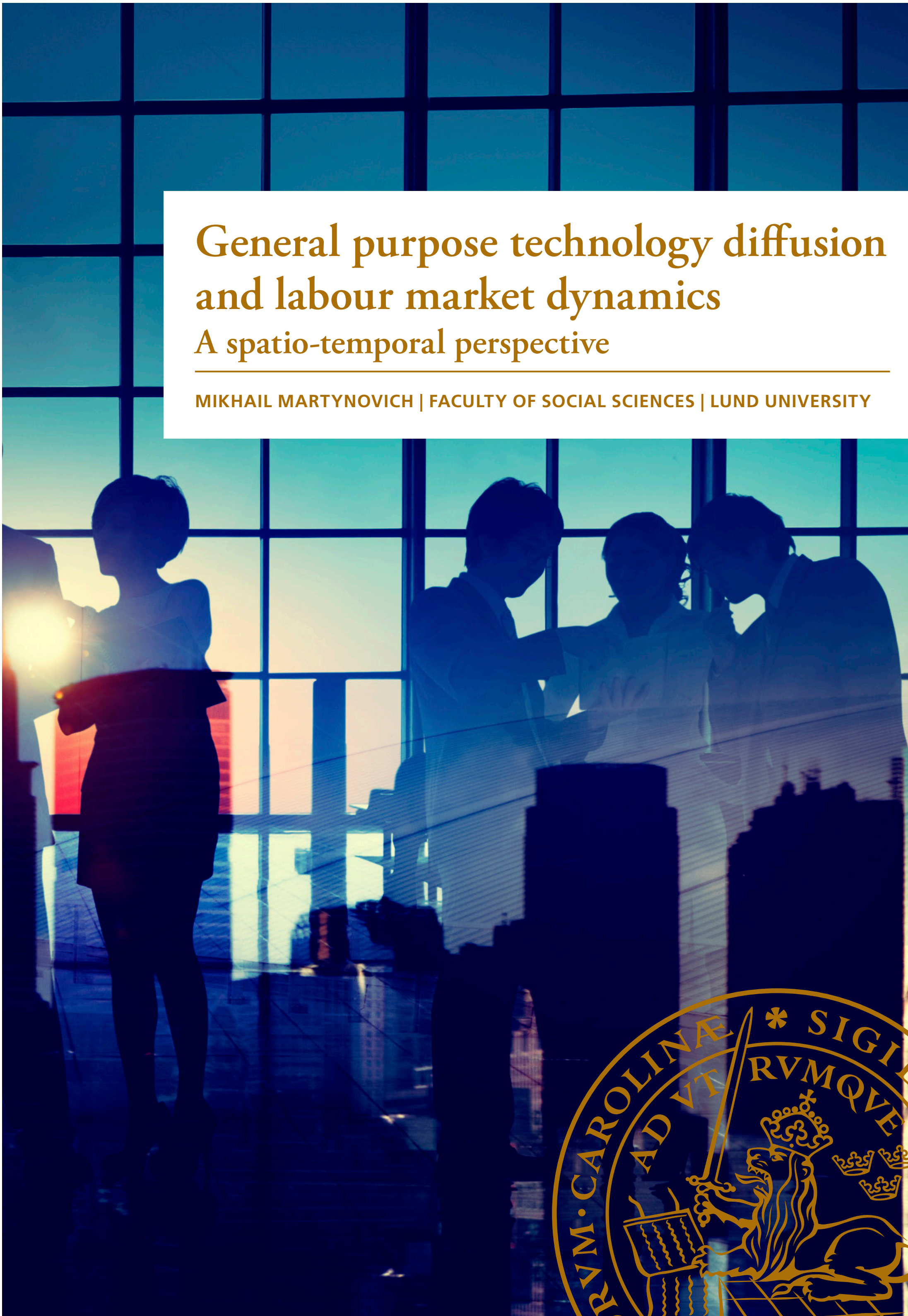

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A spatio-temporal perspective

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Mikhail Martynovich

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Abstract

This dissertation aims at advancing the knowledge about the role of the labour market in the process of the technology-induced economic transformation, taking into account the variety of factors involved at micro-, meso-, and macro-levels of the economy and at different geographical scales. Empirically, the dissertation investigates the co-evolutionary dynamics of industrial restructuring and worker reallocation across and within regional labour markets induced by the diffusion of the information technology as a general purpose technology (GPT) in Sweden in the period between 1985 and 2010.

The analytical framework employed in the dissertation combines the theoretical perspectives on the long-term economic development with the insights from the labour market studies on the dual role of the labour market in the process of technology-induced structural change. These two strands of research are integrated into the evolutionary model of economic change that links explicitly the micro-level processes of response to GPT-induced transformation pressures to the macro-level determinants and outcomes of these processes.

The findings of this dissertation indicate that the dynamics of technological change as well as its implications for functioning of regional labour markets should be approached through the prism of technology diffusion process which *unfolds in time and space*. To be able to understand the technology diffusion process one should address four intertwined questions: *what kind of technology* is diffused, *how* it is diffused, *when* it is diffused as well as *where* it is diffused at different points in time.

Also, the dissertation suggests that the role of the labour market in the technology-induced transformation is far from the smoothly operating mechanism of adjustment to economy-wide economic shocks, as it is often assumed in mainstream approaches to economic theorising. In that respect, the dissertation provides a reference point for studies of labour market evolution beyond the standard equilibrium approach.

Key words: general purpose technology, technological change, information technology, IT, diffusion, labour market dynamics, labour mobility, worker reallocation, Sweden

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If everything occurred at the same time, there would be no development. *If everything existed in the same place there could be no* particularity. *Only space makes possible the particular, which then unfolds in time.*

(Lösch 1954, p. 508; emphasis in the original)

Table of contents

Table of contents i

Acknowledgements iii

List of articles vi

List of figures vii

List of tables viii

List of acronyms ix

1. Introduction 1
    - 1.1. Beginnings 1
    - 1.2. Research background 2
    - 1.3. Aim, research questions, and contributions 4
    - 1.4. Research setting 6
    - 1.5. Core concepts 7
    - 1.6. Outline of the dissertation 8

2. Perspectives on the long-term economic development 11
    - 2.1. Long waves of economic growth – ‘the pulsation of modern capitalism’ 11
    - 2.2. Endogenising technology into Schumpeter’s framework 14
        - 2.2.1. General purpose technologies – the ‘engines of growth’ 15
        - 2.2.2. Techno-economic paradigms 18
    - 2.3. Decomposing the technology diffusion process 23
        - 2.3.1. Unfolding technological transformation in time… 24
        - 2.3.2. … and space 26
    - 2.4. A comprehensive summary 29

3. Technological change and labour market dynamics 31
    - 3.1. General remarks 31

3.2. Labour market response to structural change 33
3.3. Labour market as the mediator of knowledge transfer 36
3.4. The GPT diffusion and the dual role of the labour market 39

4. GPT diffusion and labour market dynamics in an evolutionary model of economic development 41
4.1. Evolutionary theorising of economic change 41
4.1.1. Foundations of evolutionary thinking 41
4.1.2. Evolutionary research in economic geography 46
4.2. Analytical model 48

5. Methodological considerations 55
5.1. Data 55
5.1.1. Data sources 55
5.1.2. Regional divisions 56
5.1.3. Industry divisions 58
5.2. Ontological and epistemological perspective 59
5.2. Methodological perspective 61
5.4. Methods 63

6. Current wave of technological change: Information technology as a GPT 67
6.1. Growth and productivity impact of the IT 69
6.2. Labour market impact of the IT 72

7. Research setting: Sweden 75
7.1. Swedish economic growth and labour market trends, 1985-2010 75
7.2. The IT in Sweden 78
7.3. The 'Swedish model' of the labour market 81

8. Conclusion 87
8.1. Summary of the articles 87
8.2. Synthesis of results 97

References 103

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‘So this is it, here it is’ Bon Jovi sings in my headphones. It is almost 2 a.m., and in the morning this piece of text is going to print. A bit more than four years ago – and it still feels like it was yesterday – I entered Geocentrum for the first time as a new member of the Department of Human Geography and started my journey as a Ph.D. student. Now, sitting in my office and furiously re-reading the dissertation, I still can't believe that this journey is about to come to an end.

My time as a Ph.D. student has taught me to be ambitious but realistic, to be ready to deviate from the original path, when it is necessary, but also insist on my ideas when no one else believes in them. More than anything else, however, it has taught me that any journey is much easier when you have great companions. So many people have contributed, in one way or another, to this dissertation that it fascinates me that there is only my name on the cover. I would like to express my sincere and endless gratitude to everyone who joined me on this journey. Without you, this dissertation would never have been written.

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In the end, I would like to say thanks to everyone who I met along my Ph.D. journey and whose names I have not mentioned.

Thank you so much! Tack så mycket! Спасибо огромное!

Mikhail

November 7, 2016

Geocentrum, Lund, Sweden

List of articles

Article I

Martynovich, M. and Lundquist, K.-J. (2016). ‘Technological Change and Geographical Reallocation of Labour: On the Role of Leading Industries’. *Regional Studies*, Vol. 50(10), pp. 1633-1647.

Article II

Martynovich, M. and Henning, M. (*under review*). ‘Labour sourcing in a rapidly expanding sector’. *Re-submitted to a peer-reviewed journal*

Article III

Martynovich, M. (2016). ‘Specialised pervasiveness: Diffusion of IT competences in the Swedish economy’. *An unpublished manuscript*

Article IV

Martynovich, M. (*under review)*. ‘Local or not? Spatial biographies of Swedish IT entrepreneurs’. *Re-submitted to a peer-reviewed journal*

List of figures

Figure 1. The dual role of the labour market

Figure 2. Evolutionary theory of economic change à la Nelson and Winter (1982)

Figure 3. Co-evolutionary dynamics of industrial restructuring and worker (re)allocation: A schematic summary

Figure 4. Economic growth in Sweden, 1985-2010 (annual GDP growth rate, fixed 2005 prices)

Figure 5. Total employment in Sweden, 1985-2010 (individuals aged 16-64)

Figure 6. Employment growth across Swedish regions, 1985-2010 (1985=1)

Figure 7. IT employment across Swedish regions, 1985-2010

List of tables

Table 1. Versions of SNI

Table 2. Summary of research methods

Table 3. IT employment in Sweden

Table 4. Overview of the articles

List of acronyms

ABC 80	Advanced BASIC Computer 80
BARK	Binär Aritmetisk Relä-Kalkylator (Binary Arithmetic Relay Calculator)
BESK	Binär Elektronisk SekvensKalkylator (Binary Electronic Sequence Calculator)
DEVIL	Databases of Evolutionary Economic Geography in Lund
EEG	Evolutionary economic geography
GDP	Gross domestic product
GMM	Generalised method of moments
GPT	General purpose technology
IT	Information technology
LISA	Longitudinell integrationsdatabas för sjukförsäkrings- och arbetsmarknadsstudier (Longitudinal Integration Database for Health Insurance and Labour Market Studies)
MMN	Matematikmaskinnämnden (Swedish Board for Computing Machinery)
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne (Statistical classification of economic activities in the European Community)

OLS	Ordinary least squares
PC	Personal computer
R&D	Research and development
RDC	Receiver and development competences
SNI	Standarden för svensk näringsgrensindelning (Swedish Standard Industrial Classification)
TEP	Techno-economic paradigm

1. Introduction

1.1. Beginnings

The economy is in a constant flux. The ability to incessantly transform themselves from within is the central feature of capitalist economic systems (Schumpeter 1942; Nelson 1996). The restlessness of capitalism builds upon its unlimited capacity to generate new knowledge and put it to the productive use, creating new and reviving existing economic activities. Economic agents – individuals, firms, and institutions – do not simply adjust to the current economic conditions, but rather creatively reinterpret the environment, in which they operate and which itself is the product of human design (Metcalfe et al. 2006). The creativity of economic agents is essentially linked to processes of investment and innovation that lie at the core of economic change.

The importance of innovation has for a long time been recognised by scholars of economic development. In the first half of the twentieth century, Joseph Schumpeter (1939, 1942, 1961) suggested that radical innovations are the major driving force behind the long-term upheavals in the rhythm of economic growth. The diffusion of radical innovations moves the technological frontier outward and redefines the set of opportunities and constraints for activities of economic agents, their investment behaviour and business strategies, leading to deep structural changes in the economy.

Some radical innovations – often regarded as general purpose technologies (Bresnahan and Trajtenberg 1995; Bresnahan 2010) – have an impact on economic activities in a wide variety of industries, far beyond the sector they originate in. Their diffusion leads to the emergence of new industries, revitalisation of growth in existing ones, as well as obsolescence and eventual crowding out of others. In that respect, the restlessness of capitalism manifests itself in the whirlwind frenzy of ongoing economic change that is propelled by the everlasting gale of creative destruction (Schumpeter 1942).

It would be highly unrealistic to expect that processes of technology-induced transformation and resulting economic outcomes are evenly distributed in geographic space. As there are regional differences in economic structure, business dynamics, skill endowments, investments and so on, there can never be a perfect convergence in wages, per capita incomes, productivity, etc. across different regions. In particular, creative destruction is unlikely to be spatially neutral in its dynamics and its outcomes since barriers to movements of labour, capital, and knowledge prevent the automatic self-correcting adjustment mechanisms praised by mainstream economists (Martin 2015).

Schumpeter-inspired research on the spatiality of economic change laid the basis for the research paradigm known as evolutionary economic geography (Boschma and Frenken 2006; Boschma and Martin 2007; Martin and Sunley 2015). Its main proposition is that experiences and competences acquired over time by economic agents – characterised by bounded rationality and operating in the situation of information asymmetries – determine, to a great extent, present configurations of spatial economic landscapes as well as future trajectories of regional development (Kogler 2015). The consequence is that regional economies are in constant unrest, resulting in uneven geographies of knowledge (and, thus, innovation) generation and diffusion. The technology-induced economic transformation is, therefore, a process that is inherently geographical in character (Lundquist and Olander 2009; Henning et al. 2016).

1.2. Research background

In his keynote address to the 10th Conference of the International Joseph A. Schumpeter Society Conference in 2004, Richard Nelson claimed that

> Schumpeter's theories had important implications for labor economics, but […] this was a much neglected topic, because of the historical accident that most of those with an interest in Schumpeter had backgrounds in industrial organization, and related areas. (cited in Diamond 2010, p. 44)

Indeed, Schumpeter-inspired evolutionary research in economics and economic geography has relatively overlooked the role of the labour market dynamics during the technology-induced economic transformation. This neglect of the topic is rather surprising, though.

On the one hand, in the course of creative destruction flexible labour markets smooth the processes of industrial restructuring and resulting structural change as well as lower the costs of adjustment to new industrial systems by ensuring that redundant labour laid off in declining parts of the economy is reabsorbed by those that are emerging or revitalised (Aghion et al. 2006). In the same vein, the labour market is often considered as an important adjustment mechanism that mitigates the imbalances across regional labour markets (Lindley et al. 2002; Caroleo and Pastore 2010; Pastore 2013; Hauser 2014) by ensuring the optimal reallocation of human resources and more efficient distribution of employment in space in response to the process of technology-induced transformation of regional economies.

On the other hand, '[t]he heart of the whole process of industrialization and economic development is intellectual: it consists in the acquisition and application of a corpus of knowledge' (Landes 1980, p. 111). As individuals are the principal carriers of knowledge (Bienkowska 2007; Breschi and Lissoni 2009; Maliranta et al. 2009), endowments of regions with skilled labour as well as reallocation of workers across regions may have a profound impact on the regional ability to undergo economic transformation. In other words, the labour market – being the mediator for knowledge transfer – may both enable and restrict opportunities for technology-induced economic change in regions.

In that respect, investigating the mutual dynamics of technology-induced industrial restructuring and labour market transformation may provide an important insight into where, why, and how economic change happens in geographical space.

Another, even though less obvious, drawback of the Schumpeter-inspired research, that can be inferred from Richard Nelson's quote above, is the excessive focus on industrial organisation in evolutionary research. More recently, discussing the development of the evolutionary economic geography tradition, Martin and Sunley (2015) asserted that

> evolutionary economic geography has been mainly concerned with the construction of a sort of 'evolutionary industrial geography' rather than an explicit evolutionary theory of uneven regional development. There have been studies of how particular industries have evolved across space; studies of the evolution of one or more industries in a given place […]. What has been much less in evidence is a concern with the synergy of different economic processes and structures […] and with the systemic tendency towards uneven regional

> development. Hence evolutionary economic geography has struggled to connect micro-scale processes with large-scale processes, patterns and regularities. (p. 720)

In other words, evolutionary theorising has been mainly concerned with understanding processes taking place at the micro-level of the economy. At the same time, the role of the surrounding environment and macro-level processes, both as outcomes of and conditioning mechanisms for micro-scale processes, has not been addressed in a proper way to date.

This dissertation is an attempt to connect, through the prism of labour market dynamics, the macro-level outcomes of technology-induced economic change to the micro-level behaviour of economic agents. This is done by identifying the rules operating at the meso-level of the economy which, on the one hand, condition the micro-level processes and, on the other hand, define how the latter are translated into the outcomes at the macro-level of the economy.

1.3. Aim, research questions, and contributions

On a theoretical level, this dissertation aims at *advancing the knowledge about the role of the labour market in the process of technology-induced economic transformation, taking into account the variety of factors involved at micro-, meso-, and macro-levels of the economy and at different geographical scales*. A particular attention is devoted to the temporal dimension of labour market dynamics.

The dissertation sets itself around the process of diffusion of a general purpose technology (GPT) that has a potential to generate restructuring in all parts of the economy. In this process, the labour market may be expected to play a dual role (Figure 1). On the one hand, the GPT-induced industrial restructuring manifests itself in the changing patterns of demand for labour, which generate the response of the labour market in the form of worker reallocation across jobs, industries, and regions. In that respect, the labour market may be considered a response mechanism to the technology-induced economic change. On the other hand, the very opportunities for industrial restructuring may be expected to depend on the availability of skilled labour in the new and old parts of the economy as well as across different regions.

Thus, labour market may also facilitate and/or restrict the dynamics of technology-induced transformation.

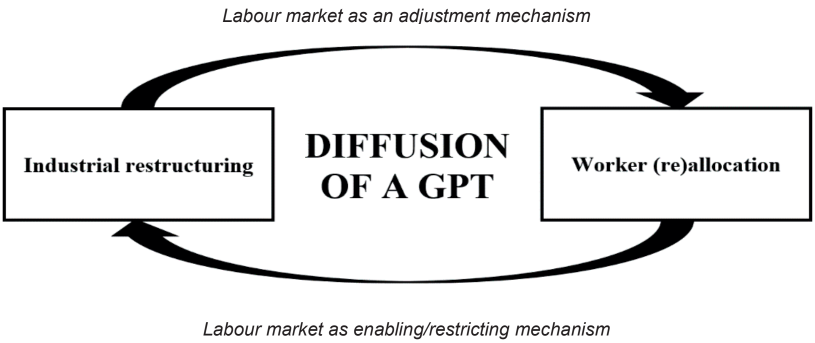

Figure 1. The dual role of the labour market

The overarching research question to be addressed in this dissertation is then formulated in the following way:

> *In what ways and to what extent is the mutual co-evolution of patterns of industrial restructuring and labour market dynamics across and within regional labour markets conditioned by the introduction and subsequent diffusion of a general purpose technology?*

Specifying the overarching research question further, the following sub-questions are posited:

> *RQ1: how does the diffusion of a GPT affect patterns of worker reallocation across and within regional labour markets?*
>
> *RQ2: how are GPT-related competences accumulated in the GPT-producing sectors?*
>
> *RQ3: what patterns do characterise the diffusion of GPT-related competences to the GPT-using sectors?*
>
> *RQ4: in what way do properties of regional economy, and particularly the position of a region in the regional hierarchy, condition the opportunities for regional GPT-induced transformation?*
>
> *RQ5: how does the role of the labour market change at different stages of the GPT diffusion in the economy?*

While the first sub-question addresses the role of the labour market as response mechanism to the diffusion of a GPT, the sub-questions 2-4 focus primarily on the potential role of the labour market as an enabler/restrictor of technology-induced industrial restructuring. Finally, the fifth sub-question aims at investigating whether these roles of the labour market change over time, as the GPT makes its way further into the economy.

By answering these research questions, the dissertation seeks to contribute to filling the research gaps in the field of economic geography. In particular:

1. The dissertation develops the evolutionary model that conceptualises the relationship between the GPT-induced industrial restructuring and labour market dynamics;
2. The dissertation provides an integration of the literature in the fields of economics, economic history, and economic geography to characterise this relationship as unfolding at *different geographical levels* as well as *over time*;
3. The dissertation links the micro-level processes of technology-induced transformation with the macro-level determinants and outcomes of these processes by identifying the meso-rules that ensure the translation of the former into the latter.

1.4. Research setting

Empirically, the dissertation is set around the latest wave of technological change induced by introduction and diffusion of the information technology (IT). It is commonly agreed that the IT is the GPT of nowadays (David and Wright 1999; Bresnahan 2010). It has been demonstrated to be adopted by a wide range of firms in different industries and to be a source of productivity growth at the firm, industry, and national levels (for reviews of the literature, see Draca et al. 2007; Stiroh 2010; Kretschmer 2012; Cardona et al. 2013; Stanley et al. 2015).

In particular, the dissertation investigates the co-evolutionary patterns of industrial restructuring and labour market dynamics induced by the diffusion of the IT as a GPT in Sweden in the period between 1985 and 2010. Over this time period, Sweden became one of the global leaders as a user of IT products and services (Giertz et al. 2015). Numerous rankings place Sweden among the top digital economies. To name a few, Sweden scored 2nd in the 2013 Digital Evolution Index (Chakravorti et al. 2014), 3rd in the 2016 EU Digital Economy and Society Index (EU 2016) and the 2016 World Economic Forum's Networked Readiness Index (Baller et al. 2016), and 5th in the 2015 Global ICT Development Index (ITU 2016).

At the same time, Sweden is also one of the major IT-producing economies in the world. In 2011, Sweden satisfied 1.59 per cent of the world's foreign demand – that is, the demand posed by economic agents outside the country – in IT products and services (Ali-Yrkkö et al. 2015). That is a huge success for a country that in the same year produced around 0.09 per cent of the world's GDP (The World Bank 2016).

Sweden's success story is, therefore, of a particular interest for studying the processes of technology-induced economic transformation. Analysing how Sweden ended up where it is today, it is possible to disentangle the success factors and barriers which arose in the process of diffusion of the IT as a GPT.

Also, Sweden represents an interesting case for analyses of long-term regional economic change for two features of its regional system. On the one hand, despite being a rather small economy, Sweden features the regional system characterised by the combination of regions that are very diverse in their economic structures and those which are extremely specialised (Enflo et al. 2014). On the other hand, Swedish regional system is characterised by highly uneven patterns of population distribution. The vast majority of Swedish population lives in Stockholm or to the south of it, which leaves Northern Sweden with vast and sparsely populated areas and large distances between regional centres (Henning et al. 2011). These features makes it interesting to investigate the mechanisms of regional diffusion of technology-induced transformation pressures and the resulting patterns of regional economic change.

1.5. Core concepts

There are two important groups of concepts that are used in the dissertation:

1. *technological change*, *structural change*, *industrial restructuring*;
2. *worker reallocation* and *labour mobility*.

To establish a common understanding with the reader as well as to ensure the consistency in the usage of terms these concepts are clarified below.

Technological change is understood generically as the process of introduction and diffusion of new technologies on the market. The market dimension ensures that these are not mere technical inventions, that are considered as leading to technological change, but rather commercialised technologies being put to the productive use. Technological change may be radical (e.g., introduction of a new GPT) leading to the revolutionary upgrade of the technological frontier within which the economy operates. It may also be incremental (e.g., refining a new technology and putting it to a broader scope of productive uses) allowing the economy to utilise the whole potential of technologies within given technological frontier.

Technological change entails changes in a composition of the economic system – that is, emergence of new sectors, products, and services, extinction of the old ones as well as redefined weights and overall importance of sectors, products, and services present on the market. This phenomenon is captured by the notion of *structural change*. It should be distinguished from *industrial restructuring* which is an economic transformation observed at lower levels of aggregation (e.g., individual industries). It describes changes in how industries produce their output and in competition conditions, under which the production process takes place.

The notions of *worker reallocation* and *labour mobility* are used interchangeably in this dissertation. The basic category is a *job mobility* which takes place whenever an individual switches a firm of employment. Depending on whether the job mobility involves certain characteristics, one can further distinguish between *occupational mobility* (when a job switch involves a change in the occupation that an individual is employed at), *inter-industry reallocation* (if industry of employment is changed), as well as *inter-regional* or *geographical labour mobility* (when a job mobility involves switching a region of employment). One may also mention the *mobility across labour market states* which takes place when an individual becomes employed from unemployment/non-participation or vice versa.

1.6. Outline of the dissertation

The core of this document contains four articles that are introduced with an opening part – the *kappa* (Swedish for 'coat'). The latter provides the discussion of the overall theoretical and methodological approaches employed in this dissertation. It aims also at contextualising the research performed in individual articles and synthesising their major findings. The following chapters are included in the *kappa*.

Chapter 1 is an introduction. It provides the background and motivation for the research project underlying the dissertation. In this chapter, aim and research questions to be answered are formulated, expected contributions are presented, research setting is summarised, and core concepts are introduced.

Chapter 2 introduces the reader to various perspectives on the long-term (regional) economic development. It provides a review of several theoretical frameworks that were developed to explain the long-term fluctuations in the rhythm of economic growth, the so-called Kondratiev waves. The discussion in this chapter suggests that the long-term economic development is an immensely complex process, explaining which requires accounting for a variety of mechanisms at different levels of the economy.

Chapter 3 provides a discussion of labour market dynamics during the technology-induced economic transformation. It suggests that the labour market plays a dual role in this process. On the one hand, it acts as an adjustment mechanism smoothing the transition to newly emerging industrial systems. On the other hand, being the mediator of knowledge transfer, the labour market may itself facilitate or restrict the opportunities for economic transformation.

Chapter 4 integrates the insights from previous two chapters into the evolutionary model of economic change that lies at the core of the explanatory framework behind this dissertation.

Chapter 5 introduces the ontological and epistemological perspectives informing the research. It also provides a discussion of major data and methodological considerations that emerged during the research process.

Chapter 6 is a contextual chapter that discusses the current wave of technological change induced by the introduction and diffusion of the information technology as a general purpose technology. Particular attention is paid to the labour market impact of the information technology.

Chapter 7 places the research in Sweden by focusing on three major topics. First, the major patterns of the development of the Swedish economy in the period between 1985 and 2010 are overviewed. Second, an overview of the history and current state of Swedish IT sector is performed. Finally, institutional aspects of the Swedish labour market are discussed.

Finally, Chapter 8 summarises findings from individual articles, synthesises them through the prism of the current debates in the literature as well as discusses the overall contribution of the dissertation.

2. Perspectives on the long-term economic development

2.1. Long waves of economic growth – 'the pulsation of modern capitalism'[1]

> *The seven years of plenty that occurred in the land of Egypt came to an end, and the seven years of famine began to come, as Joseph had said*
>
> *(Genesis 41: 53, 54)*

That economic growth is not linear over time but exhibits cyclical patterns – i.e., periodic upswings and downswings in the growth rate – is not a new story in economic research. The Kitchin inventory cycles (2-4 years), Juglar fixed investment cycles (7-11 years), and Kuznets infrastructural investment cycles (15-25 years) have solid theoretical and empirical foundations, and are considered a stylised fact by most economic growth scholars nowadays (van Duijn 1983; de Groot 2006).

At the same time, the evolution of the economy is characterised by longer dynamic phases of booming economic development that are followed by more recessed and unstable economic conditions (O'Hara 2001). As put by Hansen (1964),

> the past economic experience […] discloses prolonged periods of relatively buoyant times, extending far beyond the boundaries of the major business cycle, and similarly prolonged periods of more or less chronic hard times, within which, however, the swings of the business cycle occur. (p. 56)

1 Louçã (2007, p. 766)

These longer cycles transcend short-term fluctuations in economic activity and make a more lasting impact on economic development not only in the sense that they last longer, but also because their repercussions embrace the entire socio-economic system (Göransson and Söderberg 2005). They are known as *long waves* of economic growth, or *Kondratiev waves*, after the Russian economist Nikolai Kondratiev who was among the first scholars to bring an empirical observation of the long-term fluctuations in economic activity to international attention (Kondratiev 1925).

Not being uncontested[2], the phenomenon of long waves has attracted a substantial amount of research. Some contributions were predominantly methodological and aimed at the empirical identification of long waves in economic data (Haustein and Neuwirth 1982; van Ewijk 1982; Metz 1992; Dietbolt 2005). Other scholars focused on investigating triggering factors behind long waves.

The latter strand of research has been based on the premise that durable structures of the economy evolve over time in complex patterns of prosperity and decline (O'Hara 2001). These structures emerge around different forms of capital (fixed capital, knowledge capital, institutional capital, etc.) that have been emphasised by different scholars as triggers of Kondratiev waves. In particular, researchers have accentuated long-term fluctuations in profit rates (Mandel 1975; Gordon 1980; Mandel 1980), (re)investments in fixed capital (Kondratiev 1925; Graham and Senge 1980; Forrester 1981; Sterman 1985), and prices of primary commodities (Marchetti 1980; Rostow 1985; Volland 1987). The role of wars has also been repeatedly stressed (Rose 1941; Thompson and Zuk 1982; Goldstein 1985).

All these scholars reserved a prominent role for technological innovation. However, it was not until Joseph Schumpeter (1939, 1942, 1961) that radical technological breakthroughs were identified as the major force propelling economic dynamics and put at the core of the explanatory mechanism behind long waves.

The starting point of a long wave à la Schumpeter is an introduction of one or several radical innovations that open up new investment opportunities and have an innate potential to boost economic growth rates in the long run. These opportunities unleash a great commercial potential and attract a swarm of

2 The phenomenon of long waves has been criticised, in particular, for the lack of convincing evidence of their strict periodicity and, therefore, cyclical nature.

imitators, resulting in the emergence of new industries and rapid expansion of new demand. In the words of Schumpeter, radical innovations ‘tend to cluster, to come about in bunches, simply because first some, and then most, firms follow in the wake of successful innovation’ (Schumpeter 1939, p. 75).[3] These bunches are gradually disseminated to adjacent sectors, attracted by cost advantages of new technologies. As imitators add incremental improvements to the radical innovation and expand their activities, new technologies are pushed into the economy, taking it into the upswing of a long wave.

In this process, competition between firms on the basis of quality of products and services takes the place of price competition as the market coordination mechanism. Prices are still significant, but whereas they are central to the adjustment to limiting conditions, innovation is key for overcoming previous limiting conditions and setting the new ones (Hanusch and Pyka 2007).

As new technologies, products, and processes are introduced, existing ones become obsolete and are driven out of the market. Schumpeter used the notion of *creative destruction* to characterise this process. As new technologies diffuse in the economy, productive capital specific to old technologies – i.e., installed machinery and equipment, skills and experience embodied in workers, infrastructures used for transportation and energy distribution, etc. – can no longer be used. Firms face the choice between either adopting the new technologies or leaving the market. In that respect, creative destruction is the dual process of expansion and competition between technologies that takes place during the upswing phase of a long wave (Verspagen 2004).

However, there are inherent limitations to the developmental potential of new technologies. As the bandwagon of imitators grows, the scope for incremental innovation narrows down gradually and technological opportunities approach exhaustion. At this stage, the technology reaches maturity, its diffusion gets saturated, and the competition between firms increasingly takes the form of price competition. The ongoing entry of new firms increases competition even further, driving down profits as well as the aggregate economic growth rate. Eventually, when the saturation process is complete and the intensity of price competition is at its peak, the recession turns into a depression. For the economy to be taken into a new upswing of economic growth, a new set of

3 However, for an innovation to trigger a long wave Schumpeter nowhere insists that it must be part of a cluster of innovations; only that it is radical enough itself (Silverberg 2007).

radical innovations is needed. Schumpeter himself, however, did not offer any plausible explanations for this lower turning point.

Two important qualifications with regards to the Schumpeterian framework should be mentioned. First, for Schumpeter the notion of innovation is all encompassing.

> Technological change in the production of commodities already in use, the opening up of new markets, or of new sources of supply, Taylorization of work, improved handling of material, the setting up of new business organizations such as department stores – in short, any "doing things differently" in the realm of economic life – all these are instances of what we shall refer to by the term Innovation. (Schumpeter 1939, p. 84)

Second, Schumpeter distinguished between an innovation – a commercialised new product – and an invention, which he treated as something belonging purely to the realm of science and technology.

> In many important cases, invention and innovation are the result of conscious efforts to cope with a problem independently presented by an economic situation or certain features of it […]. Some *innovation* is so conditioned, whereas the corresponding *invention* occurred independently of any practical need. This is necessarily so whenever innovation makes use of an invention or a discovery due to a happy accident, but also in other cases. (Schumpeter 1939, p. 85; emphasis in the original)

In other words, what is technologically possible is broader than what is economically feasible and meaningful. Schumpeter, therefore, claimed that 'economic logic prevails over technological' and that technologies are exogenous to the economy and should stay 'outside the domain of economic theory' (Schumpeter 1961, pp. 11, 13-14).

2.2. Endogenising technology into Schumpeter's framework

While some prominent attempts to analyse the development of technologies *per se* and their impact on the economy date back to the 1960s (e.g., Landes 1969), it was not until the 1980s that researchers truly endeavoured to investigate technological change and innovation as such, bringing the issue of technologies' evolution to the centre of the economic growth debate. Two strands of research emerged in this literature.

The first one introduced the concept of *general purpose technologies* (GPTs) as engines of economic growth (Bresnahan and Trajtenberg 1995; Helpman and Trajtenberg 1998; Jovanovic and Rousseau 2005). Originating from mainstream economics, this approach focused primarily on market-centred mechanisms of diffusion of radical technologies.

The other strand of research emphasised a broader range of aspects – social, institutional, cultural, etc. – and suggested that the introduction and subsequent diffusion of radical technologies brought about the succession of *techno-economic paradigms* (TEPs) that provided long-term frameworks for the socio-economic development (Freeman and Perez 1988; Freeman and Louçã 2001; Perez 2010).

2.2.1. General purpose technologies – the 'engines of growth'[4]

In their seminal contribution, Bresnahan and Trajtenberg (1995) claimed that

> at any point of time, there are a handful of 'general purpose technologies' (GPT's) characterized by the potential for pervasive use in a wide range of sectors and by their technological dynamism. As a GPT evolves and advances it spreads throughout the economy, bringing about and fostering generalized productivity gains. (p. 84)

Simply put, GPTs are path-breaking technologies that push the technological frontier outward and, through their diffusion in the economy, boost the rates of economic growth (Strohmaier and Rainer 2013; Ljungberg 2016).[5] Any GPT possesses three input-side characteristics, namely: pervasiveness, technological dynamism, and innovation spawning (Jovanovic and Rousseau 2005; Lipsey et al. 2005; Bresnahan 2010).

Pervasiveness implies that a technology 'performs some generic function that is vital to the functioning of a large number of using products or production systems' (Rosenberg and Trajtenberg 2004, p. 65). It allows the GPT to

4 Bresnahan and Trajtenberg (1995, p. 83)

5 Other related terms may be found in the literature, including macro invention (Mokyr 2002), basic innovation (Freeman et al. 1982), strategic invention (Usher 1954), and epochal innovation (Rosenberg and Trajtenberg 2004).

generate new industries and affect the productivity growth across a wide range of uses and sectors (Martin 1995; Hung and Chu 2006).

Technological dynamism means that 'continuous innovational efforts increase over time the efficiency with which the generic function is performed, benefiting existing users, and prompting further sectors to adopt the improved GPT' (Rosenberg and Trajtenberg 2004, p. 65). That is, the GPT provides a wide scope for potential improvements that are an important source of value creation in the process of technological change (Trajtenberg 1990).

Finally, *innovation spawning* implies that 'technical advances in the GPT make it more profitable for its users to innovate and improve their own technologies' (Rosenberg and Trajtenberg 2004, p. 65). Thus, the GPT should exhibit strong complementarities with existing or potential new technologies, fostering complementary investments and technical change in user sectors.

While the research in economic history has identified a wide range of technologies that possess (some of) GPT characteristics (for reviews, see David and Wright 1999; Field 2008), most scholars agree that three (clusters of) technologies may undoubtedly be classified as GPTs, namely: the steam engine, electricity, and information and communication technologies.

Bresnahan (2010) referred to the combination of GPT's technological dynamism and innovation spawning as *innovation complementarities* that magnified effects of incremental innovation in the GPT itself and enabled innovation in other sectors. For instance, the productivity of R&D activities in user sectors increases as a result of innovation in the GPT. At the same time, the application in a wide range of sectors raises the returns to advances in the GPT itself, thus, generating even broader opportunities for new applications. That is, GPT's utility increases in combination with other activities (Dahmén 1988; Ljungberg 2016). These cumulative feedbacks reinforce the process of technological change and lead to sustained productivity gains and higher aggregate growth rates (Petsas 2003).

Contribution of GPTs to economic growth has been investigated in two generations of growth models, which differ in their assumptions of how and when a technology is identified as a GPT (Cantner and Vannuccini 2012). In the first generation of models (Bresnahan and Trajtenberg 1995; models collected and reprinted in Helpman 1998), a new technology is recognized *ex-ante* as a GPT. Once the technology arrives, economic agents face a decision whether to allocate resources to GPT-related R&D activities, based on their expectations of future returns. In the second generation of models (van Zon et al. 2003; Carlaw and Lipsey 2006; Harada 2010; Carlaw and Lipsey 2011), the assumption is made that the designation of a new technology as a GPT is an *ex-post* mental construct derived from an evidence that the technology provides a wide range of productive functions in the economy. 'During the innovation process, the actual pervasiveness of an innovation, when and if it arrives can only be guessed at' (van Zon et al. 2003, pp. 8-9). Therefore, the mechanism of the GPT arrival is modelled endogenously through the accumulation of knowledge, allocation of resources to R&D activities, or routinised decision-making.

The arrival of a new GPT implies that it needs to compete with technologies that are already established on the market. In this context, an impediment to the adoption of the GPT is a large number of complementary components that have to be developed by application sectors in order to bring changes to their established production processes (Helpman and Trajtenberg 1998). Also, pre-existing technologies are not static, and their incremental improvement may further delay the diffusion of the GPT. In that respect, the larger are investments in old technologies, the higher is the efficiency threshold the GPT faces, and the longer is its adoption time.

At once, if innovation complementarities, that pre-existing technologies have developed in potential application sectors of a GPT, are not (prohibitively) specific to the old technologies, they may become complements to the GPT (Bresnahan 2010). In other words, dynamic complementarities emerge between the GPT and the technologies it replaces. Costs and delays, associated with developing complementary applications of the GPT, are then dependent on the extent to which these applications have already been developed for the pre-existing technologies.

Scholars of technology diffusion have known for long that the diffusion process is very gradual (Griliches 1957; Hägerstrand 1967; Mansfield 1968). Even in presence of complementarities between the old and new technologies, the initial stage of the GPT diffusion is a period of intermittent growth, when early adopters need to make required investments, whereas laggards keep producing with the old technology. Some constraints appear on the supply-side as the value of the GPT is realised after costs of its adoption has fallen below a certain threshold or the technology itself has acquired certain features. There are also demand-side constraints: economic agents are heterogeneous (e.g., lower value users adopt later); adjustment costs (e.g., from learning-by-adopting) may appear; also, anticipated improvements in the GPT may lead to a rational delay. Besides, the pervasive use of the GPT and emergence of innovation complementarities require aligning incentives of economic agents located far from each other along the time and technology dimensions (Bresnahan and Trajtenberg 1995). This alignment is not unproblematic as the process of knowledge generation and diffusion is characterised by uncertainty and asymmetric information (Arrow 1962). Therefore, the aggregate outcomes of the GPT diffusion take a long time to materialise (David 1990).

From the perspective outlined above, it appears that the research on GPTs is a contemporary endeavour to revitalise neoclassical endogenous growth theory by adding a Schumpeterian flavour to it (Cantner and Vannuccini 2012). Its strength lies in providing elegant analytical tools to understand the long-term fluctuations in economic growth, while focusing rather narrowly on the market mechanisms of the technology diffusion and its effect on the productivity dynamics. It demonstrates how, being introduced in particular niches of the market or in specific sectors, a GPT is developed until it becomes the core technology that shapes new production configurations through industrial interaction, demand pressures and technological competition. Introduced in mainstream economics, the concept of GPT is now widely used in various research fields, such as innovation studies, economic history, economic geography, organisational studies, etc.

At the same time, focusing on the introduction and diffusion of technologies from the market perspective, the GPT literature disregards other important systemic dimensions of technological and economic change, such as social, institutional, and organisational. These became crucial components of research efforts parallel to GPT theorising, namely the research on techno-economic paradigms.

2.2.2. Techno-economic paradigms

The 1970s-1980s marked a revived interest in Schumpeter's ideas about innovation and its disequilibrium character, creative destruction as the driving force of economic transformation, and aggregate fluctuations as inseparable features of the capitalist process of development. These ideas gave rise to the debate, that would later be characterised as the 'Schumpeterian renaissance'

(Freeman 2007), and became the basic tenets of the neo-Schumpeterian economic research (Silverberg 2007).

Taking a historical approach to innovation and its impact on the economy, contributions in this stream of the literature argued against the relevance of clustering of radical innovations in time and focused on the process of their diffusion (Freeman et al. 1982; Freeman and Soete 1997; Freeman and Louçã 2001). As an outcome, several working hypotheses were formulated with regards to the impact of radical innovations on the economy.

First, it is not the introduction of new technologies *per se* that brings the economy into the upswing of a long wave, but rather their diffusion. Their maximum impact is observed when the diffusion has gone around the half way of a logistic process (Silverberg 2007). Therefore, whereas the technology diffusion is a gradual process, it has a tremendous long-term impact (Verspagen 2004).

Second, while radical innovations expand the technological frontier and define directions for new investments, the incremental innovation is instrumental for the diffusion process (Enos 1962). Product and process improvements have an impact not only on productivity growth and market expansion, but also on the new technology itself. In that respect, the radical innovations are not spread in isolation as the opportunities, offered by new and pre-existing technologies, are recombined in new ways. Thus, '[w]hat is being diffused at the end of a diffusion process may be rather different than that which started the diffusion process' (Freeman 1982, p. 6).

Third, if it is radical enough, a new technology leaves a deep structural impact on the economy. Its diffusion redefines a set of opportunities and constraints for innovative activities of economic agents. To capture this, Dosi (1982) introduced the concept of *technological paradigm*.

> In broad analogy with the Kuhnian definition of a "scientific paradigm"[6], we shall define a "technological paradigm" as "model" and a "pattern" of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies. (p. 152)

In other words, technological paradigm is a collectively-shared logic regarding the potential, relative costs, market acceptance, functional

6 Paradigm is an all-embracing conception of the world, on which all knowledge and interpretations are built, until a new paradigm replaces the old (Kuhn 1962).

coherence and other aspects of a new technology (Perez 2010).

A new technological paradigm emerges out of the crisis in the previous one. When profit rates in mature industries decline, economic agents search for new investment opportunities in technologies that have a great potential for generating profits (Perez 2002). As the problem of economic transformation is a problem of adaptation, the patterns of resource allocation and demand composition change in response to newly opening technological opportunities (Metcalfe et al. 2006). Perez (2004, 2010) referred to the switch between two successive technological paradigms as a *technological revolution*.

When a new technological paradigm is being established, 'industries differ significantly in the extent to which they can exploit the prevailing general natural trajectories, and these differences influence the rise and fall of different industries and technologies' (Nelson and Winter 1977, pp. 59-60). New, or renewing, industries – whose technological base is (closely) related to the new technologies – are exposed to broader opportunities and experience more dynamic development. Industries, that are not connected to the emerging technological paradigm to the same extent, develop along less dynamic paths (Nelson and Winter 1982; Castellacci 2008). In that respect, changes in the composition of the economy, induced by growth and decline in various industries, redefine the economy-wide relations between productivity, employment, and output as well as contribution of each industry to the aggregate growth of the economy (Metcalfe et al. 2006).

According to their role in the transformation process, the key sectors of each technological revolution may be divided into (Perez 1983, 2010):

- *motive branches*, producing key factors with pervasive applicability and other inputs directly associated with them; they define conditions for development within a new technological paradigm;
- *carrier branches*, the most visible and active users of new inputs that are best adapted to the new organisation of production; they generate a great variety of investment opportunities and have a great impact on the rhythm of economic growth;
- *induced branches* that have existed before but are modernised and assume new roles in the economic system. Their development is both a consequence of and a complement to the expansion of motive and carrier branches and is indispensable for diffusion of new technologies.

A vast reorganisation of the economy, induced by the establishment of a new technological paradigm, implies that an inherent (and recurrent) feature of any technological revolution is a crisis of structural adjustment that brings about large scale structural unemployment and social unrest (Freeman and Louçã 2001; Louçã 2007). Therefore, technological development, economic growth, and crises are inseparably connected in history (Kleinknecht 1987).

In that respect, the impact of technological revolutions goes beyond transforming the economy and requires redefining rules and regulations, such as specialised training, norms and other institutional facilitators (Perez 2010). In other words, the diffusion of radical technologies can only proceed with the major institutional change (Freeman and Perez 1988). The economic system should then be seen as comprised of two related sub-systems – techno-economic and socio-institutional – whose co-evolution determines the mode of development. When a new set of radical innovations emerges, there is an impulse for the techno-economic sub-system to adopt new technologies that offer new profitable opportunities. However, while the techno-economic sub-system is more flexible in adopting the new, it takes longer for the more inertial socio-institutional sub-system to respond to challenges posed by the newly emerging technological paradigm (Castellacci 2007). The temporal mismatch between the adjustment in each of these two sub-systems may, therefore, delay the take-off of the new paradigm as social, organisational, and institutional changes are required for its transformational potential to be fully realised. As time goes by and complementarities between two sub-systems are built, the new mode of development eventually sets in. In that respect, the notion of technological revolution is all encompassing so that it covers not only the technological innovation, but also its institutional, organisational, social and political dimensions (Freeman and Louçã 2001; Hanusch and Pyka 2007).

The impact of technological change on the economy should, therefore, be analysed through the prism of transformation of complete systems – *techno-economic paradigms* (TEPs – that intertwine technology, culture, economy, and organisation (Freeman and Perez 1988). The succession of TEPs involves a gradual replacement of technical, organisational and managerial modes of production. A technological revolution should then be seen more generally as

> a major upheaval of the wealth-creating potential of the economy, opening a vast innovation opportunity space and providing a new set of associated generic technologies, infrastructures and organisational principles that can

> significantly increase the efficiency and effectiveness of all industries and activities (Perez 2010, p. 190)

From this perspective, the focus shifts from the long-term fluctuations in economic growth to transformative effects of technological revolutions on all aspects of the socio-economic life.

It is, therefore, no longer possible to ignore particularities of the specific technological revolution and the nature of the particular set of technologies being diffused. Each major technological breakthrough develops in its historical time and in particular context, whereas various systemic factors, interacting in complex ways, shape its development path (Verspagen 2004).

In that respect, the TEP approach does not provide a (completely) deterministic perspective on the long-term development of the economy. It resembles the GPT research with respect to its focus on the diffusion of new technologies as well as the necessity of those to be pervasive and build complementarities with pre-existing technologies. At the same time, by incorporating the environment, in which the diffusion process takes place, into the core of its explanatory framework, the TEP approach emphasises a broader spectrum of potential implications of technological change for the development of the economy.

The TEP approach may, however, be criticised for taking the predominantly macro-level perspective and not paying enough attention to processes at the micro-level of the economy, e.g., the behaviour of economic agents involved in the development and diffusion of new technologies. To become a more powerful tool for analysing processes at the micro- and meso-levels of the economy, the approach would benefit from integrating the insights from innovation studies, evolutionary economics, and evolutionary economic geography, which emphasise the importance of knowledge, learning processes, social networks, etc.

2.3. Decomposing the technology diffusion process

Universal truths without reference to time and space are unlikely to characterise economic affairs.

(Penrose 1989, p. 11)

The technology diffusion process is unpredictable, as potential applications of the technology are continuously explored, tested, expanded, modified, or rejected (Louçã 2007). Even though the technology-induced economic transformation is pervasive, the forces, shaping evolution of demand and technological base in various industries, operate unevenly and cumulatively (Metcalfe et al. 2006). The adaptive development in new and old parts of the economy is, therefore, the primary process, while the aggregate economic growth is a secondary outcome. In that respect, macroeconomic explanations of economic transformation should be complemented by analyses of micro- and meso-level determinants of technology adoption and diffusion as well as their implications for functioning of the economy as a whole (Nelson and Winter 1974; Metcalfe et al. 2006).

Besides, the impact of technological revolutions is not equally distributed in space. The contemporary view of regional economic dynamics builds upon the principle of increasing returns (Krugman 1991; Fujita et al. 1999) that are connected to the capacity of regions to generate innovation and to receive and exploit ideas, technologies and market changes from the outside world (Jaffe et al. 1993; Boschma and Lambooy 1999). This capacity is dynamic and defines the ability of regions to translate technology-induced transformation pressures into the competitive regional performance. This ability as well as the roles of and relations between different regions change over time, implying that technological revolutions are essentially geographical in character (Lundquist and Olander 2009, 2010).

In the words of Mokyr (2005):

> Technological innovations […] do not affect the aggregate level of economic activity abruptly: they need to diffuse from region to region, from activity to activity, cross boundaries and seas, be evaluated, adapted, and refined. Their

> promoters have to dislodge the entrenched, persuade the sceptic, and reassure the fearful. (p. 285)

Therefore, understanding the technology diffusion requires acknowledging that it is the process that unfolds over time and proceeds unevenly across different industries and regions.

2.3.1. Unfolding technological transformation in time…

Based on years of empirical investigations of the Swedish economic growth patterns, Schön (1998, 2010, 2012) identified the recurring phases of technology-induced economic transformation that shared common features with regards to investment patterns, technology diffusion processes, and systematic lead-lag relationships between various industries and institutional structures. Each of the phases lasts about 50 years and has the common structure: transformation period – rationalisation period – structural crisis.

The *transformation period* (first investment period) is characterised by the introduction and early diffusion of a new GPT and brings about deep changes in institutions, markets and industrial organisation. This is a period of 'changes in industrial structures, where resources are reallocated between industries, and diffusion of basic innovations within industry […] provides new bases for such reallocation' (Schön 1998, p. 399).

New activities, emerging around a new GPT, take the lead in this period. Investments are directed to increasing the capacity in new areas of production and are predominantly of a long-term character (Schön 2010). The GPT diffusion across industries leads to the emergence of complementarities between the old and new parts of the economy. First-mover industries[7], implementing the new technology into their production processes, take the lead in the transformation and contribute greatly to the aggregate growth of the economy. At once, the increasing demand for intermediate products generates growth even in less technology-intensive industries acting as subcontractors. Nevertheless, the productivity and growth rates across various industries diverge during this period. The aggregate productivity growth is driven by the resource reallocation between low- and high-productivity sectors. Factor markets change in response to the transformation

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[7] Motive and carrier branches discussed in Section 2.2.2.

of relative price structures. Institutions adapt to new developments to create stable conditions for continuous growth.

The *rationalisation period* (second investment period) manifests in the maturation and ubiquitous spread of new technologies through the technical standardisation and dissemination of competences. This is a period of the "concentration of resources to the most productive units within the branches and measures to increase efficiency in the different lines of production" (Schön 1998, p. 399).

Technological development fades into the background during this period. The applications of the GPT are increasingly standardised and spread efficiently to older parts of the economy. Investments are directed to reduce costs in existing capacities; they are short-term and resource-saving in character and have a more direct impact on the productivity, growth and real income. Enhanced qualifications of the workforce around the increasingly standardised technology facilitate further productivity gains. Overall productivity growth stems from the intra-industry optimisation as economies of scale increase in importance and trigger an increased competition. The period is characterised by a relative stability in relative price structures and institutions.

With time, falling profits change investment patterns and lead to the structural crisis that weakens old economic interests and creates conditions for a new GPT to set in. It is a dramatic moment of Schumpeterian creative destruction, when new opportunities are created, and investments are re-directed towards technologies demonstrating the GPT potential (Schön 2012).

Of course, the transformation and rationalisation take place simultaneously in the economy. However, capacity-increasing and cost-reducing investments are unevenly distributed over the ordinary business cycle: there are observed long-term shifts of such emphasis (Schön 1998, 2010). In that respect, the switches between the transformation and rationalisation periods occur regularly between successive technological revolutions. Crises form particular sequences in these shifts.

While Schön's model is an empirical heuristic uncovering different stages of the GPT diffusion (Henning 2009), it has important implications for analyses of the long-term economic development. First, the model provides an insight into the behaviour of economic agents at the micro-level with respect to investment patterns, resource allocation, and the nature of competition. In that respect, it fills in the gap in the TEP approach. Second, it demonstrates that the behaviour of economic agents changes as the technology is spread in the economy, which has an impact on the overall rhythm of economic growth. In that respect, it emphasises the importance of the time dimension for analyses of technology-induced transformation of the economy.

2.3.2. … and space

The forces of economic transformation are differentiated in space (Henning 2009; Martin 2015). The national trajectory of economic transformation and its aggregate outcomes are composed of a wide range of regional trajectories (Henning et al. 2016). While much research has been devoted to endogenous determinants of regional development paths, such focus draws attention away from other critically important systemic factors that shape regional development, e.g., the shifts in macro-economic conditions (Shearmur 2011; Pike et al. 2016). Particular characteristics of the national economy may impose barriers to movements of capital and labour that inhibit the automatic self-correcting adjustment in the regional system, a mechanism so beloved by mainstream economists (Martin 2015). Imbalances in the regional system are both the outcomes and important determinants of the process of economic transformation. Such imbalances are particularly pronounced in the outcomes of transformation process between the most dynamic regions at the top of regional hierarchies and the most peripheral regions (O'Leary and Webber 2015).

Such systemic perspective, in which roles of and relations between regions change in the process of the GPT diffusion over time, and its implications for Schön's framework laid the basis for the geographical reference cycle model (Lundquist et al. 2008a, b, c; Lundquist and Olander 2009; Henning et al. 2016). It premises on the inherent geographical character of technology-induced economic transformation in that starts in certain industries and regions and, with specific time patterns, spreads through the whole regional and industrial landscape. The national growth cycle is, thus, an aggregate result of regional development, determined by unique characteristics of the regional system.

The theoretical framework of the geographical reference cycle suggests a sequential order of economic transformation in two interlinked dimensions: the GPT diffusion across industries and across regions that possess various endogenous and systemic characteristics. It provides the insight into when and where the transformation process starts and how it is diffused through the regional economic landscapes.

In compliance with the strands of research discussed above, at the early stages of the GPT diffusion the economic transformation and aggregate growth are driven by the first-mover industries that embed the GPT into their production processes. These industries generate the new demand in the economy. As the GPT is standardised over time, a broader spectrum of industries benefit from building complementarities with the GPT, expanding the new demand in the economy and creating an additional boost to the aggregate economic growth.

These developments are reflected in the spatial pattern of the GPT diffusion over time. Regions are differently equipped with the ability to develop, absorb, implement, and commercially translate the GPT-induced transformation pressures into the productive performance. That is, they possess different regional receiver and development competences (RDC) (Henning et al. 2016). The variation in regional RDC in different parts of the regional system gives rise to systemic lead-lag relationships between regions – that is, diverse transformation patterns – as the economy moves from the transformation stage into the rationalisation stage.

At the early stages of the GPT diffusion the first-mover industries, making use of new technological opportunities, mainly locate in regions at the top of the regional hierarchy (particularly, metropolitan areas). The latter are characterised by the most advanced regional RDC as they provide a superior access to infrastructure and innovating organisations (Feldman and Audretsch 1999; Simmie 2001) and are in a better position to generate knowledge spillovers necessary to facilitate diffusion of new technologies (Audretsch and Feldman 1996; Baptista 2003). The industrial diversity, facilitating opportunities for inter-industry knowledge spillovers (Jacobs' externalities), is of the crucial importance to the new and renewing industries (Neffke et al. 2011). Besides, large regions are magnets for talented individuals possessing high levels of human capital (Tödtling and Trippl 2005; Bosma and Sternberg 2014; Gordon 2015); thus, their advanced RDC are sustained through the constant inflow of knowledge embodied in individuals (Anokhin et al. 2016).

Beginning gently and experimentally in these sites, the new production takes time to become visible. While mature businesses initially dominate the scene, the realisation of the new technology potential leads to the redirection of investments towards, and resulting expansion of, new activities. This allows large regions to defend their absolute employment by sustaining job creation rates high enough to replace jobs that are phased out in declining sectors. Regions at lower levels of the regional hierarchy, lacking sufficient regional RDC, demonstrate slower growth in the new and renewing industries, resulting in an aggregate growth below national average as well as declining employment (Lundquist et al. 2008a). All in all, at the early stages of the GPT diffusion (the transformation period) the forces of technology-induced economic transformation and aggregate growth patterns are pronounced in favour of regions at the top of the regional hierarchy.

As the economy moves into the rationalisation, transaction costs gradually fall, large regional markets become strained on the resource side, new production starts to disseminate regionally and affects growth in value added, productivity and employment in a wider set of regions. The importance of factor costs rises, which benefits smaller regions that are able to provide low relative costs structures. Congestion effects in bigger regions force a regional diffusion and relocation of industries, particularly the ones drawing from the new technological opportunities (Henning et al. 2016). While the largest regions still dominate the scene, the aggregate growth at the national level is no longer constrained by regions at lower levels of the regional hierarchy (Lundquist et al. 2008a).

Particular spatial and sectoral outcomes of the GPT diffusion process depend on a range of interlinked mechanisms and channels, such as internal organisational structures of firms and sectors, imitation by new and existing competitors, emerging complementarities between the new and old parts of the economy, possibilities for decomposition and fragmentation of value chains as well as opportunities offered by standardisation, price competition and falling transaction costs.

All in all, the geographical reference cycle model provides the stylised depiction of the lead-lag relationships that characterise the regional system in the process of technology-induced economic transformation. Its key contribution is in demonstrating that the outcomes of this process are inherently determined by changing roles of different regions at different stages of the GPT diffusion process. One particular implication is that in order to understand the regional mechanisms and outcomes of technology-induced economic transformation one should account for the position of a region in the regional hierarchy.

2.4. A comprehensive summary

Ever since Kondratiev (1925) empirically identified the long waves of economic growth, substantial research efforts from scholars in various disciplines – including economics, economic history and economic geography – aimed at understanding the mechanisms, driving forces and regularities behind these waves and, more generally, the long-term economic development. One of the (early) significant contributions to this debate was in recognising the central role that technological innovation plays in this process: major technological breakthroughs are the initial impetus for generating upswings in the long-term economic growth rates (Schumpeter 1939).

Subsequent research focused on the market mechanisms that facilitate the diffusion of radical innovations (GPT research) as well as on how the socio-economic environment, in which the diffusion process takes place, is both its determinant and outcome (TEP research). Recent empirical contributions provided additional qualifications to the GPT diffusion process as unfolding in time (Schön's framework) and space (the geographical reference cycle).

Summarising the perspectives on the long-term economic development reviewed in this chapter, one should acknowledge that the technology-induced economic transformation is an immensely complex process. While its outcomes are clearly observed at the aggregate level, there is a great variety of interlinked driving forces and mechanisms at the sectoral and regional levels that have an impact on the behaviour of economic agents and, eventually, result in the economic transformation. Failing to recognise those, one cannot come up with any comprehensive explanations of the long-term economic development.

3. Technological change and labour market dynamics

3.1. General remarks

The economy is constantly hit by idiosyncratic disturbances that are driven by technological development, changes in economic agents' behaviour, terms of trade, institutional environment, etc. While there is an agreement that these disturbances are behind the (long-term) shifts in regional labour market dynamics (Bachmann and Burda 2010), their sources are debated.

Studying the relationship between employment growth in various industries and regional unemployment rates, Lilien (1982) put forward the hypothesis that the shifts in regional labour market dynamics were the outcome of permanent reductions in the demand for labour in particular industries. These reductions manifest themselves in displacements of workers, increasing regional unemployment rates and creating the need for reemployment of displaced workers in other industries, present in the regional economy.

Lilien's assumption that the labour demand shifts at the industry level take place as an independent source of regional labour demand reductions was criticised by Abraham and Katz (1986). In their view, regional labour market dynamics are propelled by aggregate shocks that have a different impact on different industries. In other words, regional variations in the labour market performance are explained by asymmetric responses of various industries, present in the regional economy, to the same aggregate shock.

In an attempt to discriminate between these two explanations, Robson (2009) demonstrated that the impact of the labour demand shifts on the regional labour market dynamics was transmitted through several channels. First, in the short run, regions, characterised by the high concentration of employment in cyclically-sensitive industries, are more vulnerable to the labour demand shocks at the industry level. Second, the long-term shifts in the demand for labour across sectors, induced by aggregate shocks, put stronger pressures on regions with higher concentration of employment in declining industries. In that respect, aggregate shocks generate asymmetric responses of regional labour markets through their non-neutral impact on industries (Neumann and Topel 1991). Third, the regional labour market performance is conditioned by the degree of specialisation/diversification in the regional employment mix. More diversified regions tend to have a better capacity to reabsorb displaced workers through more efficient matching process (Moretti 2011). In that respect, analyses of regional labour market dynamics should acknowledge the potential impact of both industry-level demand shocks (following Lilien 1982) and the differential response of various industries to aggregate shocks (in the vein of Abraham and Katz 1986).

Technological change is an overwhelming aggregate shock that has an impact on both old and new parts of (regional) labour markets. Old jobs are destroyed when new technologies arrive (as existing job matches become ineffective and unprofitable), but are replaced by either more productive employment opportunities in existing sectors or completely new jobs in emerging ones (Mortensen and Pissarides 1998).

The discussion of the overall impact of technological change on the labour market divided researchers into technology pessimists, who pointed at the labour-saving and rationalising effects of new technologies that led to higher levels of unemployment as a result of the technology diffusion, and technology optimists, who considered technological change as a necessary condition for attaining full employment as its job creation effect was larger than the job destruction one (Matzner et al. 1990).

One should, however, look beyond the direct effects of job creation in expanding industries and job destruction in declining industries, and consider entire value added chains to take account of indirect effects (Freeman et al. 1982).

> It is […] necessary when evaluating the actual effects on employment of new technology, to differentiate between the direct (primary) employment effects resulting from the introduction of new technology in an enterprise and the indirect (secondary) effects which are transmitted by other mechanisms. (Matzner et al. 1990, p. 688).

Technological change is associated with changing patterns of demand for labour that lead to potentially severe problems of structural unemployment (Hanusch and Pyka 2007). In that respect, since the development of new and old industries in the process of technology-induced economic transformation is uneven over time and space (as it was demonstrated in the previous chapter), analyses of the impact of the new technology diffusion on job creation, job destruction, and other aspects of labour market dynamics should address its spatial and temporal dimensions.

3.2. Labour market response to structural change

The speed with which economies must adjust to change has increased over last decades due to forces of technological development and globalisation (Dahlman 2007). Ever since Mundell (1961), it has been acknowledged that the factor mobility is an important response mechanism of regional and national economies, which balances out the asymmetric effects of aggregate economic shocks. In that respect, the reallocation of workers is an inseparable component of technology-induced structural change (Aghion and Howitt 1992; Kremer and Maskin 1996; Mortensen and Pissarides 1998; Bauer and Bender 2004). Flexible labour markets facilitate an adjustment process by ensuring that changing labour demand patterns meet a response in the form of worker reallocation (Greenaway et al. 2002; Aghion et al. 2006; Bachmann and Burda 2010; Pastore 2013).

As the transformation pressures of the technology diffusion are unevenly distributed across the new and old parts of the economy, technological change leads to the relative or absolute long-run decline of some industries as well as the emergence and expansion of others. This implies changes in profitable opportunities that manifest themselves, among other things, in differential rates of job creation and job destruction between expanding and declining industries (Greenaway et al. 2000). The outcome of this process is the reallocation of labour, as the growth of new and already existing firms is necessarily related to the inflow of workers, while the contraction and closure of firms have the opposite effect (Davis et al. 1996).

This process, however, cannot be reduced to the simple picture of workers being displaced in declining industries and finding jobs in expanding ones. Individuals can still move from expanding to declining industries, while worker reallocations within industries are also common (Greenaway et al. 2000). The latter are particularly pronounced in technologically dynamic and rapidly expanding industries, playing key roles in the technology diffusion process, as they are characterised by high turbulence in terms of firm entries and exits (Antelius and Lundberg 2003; Mamede 2009).

Besides, direct job switches are not exclusive in the adjustment process (Sorm and Terrell 2000; Elliott and Lindley 2006; Bachmann and Burda 2010). There is a time lag between changes in the labour demand and response from the supply-side of the labour market. It takes time for displaced workers to find new jobs due to retraining, limitations in vacancies information accessibility, etc. Therefore, the shifts in the demand for labour lead to temporary increases in structural unemployment (Matzner et al. 1990; Neumann and Topel 1991). Flows to and from unemployment and non-participation play an important role in the adjustment process. Declining industries tend to release workers into unemployment, while the employment growth in expanding sectors is often fuelled by workers coming from outside the labour force, for instance, recent graduates from universities (Bachmann and Burda 2010; Arpaia et al. 2015).

Changes in the labour demand patterns, and the subsequent response in the form of inter-industry worker reallocation, have implications for regional labour market dynamics, as it has been for a long time claimed in the literature on dualism and structural change (Lewis 1954; Uzawa 1961, 1963; Chenery et al. 1986; Capasso et al. 2012). Key industries, associated with technological change, tend to exhibit different location patterns at different stages of the technology diffusion process. Thus, the distribution of job creation and job destruction is uneven across regions. Therefore, the shifts in the demand for labour manifest themselves spatially. At different stages of technology-induced economic transformation, labour markets of different regions are characterised by a varying capacity to reabsorb workers displaced in declining sectors, resulting in spatial labour market imbalances (Caroleo and Pastore 2010; Pastore 2013). Thus, the inter-industry reallocation of workers is often accompanied by the additional response of the labour market in the form of geographical labour mobility.

However, such response of the labour market may only be considered an effective adjustment mechanism if it leads to the mitigation of imbalances (that is, convergence) across regional labour markets. Whether this is the case is still debated in the literature, despite the huge number of studies on the issue (for a review, see Magrini 2004).

On the one hand, in mainstream economic models, the worker reallocation is directed to places that are more endowed with physical capital, leading to convergence in the capital-to-labour ratio and, therefore, per capita income and unemployment levels (Boldrin et al. 2001; Boldrin and Canova 2003; Barro and Sala-i-Martin 2004). In that respect, the labour mobility is an equilibrating force reducing disparities between regional labour markets.

On the other hand, the research in economic geography suggests that the worker reallocation widens, rather than reduces, disparities across regional labour markets by reinforcing agglomeration externalities (Krugman 1991; Baldwin 1999; Overman et al. 2002; Puga 2002; Epifani and Gancia 2005; Francis 2009). Two interlinked mechanisms contribute to that (Fratesi 2014). On the one hand, workers are attracted to regions characterised by higher rates of job creation and, thus, offering more job opportunities. These are predominantly large regions with already dynamic labour markets. On the other hand, the outcome of such reallocation is an increased labour supply in receiving regions, providing a supply-side stimulus to the job creation process. In that respect, the worker reallocation and job creation are involved in a virtuous circle of mutual reinforcement that results in divergent trends across elements of the regional system.

Another important aspect is that higher returns to production factors tend to be paid in regions where they already concentrate (Reichlin and Rustichini 1998; Funck and Pizzati 2002, 2003; Moretti 2004). In that respect, there are limits to reallocation of relatively unskilled labour because of the smaller differences in expected returns to relocation across regions. Skilled workers, however, potentially benefit more from relocation (Caroleo and Pastore 2010). Higher level of human capital allows them to adapt more easily to different jobs – particularly, new jobs generated as an outcome of technology-induced economic transformation – and to benefit more from opportunities offered by various regions (Giannetti 2003; Coulombe and Tremblay 2009). Human capital gains of receiving regions are, in that respect, increasingly a force of the regional divergence (Kanbur and Rapoport 2005; Fratesi and Riggi 2007; Fratesi and Percoco 2014).

All in all, the technology-induced structural change results in complex patterns of worker reallocation across sectors, labour market states, as well as regions. However, it does not necessarily lead to the convergence between regional labour markets as there are cumulative mechanisms that favour the most dynamic labour markets of large regions. Therefore, while the worker reallocation is certainly a response mechanism to aggregate disturbances, it is not necessarily an effective mechanism of adjustment that allows to fully absorb their effects.

3.3. Labour market as the mediator of knowledge transfer

The role of individuals as carriers and distributers of knowledge has been extensively discussed in various fields, including sociology, organisational studies, economics, economic geography, etc. (e.g., Szulanski 1996; Lawson 1999; Lam 2000; Song et al. 2003; Bienkowska 2007; Breschi and Lissoni 2009; Maliranta et al. 2009). Human capital, embodied in individuals, is increasingly seen as the key input to firms' production processes. According to the knowledge-based view of a firm (Grant 1996; Nickerson and Olin 2004), firms' workforce is a key element of constructing and sustaining their competitive advantage (Hatch and Dyer 2004; Lund Vinding 2006; Coff and Kryscynski 2011).

Extensive research on the knowledge distribution across various levels of the economy has shown that the heterogeneity in knowledge endowments is a characteristic of firms (Srholec and Verspagen 2012; Grillitsch et al. 2016), industries (Pavitt 1984; Malerba 2002; Consoli and Rentocchini 2015), clusters (Jensen et al. 2007; Arikan and Knoben 2014) as well as regional (Cooke et al. 1998; Asheim and Coenen 2005) and national innovation systems (Freeman 1995; Carlsson et al. 2002).

Knowledge endowments of firms are not only important at single points in time, but also define dynamic properties of their success. Patterns of firm evolution and turnover of labour at the firm level are intrinsically related, particularly in knowledge-intensive industries, where firms' success is conditional upon their capacity to recruit skilled labour (Mamede 2009), such as hi-tech sectors (Baron 2004) and business services (Mamede 2002). The labour market may be seen as a coordination device that ensures coherence between the labour demand posed by firms and the pool of capabilities that are available on the supply-side. The 'recruitment-based competition'

(Sørensen 2004), and the resulting heterogeneous access of firms to human capital, impacts patterns of sectoral evolution over time. Evolving skill structures of industries are, in that respect, both the cause and the effect of shifting industrial regimes based on the generation, adaptation and diffusion of knowledge (Consoli and Rentocchini 2015).

As knowledge is embedded in individuals (Nelson and Winter 1982), it cannot be transferred easily without individuals' relocation. Ever since Alfred Marshall's work on industrial districts, it has been argued that the worker reallocation across firms is a mechanism of knowledge transfer (Song et al. 2003; Bathelt et al. 2004; Power and Lundmark 2004; Maliranta et al. 2009). Hiring workers is instrumental for firms to gain (relatively cheap) access to the superior knowledge developed elsewhere (Stoyanov and Zubanov 2014). Also, the worker reallocation facilitates the cross-fertilisation of previously unconnected knowledge (Saxenian 1994; Rosenkopf and Almeida 2003). Skilled workers take their knowledge with them and share it in a new workplace, while also acquiring new knowledge, establishing new links and social networks, and promoting new combinations of ideas (Laudel 2003; Trippl and Maier 2010). Moreover, mobile workers are more productive than their non-mobile counterparts (Hoisl 2007, 2009; Lenzi 2009; Singh and Agrawal 2011) as labour mobility improves the employer-employee match quality, which in turn implies efficiency gains and enhanced productivity (Jovanovic 1979; Liu 1986; Topel and Ward 1992).

Knowledge transfer takes place not only across firms, but also across regions. The research has extensively documented the influence of extra-local knowledge sources on firms' innovative performance and knowledge acquisition (Owen-Smith and Powell 2004; Gittelman 2007; Simonen and McCann 2008; Boschma et al. 2009). In that respect, the labour mobility is a principal mechanism of knowledge dissemination which helps to establish cross-regional linkages and spread knowledge and information across space (Coe and Bunnell 2003; Fratesi and Senn 2009; Breschi et al. 2010).

Technological change adds another dimension to the importance of human capital availability and knowledge diffusion. Learning capacity, possessed by highly skilled individuals, facilitates the innovative activity, especially at the early stages of the technology diffusion when the knowledge, related to the new technology, is tacit, sticky and, importantly, outside of the established knowledge domain (Gertler 2003; Baumol 2004). Therefore, the supply of adequate skills lags behind the demand for them, increasing structural skill mismatches. At this stage, the knowledge transfer is conditional upon the mobility of a few skilled individuals.

As time goes by, the adoption of new technologies by firms and repeated learning-by-doing improve workers' performance, while the gradual standardisation of skills leads to their diffusion beyond the early technology adopters. In that respect, the uneven distribution of knowledge among economic agents provides incentives to explore the new technological paradigm, while coordinated efforts to systematise new knowledge facilitate the diffusion of skills throughout the economic system (Vona and Consoli 2015). The process of catch-up to the technological frontier is then conditional upon increasing the availability of human capital associated with the technology that is diffused (Benhabib and Spiegel 2005).

The worker reallocation does not, however, imply that the knowledge transfer happens automatically. Each potential job switch is characterised by an ease, with which it may be performed, and is influenced by three factors: (costs of) acquiring information about available job opportunities, desirability of a job, and direct costs of job switching (Lindley et al. 2002; Elliott and Lindley 2006; Neffke and Henning 2013). The latter are divided into 'hard' costs (e.g., housing-related costs, credit constraints, economic status of a partner) and 'soft' costs, primarily redundancies in the human capital associated with a job switch. It is costlier for a worker if her skills are not transferrable from an old job to the new one. In that respect, it is possible to distinguish between the general human capital – knowledge and skills used at an old job that remain useful in alternative jobs – and specialised human capital – knowledge and skills that are hardly (if at all) transferrable across jobs (Gathmann and Schönberg 2010).

Nowadays, workers, particularly skilled workers, possess highly specialised human capital as they invest heavily in education and training to acquire specific skills that allow them to carry out certain tasks (Neffke et al. 2016). The specificity of human capital develops in several domains. Earlier contributions underlined that human capital, accumulated by a worker at a particular job, was specific to a firm where she is employed (e.g., Becker 1964). More recent work suggests that the human capital is industry- (Neal 1995; Parent 2000; Sullivan 2010) or occupation-specific (Neal 1999; Poletaev and Robinson 2008; Kambourov and Manovskii 2009; Gathmann and Schönberg 2010; Neffke and Nedelkoska 2010). Besides, there are claims that regional variation in production technologies may impact the accumulation of human capital (Rigby and Essletzbichler 1997). These domains of human capital specificity are complementary to each other. For instance, industry tenure benefits the worker, but the extent of those benefits depends on the occupation she is employed at (Sullivan 2010).

Specificity of human capital is an important factor affecting job switch decisions (Elliott and Lindley 2006). Workers tend to switch to jobs where they incur less shortages (skills to be acquired) and smaller redundancies (skills not needed anymore) in their human capital (Neffke and Nedelkoska 2010; Neffke et al. 2016). Simply put, workers switch to jobs that provide opportunities to reuse their skills. In that respect, an overlap in human capital requirements across different industries facilitates the inter-industry worker reallocation, while the lack of such overlap may constrain it. That is, workers tend to become employed in industries where skill requirements are similar to those in the industry of current employment – or, skill-related industries (Neffke and Henning 2013).

In the process of technological change, new industries emerge, others die out, whereas the very nature of production process changes. This results in the destruction of established linkages between previously skill-related industries. At the same time, however, the process of the new technology diffusion leads to the emergence of new complementarities between previously unconnected industries. In that respect, the whole network of skill-related industries is reorganised, which manifests itself in restructuring of the worker reallocation opportunities.

3.4. The GPT diffusion and the dual role of the labour market

The diffusion of a new GPT induces structural change, that is expansion of new industries, revitalisation of growth in renewing industries, as well as a decline in obsolescent industries. These processes lead to changing patterns of the demand for labour between the new and old parts of the economy, which, in their turn, generate response of the labour market in the form of worker reallocation across expanding and declining sectors.

The problem, however, is that the skill requirements of new industries are continuously redefined as the new GPT undergoes incremental innovation, builds complementarities with existing technologies and is diffused to (more) application sectors. In the situation of technological turbulence and rapidly changing skill requirements, there is only a limited support coming from the educational system, due to its inertial development, in terms of providing suitable skills for the newly emerging technological paradigm. Therefore, particularly at the early stages of the GPT diffusion, the new qualifications in the workforce may not be sufficiently available, while obsolete qualifications abound.

In that respect, the adjustment of the labour market to the technology-induced structural change does not necessarily operate smoothly because of redundancies in human capital that arise in the process of worker reallocation. If such redundancies are too large, the direct reallocation of workers between declining and expanding sectors becomes problematic. Indeed, while the process of rapid employment growth in new sectors requires new skills, employees of mature industries cannot easily obtain them. Therefore, established skill structures on the labour market may restrict the opportunities for worker reallocation, and, more generally, labour market response to the technology-induced structural change.

These processes have important spatial implications. On the one hand, the GPT diffusion is uneven across regions at different levels of the regional hierarchy. The expansion of labour demand in the new and renewing industries may be expected to take place in the largest regions, at least at the early stages of the diffusion process. At the same time, displacement of workers from obsolescent sectors affects regions at all levels of the regional hierarchy, giving rise to spatial mismatches between the labour supply and labour demand and facilitating inter-regional reallocation of workers.

On the other hand, the GPT diffusion across industries and regions is conditional upon the availability and relocation of individuals who possess these skills. As the labour market is the mediator of the knowledge diffusion, it may both enable and restrict opportunities for technology-induced transformation. In that respect, the availability of human capital and its dissemination across regions is instrumental in the process of establishment of the new technological paradigm in regional economies.

4. GPT diffusion and labour market dynamics in an evolutionary model of economic development

4.1. Evolutionary theorising of economic change

The Mecca of the economist lies in economic biology

(Marshall 1948, p. xiv)

4.1.1. Foundations of evolutionary thinking

The point of departure in evolutionary thinking is the idea that the economy is in constant flux, subject to evolution through the ongoing process of change that 'revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one. This process […] is the essential fact about capitalism' (Schumpeter 1942, p. 82; emphasis in the original). According to Witt (2003, 2008), any evolutionary theory of economic change should be based on the following premises.

First, it should be dynamic. Economic change is the engine of growth (Metcalfe et al. 2006) that is based on the reciprocal dynamics of structural change and technological change (Quatraro 2012). Arising endogenously from within the economy, technological change stimulates industrial restructuring through transformative and adaptive mechanisms (Kogler 2015), which, in their turn, generate the creative response of economic agents and facilitate their innovation efforts leading to further technological change. Industrial restructuring is, in that respect, both the cause and the effect of an endogenously determined process of technological change. This cumulative process ensures that the economic landscape is in constant unrest, in which previous events affect the probability of future events to occur (Boschma and Frenken 2006). In short, history matters (David 1985). Thus, analyses of economic development should explicitly take the time component into the consideration.

Second, evolutionary thinking deals with irreversible processes. The co-existence of random and systematic determinants of economic evolution (Nelson 1995; Verspagen 2005), together with its inertial and dynamic forces, makes it impossible for the economy to approach any kind of steady state, praised by scholars within mainstream economics.

> The system is by itself not moving towards any sort of balance between forces, but is constantly on the move away from such a situation. In the normal case a change does not call forth countervailing changes but, instead, supporting changes, which move the system in the same direction as the first change but much further. Because of such circular causation as a social process tends to become cumulative and often gather speed at an accelerating rate. (Myrdal 1957, p. 13)

Simply put, economic development is 'an autocatalytic process in which change begets change' (Metcalfe et al. 2006, p. 9).

Finally, evolutionary theorising builds upon the generation and impact of novelty as the ultimate source of self-transformation. The restlessness of capitalism is based on its capacity to generate new knowledge; and the endogenous variation of knowledge makes economic systems so dynamic and versatile. Knowledge is not just a regular factor of production, in the manner that it can be detached from the production process; rather, it grows in the day-to-day conduct of economic activity (Metcalfe et al. 2006). It is the endogenous generation of knowledge that makes the process of economic evolution both adaptive and transformative in character (Fine 2000). The uneven distribution of knowledge across economic agents opens up various innovation and investment opportunities. Knowledge-based systems are, in that respect, necessarily evolutionary in their nature.

One of the most influential branches in evolutionary thinking traces back to Nelson and Winter (1982). In a nutshell, their theory explains economic evolution in terms of the dynamic interaction between heterogeneity (variety) of economic agents, competition and selection between them, as well as innovation process that reinforces heterogeneity and perpetuates growth.

Heterogeneity of economic agents is fundamental for evolutionary economic systems. In that respect, evolutionary accounts disregard the concept of representative agent, be it an individual or a firm. In a world, characterised by uncertainty and bounded rationality, firms act through routines, which constitute the organisational memory, through which firms develop their productive and commercial activities, and allow them to act without deliberation (Robert and Yoguel 2016). Within firms, activities are guided by routines at different levels. On the one hand, the routine repertoire includes knowledge held by firms' employees. On the other hand, there are organisational routines, which cannot be reduced to the sum of individual workers' knowledge. The routines determine organisational behaviour in terms of selection of products and production processes, investment behaviour, as well as search for new routines and solutions (Castellacci 2007).

Routinisation of firms' activities generates inertial forces and explains an inherent persistency of firm behaviour, resulting in a relatively stable pattern of economic activities over time. However, this stability is counteracted by dynamic forces pushing the economic system evolution, change and transformation (Castellacci 2007).

Just as animal species compete for their survival in the natural environment, heterogeneous firms compete on the basis of their routines. This competition is predominantly Schumpeterian, based on new products and technologies that require new routines. Competition is a *selection mechanism* that ensures the survival and diffusion of smart, fit routines (that are better adapted to the prevailing environment) and the demise of stupid, unfit routines (Verspagen 2005; Boschma and Frenken 2006).

While competition tends to reduce the initial variety over time, the dynamics of economic systems is not confined to the selection process but 'involves restless minds, constantly seeking to invent, to innovate and to connect with other minds in productive organisations in the quest for profits' (Foster 2011, p. 24). The innovation process enriches the variety so that the economic evolution is a never-ending process.

In reality, the variety generation and competitive selection take place simultaneously and mutually affect each other. In that respect, the economy is a complex adaptive system with positive and negative feedbacks.

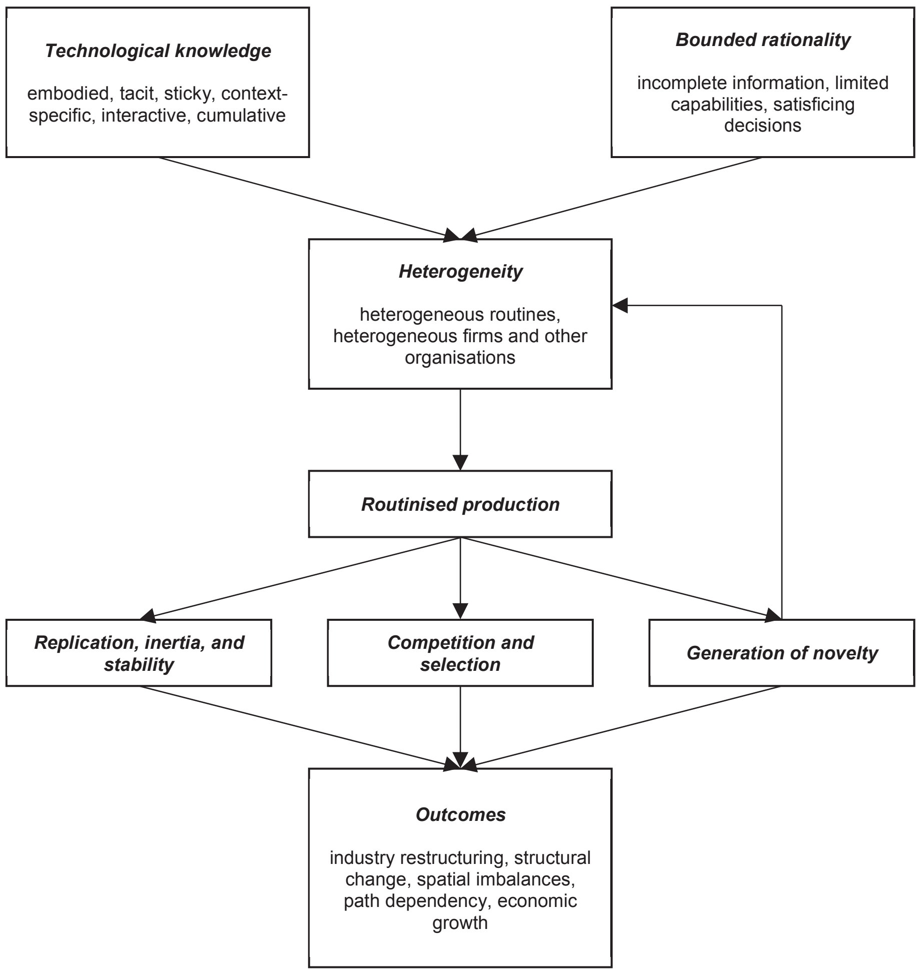


Figure 2. Evolutionary theory of economic change à la Nelson and Winter (1982)[8]

One problem with this approach is that its explanatory framework is primarily firm-centred and, to a great extent, abstracts from the environment in which the selection and variety generation take place. However, these micro-level processes are affected by the constraints imposed by meso- and macro-level determinants of economic change (Cimoli et al. 2016).

8 Inspired by Castellacci (2007).

The economy may be considered as a complex structure of economic meso-rules[9] that determine the selection process among the routines that were developed to solve a specific problem (Dopfer et al. 2004). Economic rules are embedded in a broader environment of rules, such as behavioural, social, legal, political, etc.

The meso-rule system is hierarchical and ranges from long-lived rules that are applied to the whole economy to relatively short-lived contingent rules (Foster 2011). For instance, meso-rules applied in one particular sector are complementary to the economy-wide meso-rules upon which they rely. At the same time, these rules are not completely deterministic: it is impossible to predict which routines will be developed, given a meso-rule. Neither is it possible to foretell whether any micro-rule will be adopted as a meso-rule in the future.

Evolution of the economy in general, and the processes of selection and variety generation in particular, are, in that respect, reflected in the origination, adoption, adaptation and diffusion of meso-rules. Briefly put, economic evolution is a process of shifts in meso-rule sets (Dopfer et al. 2004) that is systemic rather than purely endogenous or exogenous (Foster 2011).

This perspective allows avoiding the reductionism from the micro to the macro (Robert and Yoguel 2016). The macro should not be seen as an aggregation of the micro. It is composed of a deep level – the level of meso-rules – and a surface level – the domain of the aggregate outcomes (Dopfer 2007). In that respect, the macro is a systemic perspective on the meso-rule system as a whole. Neither is the micro just a reduction to an individual economic agent: it is a bottom-up perspective on the meso viewed in terms of its component parts (Dopfer et al. 2004). The meso, therefore, gives the micro its distinct position and represents the building block in the construction of the macro. While evolution of the meso-rules cannot be observed directly, the micro and the macro are two perspectives that *reveal* the structural aspects of changes in the meso.

In that respect, while the outcomes of economic evolution are observable at the macro-level, they can neither be understood, nor be explained at this level (Carlsson and Eliasson 2003). Macro-level phenomena are constructed

9 Related terms of 'meta-routines' (Aldrich 1999) or 'higher-order principles' (Kogut and Zander 1996) are also used in the literature.

statistics, reflecting changes in the underlying economic structure (Metcalfe et al. 2006). The sources of these phenomena should be sought in the industry dynamics that is, in its turn, driven by generation of novelty and competitive selection at the micro-level (Hanusch and Pyka 2007).

Heterogeneous economic agents, industries at different stages of maturity, and institutional frameworks varying across sectors and regions are all elements of the complexity of the economic systems characterised by non-linearities, such as unbalanced growth processes, catching-up, lag-behind and forging-ahead dynamics, should be considered (Hanusch and Pyka 2007). In that respect, macro-level phenomena are the emergent properties, i.e. 'the collective and largely unintentional outcome of *far-from-equilibrium micro interactions*' (Dosi and Winter 2000, p. 5; emphasis in the original).

Studies of economic change should, therefore, incorporate the full set of factors conditioning the evolutionary dynamics. This implies combining analyses of micro-level processes (i.e., behaviour of individual economic agents), the macro-level environment that constrains and/or facilitates a particular evolutionary path of the economy, as well as the system's and its components' connections with and dependencies on other systems elsewhere (Martin and Sunley 2015).

4.1.2. Evolutionary research in economic geography

Broadly speaking, economic geography deals with the uneven distribution of economic activity – organisation of production, distribution, and consumption – across space. Evolutionary economic geography (EEG) is concerned with how this spatial distribution is transformed over time. It bases on the premise that (emerging) spatial structures are not just the outcome of the economic evolution, but also condition and constrain micro-economic behaviour of economic agents that shapes this evolution (Boschma and Martin 2007).

More specifically, EEG focuses on *spatialities of economic novelty* (innovation, new firms, new industries), on how the *economic landscape emerges from the behaviour of economic agents* (individuals, firms, institutions) at the micro-level of the economic system, on how emerging spatial structures exhibit *self-organisation features*; and on how the *processes of path creation and path dependence shape geographies of economic* *evolution*, and whether such processes are *place dependent* (Martin and Sunley 2006).

EEG aims at explaining the spatial distribution of routines over time, that is, the emergence and diffusion of new routines as well as mechanisms through which 'fitter' routines are diffused. As the dissemination of routines is primarily driven by spin-off processes and labour mobility, their spatial evolution develops along a localised structure (Essletzbichler and Rigby 2007; Boschma and Frenken 2011a), with successful routines having a higher chance to survive and be transmitted to other local firms. This results in regional branching, that is, the process in which new routines at a particular location develop out of technologically related routines already present in that location (Frenken and Boschma 2007; Boschma and Frenken 2011b). In that respect, conditions for generation and diffusion of new routines differ across various spatial scales, depending on local institutions, structure of networks of economic agents, patterns of labour mobility, etc.

Spatial structures emerge out of the myriad individual actions and interactions of economic agents that generate economic outcomes – such as daily behaviours, investment decisions, labour sourcing, profits, etc. – that reproduce these spatial structures. In contrast to the natural biological world, where self-organisation is often considered spontaneous, in the economic realm the development of spatial structures is the complex result of intentional behaviours, not (necessarily) intended outcomes, and learning of economic agents that pursue their own objectives (Martin and Sunley 2015).

For instance, the stable prosperous development of regions over time often depends on the location choice of a few firms. At the same time, the motivation behind that location choice may be traced back to the past to the choices made by other firms in the same industry and region, and in other industries and regions. In that respect, history and space matter for the evolution of firms, industries, and networks of economic agents (Capasso et al. 2012). In other words, uneven spatial distribution of economic activity is an outcome of connected, path-dependent historical processes (Dosi and Nelson 2010). However, the success of regions is only partly determined by their historical experience. In times of radical technological change, the development of knowledge (and, thus, spatial evolution of routines) is characterised by a high degree of uncertainty, which creates the windows of opportunities for places and regions to elevate their knowledge production and innovativeness under particular circumstances (Storper and Walker 1989; Boschma and Lambooy 1999).

The spatial evolution of the economy as a whole is addressed in a framework of structural change (Boschma and Frenken 2006). The evolving pattern of uneven spatial development is a process of spatially-biased cumulative causation, which takes place at all spatial scales – within firms, within clusters, cities, regions, and globally (Boschma and Frenken 2011a; Martin and Sunley 2015). In that respect, economic systems are discontinuous in space, characterised by fuzzy boundaries, and cannot be separated from their environment, which makes them neither completely closed, nor completely open (Martin and Sunley 2015).

Despite being a contextual approach, EEG aims at understanding whether geography matters for evolution of economic activities rather than theoretically assuming *a priori* that it matters all the time (Boschma and Frenken 2006). Institutional differences across regions, indeed, constrain and/or enable the spatial evolutionary mechanisms in the economy. However, regional institutions do not condition the behaviour and performance of firms in a deterministic manner, as routines of firms may vary a lot even under the same institutions (Gertler 2010). Moreover, these same institutions are subject to evolutionary mechanisms as the institutional environment co-evolves with technological development and industrial dynamics (Nelson 1995; Schamp 2010). In that respect, institutions are both the context and the outcome of economic evolution (Martin and Sunley 2015).

Therefore, from the EEG perspective, places emerge from actions of economic agents, rather than fully determine their activities. Real places emerge from the neutral space as new knowledge is generated, new firms and industries emerge, evolve, become spatially concentrated in some regions, and launch the transformation of the institutional base of these regions. Regional development is, in that respect, more about path dependence than place dependence (Boschma and Frenken 2006).

4.2. Analytical model

In this section, various perspectives on the long-term economic development (Chapter 2) and on the dual role of the labour in the process of technology-induced structural change (Chapter 3) are synthesised into the evolutionary analytical model that lies at the core of the explanatory framework employed in this dissertation. In essence, it deals with the co-evolutionary dynamics of industrial restructuring and worker reallocation across industries and regions in the process of the GPT diffusion.

Two important reservations should be made before moving on to the discussion of the model. First, while evolutionary theorising is appropriate for investigations of the ongoing transformation, based on incremental innovation, it lacks the solid theoretical foundation explaining the generation of Schumpeterian radical innovation that is behind any technological revolution (Castellacci 2007). Therefore, the very arrival of the GPT is considered exogenous in the model. Rather, the model focuses on the process of the GPT diffusion and its implications once the GPT has arrived.

Second, the model focuses primarily on the market mechanisms and implications of the GPT diffusion process. In that respect, the institutional environment, in which the diffusion takes place, is not taken into the consideration explicitly. However, as the institutional environment is subject to the co-evolution with the technology-induced transformation dynamics, it makes its way into the model as an implicit factor that facilitates and/or constraints the latter. This is reflected in both the overall explanatory framework as well as in the analyses performed in individual articles.

Arrival of a new GPT and the process of its diffusion generate different transformation pressures on existing economic activities. Firms' response manifests in the development of new routines that are necessary to accommodate these pressures. The variety of routines increases leading to the boost in the selection process that benefits those organisations that are more able and willing to adapt their routines to the transformation impulses, generated by the GPT diffusion, and disadvantage those that are lagging behind in transforming themselves. This ability is conditional upon the openness of organisations to change and their capacity to respond to it (known as absorptive capacity (Cohen and Levinthal 1990); for a review see Zahra and George 2002). Besides, (emerging) complementarities between routines, that already exist at the organisational level, and ones, that are required, play an important role in this process. The generation of variety through innovation and the subsequent selection process lead to the restructuring process in existing industries and the emergence of new industries.

Processes of variety generation and selection within industries lay the evolutionary foundation for processes of variety generation and selection between industries. Uneven patterns of generation and dissemination of new knowledge lead to the uneven distribution of growth across sectors, producing structural change in the economy. Consequent changes in the relative importance of various sectors continuously define and redefine the dynamic complementarities between them (Metcalfe et al. 2006).

Therefore, the combination of transformation pressures and heterogeneous abilities of firms and industries to accommodate these pressures generates both qualitative change within industries (that is, how the output is produced and under which circumstances of competition) and structural change in the economy as a whole (that is, changes in the shares of industries in the total output, employment, and productivity growth).

Both qualitative change within and structural change across industries have an impact on the labour market by generating new patterns of demand for labour. In particular, there is an explosive employment growth in new industries, reallocation of workers between occupations in renewing industries, as well as displacement of labour in declining sectors. These changes generate the response of the labour market in the form of the inter-industry reallocation of labour.

At the same time, there are spatial implications of the labour demand shifts. Regions at different levels of the regional hierarchy are characterised by different receiver and development capacities. In other words, they provide different environments for accommodating the transformation pressures of the GPT diffusion process. In particular, the most dynamic regions at the top of the regional hierarchy are the most successful ones in attracting new industries. Besides, being characterised by the diversification (Jacobs') externalities, they provide the most fertile ground for establishing complementarities between the old and new parts the economy. These regions may, thus, be expected to dominate the process of technology-induced economic transformation, at least at the early stages of the GPT diffusion. For regions at lower levels of the regional hierarchy it takes much longer time to benefit from this process. Moreover, even the regions at the same level of the regional hierarchy might differ in their ability to reabsorb redundant labour from declining sectors. This depends on the diversification of the regional employment mix, and particularly the structure of regional networks of skill-related industries. Therefore, patterns of job creation in new/renewing industries and job destruction in declining industries manifest themselves spatially.

All in all, transformation pressures generated by the GPT diffusion lead to qualitative changes within industries as well as the change in importance of various sectors for the economy as a whole. As regions have different capacities to accommodate these pressures, patterns of industrial restructuring and structural change are unevenly distributed across regions, leading to the emergence of spatial imbalances across regional labour markets and generating the response in the form of worker reallocation across regions.

Therefore, the industrial restructuring and resulting structural change have an impact on patterns of worker reallocation. This motivates the role of the labour market as a response mechanism to the technology-induced economic change. This kind of relationship is addressed in Article I that investigates the impact of the uneven distribution of key industries, associated with the GPT, on the patterns of inter-regional reallocation of labour. The particular focus in the article is made on the dynamic roles of different groups of key sectors on the ability of regions to attract and retain labour at different stages of the GPT diffusion.

There is, however, another side of the story. The generation and diffusion of new routines requires application of new skills and knowledge. Therefore, the availability of relevant knowledge conditions the capacity of firms and industries to respond to the transformation pressures, generated by the GPT diffusion. In that respect, the labour market, being the mediator of knowledge transfer, may facilitate and/or restrict the opportunities for industrial restructuring and structural change across industries and regions. Two interlinked dimensions contribute to that.

First, knowledge, related to the GPT, is predominantly outside of the established knowledge domain. Therefore, the supply of new skills lags behind the demand for them, particularly at the early stages of the diffusion process. In that respect, firms, willing to accommodate the transformation pressures of the GPT diffusion, face the deficit in relevant knowledge and skills, embodied in workers who are available on the labour market. Therefore, mismatches arise between the skills demanded and those supplied. As the potential for upgrading organisational routines is dependent on, among other things, the availability of adequate skills, firms and industries that manage to attract workers, possessing these skills, will be more successful in responding to the transformation pressures. Therefore, the availability of labour is a restricting factor for the industrial restructuring.

At the same time, if there are complementarities between the new skill requirements and skill structures, already available in the economy, the reallocation of workers, who have developed specialised human capital that is complementary to the GPT, may be the enabling factor for the industrial restructuring process.

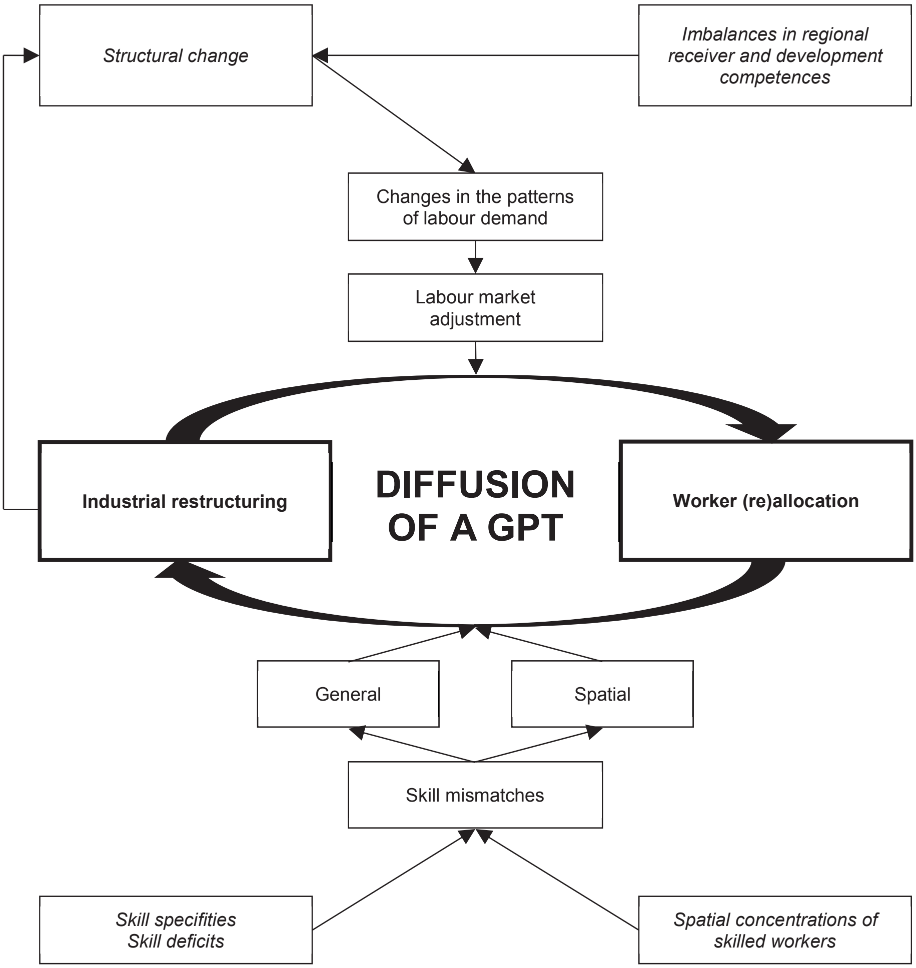


Figure 3. Co-evolutionary dynamics of industrial restructuring and worker (re)allocation: A schematic summary

Second, it matters not only whether the complementary knowledge and skills are available, but also *where* they are available and how they are *diffused* through the regional system over time. Different regions have different endowments with skilled labour, which depends on a range of both demand- and supply-side factors. On the one hand, they are realisations of industrial structures of regions: regions characterised by more diverse industrial landscapes accommodate workers with a wider variety of skills. Also, regions, characterised by denser networks of skill-related industries, might find it easier to accommodate the transformation pressures of the GPT if skills employed in these industries are complementary to the GPT, and more difficult otherwise. On the other hand, workers themselves have different preferences with regards to living conditions in different regions (e.g., creative class and the cities, see Florida 2014). The resulting pattern of uneven distribution of skilled workers is an enabler for industrial restructuring for regions where the availability of such labour is high, and a restrictor – where it is low. Spatial patterns of skilled workers availability and reallocation, therefore, condition the opportunities for the accommodation of the technological pressures in different regions.

More generally, processes of industrial restructuring are shaped by the dynamics of knowledge creation and diffusion in the geographic and the technological spaces. Articles II-IV address these issues from various perspectives. Article II investigates the labour sourcing strategies in the sector, that is paradigmatic to the GPT itself, focusing, in particular, on the temporal dimension of the labour sourcing process. Article III analyses the diffusion of skills, related to the GPT, throughout the whole spectrum of industries and regions. Finally, Article IV considers the most dynamic regions at the top of the regional hierarchy as learning regions for individuals, willing to obtain GPT-related skills, and analyses the role of these regions in shaping GPT-related entrepreneurial activity in more peripheral regions.

There are several novelties that this model offers for investigations of the determinants and outcomes of the long-term economic development. First, it enriches the economic and economic historian research on general purpose technologies and techno-economic paradigms with a spatial component, which remained largely disregarded in these streams of the literature. Second, the model focuses on long-term aspects of spatial processes. In that respect, it puts forward the temporal dimension of the economic transformation that, to a great extent, is largely ignored in the economic geography research. Finally, the model provides a framework that links explicitly the micro-level processes of response to GPT-induced transformation pressures to the macro-level determinants and outcomes of these processes. This allows identifying the mechanisms which translate the micro-processes to the macro-outcomes. In other words, it allows specifying meso-rules that determine the evolution of (regional) labour markets during the technology-induced economic transformation. In that respect, it helps coming closer to the true explanatory mechanisms of economic evolution within the micro-meso-macro ontology.

5. Methodological considerations

5.1. Data

5.1.1. Data sources

Data employed in this dissertation come primarily from two sources: the Longitudinal Integration Database for Health Insurance and Labour Market Studies (*Longitudinell integrationsdatabas för sjukförsäkrings- och arbetsmarknadsstudier, LISA*), provided by Statistics Sweden, and the Databases of Evolutionary Economic Geography in Lund (DEVIL), collected and compiled by researchers at the Department of Human Geography at Lund University.

LISA is an anonymised linked employer-employee database that aims at complementing traditional labour market statistics and providing a better description of the labour market and people's relationship to the world of work (SCB 2016b). It is a total-count individual register: all individuals registered in Sweden on December 31, are included in the population for the reference year. LISA is a longitudinal database, meaning that the data for the same person can be linked for all years, when she is included in the population.

LISA integrates the annual data from several registers, including education, income, employment, health insurance, and population registers. In that respect, it provides information on various dimensions of working life, connection to work, labour mobility, movement in and out of the labour market, etc. The connection of an employee to an employer is denoted by the identity number of the firm and the establishment where she has her main employment. The data contains also the detailed information on various individual variables, such as age, education, annual earnings, municipality of residence and employment, industry of employment, etc. Thus, the data allows tracing employment histories of individuals and, for instance, constructing a very precise measure of worker reallocation flows. Annual data cover the period between 1985 and 2010.

One reservation should be made here. LISA is built around the data that comes from administrative registers and, thus, is primarily created for administrative purposes. That implies that the objects and variables can appear/disappear and change values as the purposes of the registers they comes from change over time (SCB 2016b). At the same time, being a high-quality dataset, it comes with clear explanations for the process of variable construction, compatibility of different variables, translation keys between different versions of variables, etc. This allows ensuring consistency of observations made for different years.

DEVIL is a longitudinal firm-level database, constructed from business registers of Statistics Sweden for studies of regional economic transformation. For the period between 1968 and 2008, it provides the information on a firm's municipality of registration, number of employees, value added, wage costs, etc. In that respect, it allows constructing measures of regional industrial profiles, industry concentration/diversification patterns, etc.

Finally, the research relies on data publicly available from Statistics Sweden.

5.1.2. Regional divisions

The principal spatial unit employed in the analysis is a local labour market (*lokal arbetsmarknad*), which represents a group of Swedish municipalities (*kommuner*). This definition of a region is chosen due to the specificity of its construct. The boundaries of local labour markets are defined by the statistics on commuting between municipalities in the way that maximises the self-containment of commuting flows. In other words, local labour market areas are defined in the way that maximises homogeneity of mobility patterns within a region while sustaining cross-regional heterogeneity.[10]

With regards to investigations of labour market dynamics, it implies that, for instance, there is a minimum chance to confuse commuters for individuals

[10] For more detailed information regarding definition and construction of local labour markets refer to SCB (2010).

who truly relocate between regions. In that respect, operationalising spatial units as local labour markets is associated with minimising the risk that the labour market dynamics of a region will be affected by that of neighbouring regions.

Longitudinal character of investigations behind individual articles, included in this dissertation, posed some challenges with assigning municipalities to local labour markets. First, the Swedish municipality system underwent reforms over the considered time period. In 1985, there were 284 municipalities in Sweden. Two new municipalities were added in 1992 and in 1995. Also, one new municipality was added in 1999 and 2003. After 2003, the number of municipalities in Sweden remained the same: 290 municipalities.

Second, as a result of county reforms of 1997 (merging Malmöhus and Kristiandstad counties into Skåne county) and 1998 (merging Göteborg and Bohus, Älvsborg, and Skaraborg counties into Västra Götaland county), some municipalities changed their codes.

In cases of both new municipality additions and municipality code changes, division of municipalities into local labour markets was checked manually to make sure that it was consistent over time.

For the purpose of investigating the dynamics of industrial restructuring and labour market transformation at different levels of the regional hierarchy, local labour markets were also divided in regional groups. In Article I, seven groups are defined based on the population statistics, namely: Stockholm, Gothenburg, Malmö, large regions, medium-sized regions, small regions, and micro-regions. In Articles II-IV, instead, six regional families were introduced according to the methodology suggested by the Swedish Agency for Economic and Regional Growth (NUTEK 2004), namely: Stockholm, Gothenburg, Malmö, large regional centres, smaller regional centres, and peripheral regions. Criteria involved in the definition of these groups include population size and density, business dynamics, share of individuals with higher education as well as access to higher education institutions.

These two classifications correspond neatly to each other. Top three levels in both are the same – three Swedish metropolitan areas. Large regions in Article I match large regional centres in Articles II-IV, while medium-sized regions correspond to smaller regional centres. The only difference between two classification schemes is that small and micro-regions in the former are merged into the peripheral category in the latter.

5.1.3. Industry divisions

In LISA and DEVIL, the division of productive activities of firms into industries is performed according to the Swedish Standard Industrial Classification (*Standarden för svensk näringsgrensindelning, SNI*). SNI is primarily a statistical standard used to classify entities – that is, companies and workplaces – based on their primary economic activities. SNI is a part of an international system of economic classifications and is based on the Statistical classification of economic activities in the European Community (*Nomenclature statistique des activités économiques dans la Communauté européenne, NACE*). SNI and NACE are identical in the first four levels: sections, divisions, groups, and classes. In addition, SNI has a fifth level. In that respect, each workplace is characterised by a five-digit code representing its belonging to a certain industry.

Over the considered time period, three versions of SNI were provided in LISA and DEVIL: SNI69, SNI92, and SNI02. The summary of divisions into sections, groups, and classes according to these classification schemes is presented in Table 1.

	SNI69[11]	SNI92	SNI02
Sections	9	17	17
Divisions	33	60	62
Groups	79	223	224
Classes	185	505	514
Sub-classes	328	755	774

Table 1. Versions of SNI

SNI92 and SNI2002 have a rather similar structure. Indeed, SNI02 was a result of a minor revision of SNI92. Therefore, it was no problem to establish unambiguous links between these two classification schemes in order to ensure the data consistency over time.

11 SNI69 industry classification has six levels of industry classification. There are 368 six-digit level classes.

At the same time, ensuring the compliancy of industry classifications between SNI69 and subsequent classification schemes was more problematic. It was, however, important since that was the only classification system for the period before 1990. As SNI69 is more aggregated than SNI92 (see Table 1), it was not possible to go back in time before 1990 with the same level of detalisation as for years after 1990 (after SNI92 was established). Therefore, only when data was required for broad categories of industries, was it possible to make necessary aggregations from both SNI69 and SNI92 to make them consistent over a long period of time.

5.2. Ontological and epistemological perspective

This dissertation is informed by the critical realist perspective that was originally suggested by Bhaskar (1975, 1979) and further developed in works of other authors (e.g., Sayer 1992; Archer et al. 1998; Sayer 2000). The basic notion behind this perspective is that there is an objective reality – physical processes and social phenomena – that exists independent of our knowledge of it but may be scrutinised by research efforts.

There is a fundamental division between the intransitive and transitive dimensions of science (Bhaskar 1975; Sayer 2000). The former relates to objects of science, that is physical processes and social phenomena. The latter refers to theories and discourses that are developed as means of understanding and explaining the objects of science. Two dimensions, thus, represent the existing world and researchers' subjective and limited experience of it. Changes in the transitive dimension do not necessarily imply that the intransitive dimension undergoes changes as well. While science is socially-influenced, investigated phenomena and explanatory mechanisms behind them exist independent of the scientific thought. Critical realism, thus, differs itself from relativism that rejects the existence of an objective reality and views the world as constructed in minds of individuals who experience it.

At the same time, critical realism rejects the notion of universal truth, suggested by proponents of positivist approaches, and underlines the temporary and revisable nature of theorising. Social phenomena, being outcomes of social interactions, are subject to transformation if the context around them, as well as the very interactions producing these phenomena, change. The theory explaining social phenomena should then change as well

(Bhaskar 1979). Therefore, the truth is conditional, related to recognisable forms of social organisation, and in the need of continuous reassessment (Pratt 1995).

The tension between the real world and limited ability of individuals to understand it is resolved through the stratified ontology: a distinction between the real, the actual, and the empirical (Bhaskar 1975). The real refers to whatever exists in the world – be it natural or social – independent of our understanding of it. It is the entirety of all objects of the world, including the structures and mechanisms governing their conduct, that are not directly observed. The actual refers to what happens if and when these mechanisms are activated and includes all events which can potentially be observed. Finally, the empirical is the domain of concrete experience of these events, which is accessible to a researcher through observation and empirical analysis. The objective of the critical realist research is then to identify the structures and mechanisms in the domain of the real and their impact on social interactions.

The critical realist methodology seeks to reconstruct the causal mechanisms behind social interactions and to understand when, and under what conditions, they are activated. Different from positivist approaches, where the causation is a model of regular successions of events, the causation in critical realism is not pre-determined and refers to potential rather than actual mechanisms (Yeung 1997).

> What causes something to happen has nothing to do with the number of times we have observed it happening. Explanation depends instead on identifying causal mechanisms and how they work, and discovering if they have been activated and under what conditions. […] [E]xplaining why a certain mechanism exists involved discovering the nature of the structure or object which possesses that mechanism or power. (Sayer 2000, p. 14)

The research process begins with identifying an empirical phenomenon to be investigated and proceeds from describing the phenomenon to something that causes or produces it (Yeung 1997). The empirical phenomenon is approached from a perspective of a certain theoretical framework. However, this framework does not fully pre-determine the analysis but is rather subject to the ongoing scrutiny, based on insights from the empirical world. In other words, while the theoretical framework provides an initial set up for research, empirical investigation provides the basis for its revision or even rejection in certain cases.

In that respect, the central tool of the realist methodology is an abstract research (Sayer 1992, 2000). Abstraction is an adequate method to conceptualise social structures and causal mechanisms. To be able to address certain research issues, it is necessary to abstract from particular contingencies, that is to exclude those factors which do not have significant explanatory power in order to concentrate on those which do (Yeung 1997). Abstraction, though, should not be seen as a linear process, so that it only appears in the beginning of the research processes. Rather, it is an iterative and reciprocal movement between the abstract and concrete. In other words, one moves between pure descriptions of a phenomenon under consideration to abstractions of its possible causes.

Causal mechanisms and their properties are abstracted *a posteriori* as it is often impossible to realise *a priori* the existence of particular social interactions without experiencing some of their effects (Yeung 1997). Moreover, social phenomena are rarely as durable as natural science objects. In that respect, identified casual mechanisms are historical and contextual.

In particular, any empirical observation has spatial and temporal dimensions since social interactions are situated in particular conditions in time and space (Sayer 2000). At the same time, at any point in time space itself is constructed through the social relations and characteristics of objects occupying it. Thus, space and time provide contexts in which the empirical is observed. In that respect, from a critical realist perspective, explanations in social sciences should not be expected to remain stable over time and space.

5.2. Methodological perspective

The literature on research methods in the social science suggests that there is no predetermined connection between selection of a research method and a philosophical stance on which the research is based (Yeung 1997). In particular, choosing between qualitative and quantitative research strategies 'ought often to depend on the purposes and circumstances of the research, rather than being derived from methodological or philosophical commitments' (Hammersley 1992, p. 51). In this dissertation, quantitative research methods are employed that are sometimes referred to also as extensive methods (Sayer 1992).

Quantitative methods have been employed in a considerable body of research in economic geography since the mid-1950s, the period known as the quantitative revolution. At the time, however, this research was dominated by researchers who, explicitly or implicitly, accepted assumptions associated with positivism (Philip 1998). For that matter, they were criticised for commitment to the forms of economic modelling based on highly restrictive notions of rational behaviour, convexity, and perfect competition. Reductionist mathematical modelling may produce oversimplified explanations regarding the causal mechanisms for social interactions and nature of societal change. Particularly, if factors of context (e.g., spatial factors) are disregarded (Plummer 2003).

A considerable number of criticism towards quantitative methods in geography was expressed in years following the quantitative revolution. One of the claims being made was that quantitative geography did not address social, economic, and political challenges of the time, and dismissed research areas where objects of research were fuzzy, difficult to observe, classify and measure (Philip 1998).

> [T]he radicalism of the quantitative revolution […] did little if anything to loosen political perspectives or broaden the spectrum of political acceptability. Indeed it produced a form of selective objectivity, largely confining attention to previously 'acceptable' topics which could be squeezed to produce data amenable to quantification (Muir 1978, p. 323)

The ‘cultural turn’ in economic geography contributed further to the criticism of potential use of quantitative methods. Proponents of the cultural turn suggested that theorising in economic geography should abandon that of mainstream economics and search for economic knowledge elsewhere (Plummer and Sheppard 2001). Amin and Thrift (2000, p. 5) promoted a ‘skill base depending upon the understanding of open systems, appreciation of context, and qualitative techniques’.

Cultural, social, and institutional processes, that are difficult to incorporate into quantitative explanatory frameworks, are, indeed, important for understanding the evolution of economic landscapes. One, however, cannot simply imply these processes are *the* explanation and economic factors should be squeezed out (Martin 2001). Sharing the position of cultural turn proponents that one of the tasks of economic geography is to be a critique of mainstream economics, one should realise that such critique should be also expressed in the theoretical language of mainstream economics (Plummer and Sheppard 2001).

> Genuine refutation must penetrate the power of the opponent and meet him on the ground of his strength; the case is not won by attacking him somewhere else and defeating him where he is not (Adorno 1982, p. 5).

Employing quantitative tools of analysis, economic geographers can effectively criticise mainstream uses of quantitative regional science within their own terms of reference and develop alternative models aiming at understanding the dynamics of space economies (Plummer and Sheppard 2001). In that respect,

> [q]uantitative methods can contribute by describing and analysing the broad contours of difference, by providing a basis for informed policy making and progressive political change, by identifying people and places for in-depth studies, and by situating qualitative research in a broader context (McLafferty 1995, p. 436).

One should bear in mind that quantitative research is not tied to positivist approaches in social inquiry *per se*, at least unless it is used to suggest universal laws and other generalisations. Besides, quantitative research may be thought of as 'a tool developed for use within the value position or the research question in hand. In itself it is neither a ready-made philosophy nor a value-free method of research' (Bennett 1985, p. 223).

Quantitative methods may, among other things, be useful for identifying and explaining external and contextual relations between objects (Yeung 1997). It should be noted, however, that observed empirical regularities should not be always treated as causal mechanisms. Rather, these should be treated as generalisations of empirical patterns. In this dissertation these generalisations are not considered universal, but rather contextual and valid at a specific spatio-temporal intersection.

5.4. Methods

Following the discussion in the previous sections, the co-evolutionary dynamics of patterns of industrial restructuring and worker reallocation was studied in individual articles through the combination of abstraction and quantitative research methods.

Abstraction was the first step of research process underlying each individual article. The important component of the abstraction process is the previous research and theoretical frameworks relevant to the formulated research questions. Through reading of the relevant literature, the focus, with which empirical observations in the data were approached, was determined. This focus, in its turn, defined the operationalisations and selection of particular statistical tools and techniques that were employed in individual articles.

The first important aspect to be considered was to determine the way in which the diffusion of the GPT was operationalised in different papers. In Article I, the Perez' classification of leading industries[12], associated with the GPT diffusion, was revisited and empirically refined to analyse the role of locational patterns of these industries in shaping the inter-regional worker reallocation patterns. In Article II, the dynamics of labour sourcing in the GPT-related sector (i.e., the knowledge-intensive IT services sector) were analysed. Article III focused on the diffusion of GPT-related competences (operationalised as workers employed in IT occupations) across different industries and regions. Finally, in Article IV, entrepreneurship in the GPT-related sector (again, the knowledge-intensive IT services) was considered as a mechanism of spatial diffusion of the GPT-related activities. In that respect, while different articles have rather different empirical foci, all of them address certain aspects of co-evolutionary mechanisms between the process of industrial restructuring and labour market dynamics during the GPT diffusion.

In that respect, the execution of empirical analyses in different articles required specifying different units of analysis, spatial and temporal divisions, as well as statistical tools and techniques that would, according to the author's/authors' view, suit best to answer posited research questions. Table 2 provides the summary of methodological issues connected to each of four articles.

In terms of primary units of analysis, the articles focused on individuals (Articles II and IV), firms (Article IV), industries and industry groups (Article III), as well as regions (Articles I and III). Flexible selection of the units of analyses allowed uncovering the mechanisms taking place at various levels

12 Discussed in Section 2.2.2.

of the economy with a goal of identifying the meso-rules underlying these mechanisms.

	Article #1	Article #2	Article #3	Article #4
Data sources	LISA; DEVIL	LISA	LISA	LISA
Units of analysis	Regions	Individuals	Industry groups; regions	Entrepreneurs (individuals); entrepreneurial entries (firms)
Spatial units	Local labour markets; population-based regional groups	Local labour markets; regional families	Local labour markets; regional families	Local labour markets; metropolitan and peripheral areas
Time period	1985-2008	1991-2010	2001-2010	1991-2010
Time sub-periods	1985-1998; 1999-2008	1991-1993; 1994-1997; 1998-2001; 2001-2004; 2005-2007; 2008-2010	No	1991-2000; 2001-2010
Statistical tools and techniques	Exploratory data analysis; instrumental system-GMM regression (Arellano-Bover estimator)	Exploratory data analysis; OLS regression; logistic regression; Heckman-probit selection model	Exploratory data analysis	Exploratory data analysis; logistic regression; Cox proportional hazards model

Table 2. Summary of research methods

The principal spatial units – local labour markets – were the same in all four articles, even though the division of them into the levels of the regional hierarchy was performed differently in Article I as compared to Articles II-IV (see Section 5.1.3.).

Issues with data availability and ensuring the consistency of industry classifications over time made it impossible to cover the same time periods in different papers. For instance, Article I covers the longest time period (1985-2008). Articles II and IV cover the time period between 1991 and 2010. Finally, analyses in Article III are provided for the period 2001-2010.[13]

13 Analyses in Article III are based on the information about the occupation an individual is employed at, which is only available for the 2000s.

Besides, in all articles but Article III, the whole considered time period is divided into sub-periods according to different criteria (for the specifics, see methodology sections of the articles).

Finally, depending on the way the research questions in individual articles were posited, a wide range of statistical tools and techniques was employed. Some of them are widely used in quantitative economic geography research relatively and are relatively easy to implement and interpret (e.g., exploratory data analysis and OLS regression). Others are more specific (e.g., Arellano-Bover GMM estimation, Heckman-probit selection model, and Cox proportional hazards model). The selection of these techniques was dictated by the necessity to deal with particular features of the data at hand and inability of more conventional techniques to properly address the empirical issues. Simply put, the selection of statistical techniques, employed in individual articles, was driven primarily by their suitability to deal with the problem at hand, rather than simplicity of their application.

6. Current wave of technological change: Information technology as a GPT

There is no reason for any individual to have a computer in his home.

(Kenneth Olsen, CEO of Digital Equipment Corporation, at the 1977 World Future Society meeting in Boston, USA)

You can see the computer age everywhere but in the productivity statistics.

(Solow 1987, p. 36)

Two famous quotes above represent two early misconceptions regarding the role of the information technology (IT) for the economy and society. Nowadays, it is difficult to imagine our lives without computers and other electronic devices. However, some forty years ago even leaders of the world's largest manufacturers of computer equipment did not see the potential for using computers beyond specialised applications in the military (Kenneth Olsen's quote). Even later, when computers were already employed in a wide range of personal and business applications, economists cast doubt on benefits that the IT could bring in terms of generating productivity gains (reference to Solow).

One particular issue with the IT lies in identifying what exactly it embodies. Most often the IT is referred to generically. There are, however, more specific references to semiconductors (Bresnahan and Trajtenberg 1995), computers (David 1990), the Internet (Clarke et al. 2015), and others. However, even such delimitations are often not enough.

> When we speak of the “internet”, for example, what is paramount? Is it the hardware and software protocols such as TC/ICP, the http protocol, html markup language? Or is it the switches and routers, or the innovations that permitted multiplexing hundreds of bitstreams over a single fiber optic cable? (Field 2008, p. 11)

David and Wright (1999) considered the IT as a cluster of technologies that developed in certain stages. Each of these stages broadened the spectrum of potential uses of the IT and marked different phases of its diffusion.[14]

Early on, available technologies were purpose-built and task-specific (such as, monitoring material flows and delivery processes in manufacturing industries). At that stage, the narrow scope of applications of the IT made the mass production of personal computers neither appropriate nor robust.

Around the early 1990s improving capabilities of computers as network servers allowed companies to develop client-server data processing systems instead of using the centralised mainframe environment.[15] Client-server architecture put the power of a mainframe into a server, whereas networks, connecting different servers, gave companies more flexibility with less powerful clients, thus, contributing to lowering costs required to implement IT solutions into business processes (ter Weel 2006). Bresnahan et al. (1996) used an analogy with Jonathan Swift’s Gulliver’s Travels to describe the advantage of client-server computing:

> Before 1989 workstations and personal computers could no more replace mainframes than could the people of Lilliput wrestle Gulliver to the ground. Yet, like the Lilliputians ropes, networking cables created strength from numbers. Workstations, a technology originally intended to serve individuals, were deployed as servers. They did not need as much capacity as hosts, since PCs, deployed as clients, assumed some of the computing tasks (such as effectively interfacing with people). This technical opportunity produced large market and organisational change. (pp. 3-4)

Finally, a widespread propagation of the Internet opened up opportunities for a new class of data processing applications that enhanced the potential for

14 These stages are not related to the spread of computers for private use, but rather business applications of the IT.

15 A mainframe is a central data repository in the data processing centre of an organisation that is accessed by individual users through workstations and/or terminals. Mainframes are typical for a centralised form of computing, as opposed to a distributed (client-server) form of computing.

collective and cooperative forms of work organisation. Parallel to this, the elaboration of standards and increased compatibility of different software and hardware improved the ease of collaboration between workers within organisations as well as collaboration between organisations.

In what follows, the review of studies regarding the impact of IT on the economy is performed. Two dimensions are addressed. First, it is explored whether the IT lives up to the expectations of it as a driver of productivity gains and aggregate growth. In other words, can the IT be characterised as a GPT? Second, given the particular interest of this dissertation in labour market dynamics, some general aspects of the labour market impact of the IT are discussed.

6.1. Growth and productivity impact of the IT

This section summarises the empirical studies on the overall impact of the IT on the economy in three dimensions: determinants of IT adoption, productivity and growth implications of IT adoption, and mechanisms through which the IT generates productivity gains and aggregate growth.

When it comes the IT adoption, numerous studies have investigated various sets of traditional and non-traditional variables. It has been demonstrated that the probability of IT adoption co-varies with firms' age and size (Hollenstein 2004; Haller and Siedschlag 2011), share of skilled labour (Bayo-Moriones and Lera-López 2007; Haller and Siedschlag 2011), (local) competitive pressures (Fabiani et al. 2005; Bayo-Moriones and Lera-López 2007), export orientation and openness to international environment (Baliamoune-Lutz 2003; Haller and Siedschlag 2011), organisational structures (Caroli and Van Reenen 2001; Hollenstein 2004), expected performance benefits for more complex applications (Tsikriktsis et al. 2004), and others. Despite differences across firms with regards to mentioned variables, all these studies point to an impressive pace of the IT diffusion, pointing to the pervasive nature of the technology.

Many of adoption studies emphasise the division between basic and strategic adoption. The basic adoption is associated with generic applications such as establishing basic infrastructure (e.g., Internet access), e-mail use, passive document sharing. The strategic adoption involves technologies that change existing internal processes in firms and require substantial co-invention at the firm level to be used successfully.

The difference between basic and strategic adoptions manifests spatially (Forman et al. 2005). On the one hand, when it comes to the basic adoption, there is little variation in adoption rates between dynamic urban agglomerations and more peripheral regions. In other words, at least the basic IT applications are pervasive in the geographic space. On the other hand, when it comes to technology-intensive applications that require strategic adoption, firms located in larger regions tend to have a higher probability of adopting the IT (Galliano et al. 2011; Haller and Siedschlag 2011). These regions offer a combination of benefits – such as availability of complementary inputs, thicker labour markets, etc. – that make costs of the strategic adoption lower. What is interesting, however, the role of location of firms in the strategic IT adoption is secondary to that to which industry a firm belongs to (Forman et al. 2005). One can, therefore, infer that regional differences in IT adoption rates are primarily driven by the geographical distribution of IT-using industries.

The impact of the IT adoption on productivity has been investigated in numerous contributions that focused on different levels of analysis and employed various frameworks and definitions of the IT. Early studies demonstrated that prior to the 1990s the estimated contribution of IT to productivity growth was lower than expected (e.g., Oliner and Sichel 1994). This was the reason behind the productivity paradox formulated by Solow.

More recently, the positive productivity impact of the IT adoption has been repeatedly and extensively documented by many empirical works at firm, industry, regional, and national levels (see reviews by Draca et al. 2007; Stiroh 2010; Kretschmer 2012; Cardona et al. 2013; Stanley et al. 2015). The IT has become a driver of rising productivity through direct productivity increases in IT-producing sectors and through capital deepening and labour productivity improvement in IT-using sectors (Liao et al. 2016). In their turn, productivity gains in both IT-producing and IT-using industries have increasingly contributed to the aggregate growth of regional and national economies (Strohmaier and Rainer 2013).

What is the reason behind the Solow paradox then? Studies of the productivity impact of the IT demonstrate that, on the hand, a certain amount of the IT capital had had to be accumulated in the economy before its effect became visible, and, on the other hand, there were pronounced lags between the IT investments made and productivity benefits reaped (Rincon et al. 2013; Strohmaier and Rainer 2013). For instance, productivity gains of IT investments in IT-using industries take 5 to 15 years to be realised (Basu and Fernald 2007). In that respect, the Solow productivity paradox was, to a great extent, an artefact of time and measurement:

> The problem with "we see computers everywhere around us except in the productivity statistics" was not with productivity, but with looking at computers in economics departments rather than in firms. At the time of Solow's remark, the ICT capital stock was far too small to have (yet) created a growth boom, even though the private returns to use of computers were very substantial. (Bresnahan 2010, p. 789)

The mechanism of achieving productivity gains through IT investments lies primarily in fostering complementary innovation in IT-using industries. These complementarities offset potential diminishing returns to the IT itself and shift the demand curve for the IT capital further out (Basu and Fernald 2007). Vast amount of empirical literature investigated productivity-boosting spillovers that are the outcome of the IT diffusion and identified several domains of these spillovers.

First, the IT facilitates organisational change at the firm level through decentralisation of decision-making, improved team work, easier information sharing, etc. (Brynjolfsson and Hitt 2000; Bresnahan et al. 2002; Brynjolfsson and Hitt 2003). The organisational change is an outcome of learning-by-adopting and learning-by-doing processes (Rincon et al. 2013). In that respect, the IT capital is an input that is complementary to the organisational capital (Bertschek and Kaiser 2004; Belloc and Guerrieri 2015).

Second, the IT improves the efficiency of transactions among firms by, for example, reducing administrative and search costs, improving supply chain management, etc. (Rowlatt 2001; Criscuolo and Waldron 2003). In short, the IT makes it faster, easier and more efficient for firms to interact with each other (Brynjolfsson et al. 2002). This results in positive network externalities, efficiency of which increases with time as the IT is adopted by more users (Rincon et al. 2013).

The realisation of these spillovers has a temporal component in it (Rincon et al. 2013). Immediately after the investments in the IT capital are made in IT-using industries, intra-industry IT spillovers are negative because of the costly restructuring process in firms. Inter-industry IT spillovers – that is, network externalities – are, however, directly positive. The total spillover effect is negative. The complementarity between the IT and R&D efforts at the firm level allows the most innovative firms to overcome the negative intra-industry spillovers relatively fast. With approximately five-year lag, intra-industry spillovers become positive for most (even the least innovative) firms. Therefore, the IT diffusion imposes periods of experimentation leading to delays between initial investments and performance improvements that also justify the lagged IT spillover effect (Brynjolfsson and Hitt 2003). In other words, just as with the direct effect of the IT on productivity, the indirect effect in the form of spillovers is lagged since IT investments, made by IT-using firms, need to accumulate before their positive effects are realised (Liao et al. 2016).

All in all, the empirical studies on the IT adoption and its effects demonstrate that the IT possesses features – such as, pervasive use, positive impact on productivity, ability to generate spillovers, the delay between the diffusion and its impact – that correspond neatly to the characteristics of a GPT discussed in Section 2.2.1.

6.2. Labour market impact of the IT

The division of labour between particular tasks is determined by a trade-off between specialisation benefits and costs of communication between individuals involved in various tasks (ter Weel 2006). Diffusion of the IT has improves communication and production opportunities, resulting in fundamental changes in the division of labour as well as the labour demand.

On the most obvious side, the IT diffusion as well as ongoing standardisation of certain tasks has led to the substantial growth in the number of processes the IT can automate and, thus, to the substitution of certain kinds of labour and decreasing labour intensity of production processes (Autor et al. 2003). According to the routinisation hypothesis (Autor et al. 2006)[16], computers are particularly suited to perform routine, repetitive tasks that can be described by rules, while humans have a comparative advantage in non-routine tasks that involve creativity, social interaction, pattern recognition, etc. (Levy and

16 In the literature, related notions of task-biased (e.g., Adermon and Gustavsson 2015) and routine-biased technological change (e.g., Goos et al. 2014) are also employed.

Murnane 2004). The classical study by Autor et al. (2003), who investigated the replacement of intellectual skills of workers by computers in the assessment of mortgage applications, was followed by other studies that demonstrated the overall increasing demand for routine tasks – such as, book-keeping, middle-management and non-specialist blue collar occupations – but a declining demand for workers to perform these tasks (Autor et al. 2006; Spitz-Oener 2006; Goos and Manning 2007). The new generation of the IT allows automating even more complex tasks, such as driving, speech recognition, and basic motor skills (Brynjolfsson and McAfee 2014).

Does it mean that computers are eventually going to substitute all human labour through automation? Actually, not. The IT diffusion, while decreasing the demand for routine, repetitive skills, has boosted the demand for non-routine analytical and interactive skills, leading to profound changes in the content of existing occupations and emergence of entirely new occupations (Vona and Consoli 2015). The increase in importance of non-routine tasks has increased the relative demand for highly educated workers who possess a comparative advantage in executing these tasks (Böckerman et al. 2016). The benefits of the IT can be enjoyed fully if human capital, accumulated at the organisation level, is upgraded accordingly resulting in better information collecting, processing and communicating (Caroli et al. 2001; Belloc and Guerrieri 2015). The IT diffusion has, therefore, been accompanied by investments in skilled labour (Caroli and Van Reenen 2001; Strohmaier and Rainer 2013). This tendency is particularly pronounced for industries, heavily investing in new technologies (Berger and Frey 2015). The decreasing relative demand for lower skilled labour and increasing relative demand for higher skilled labour, therefore, points to the fact that technological change is not only task-biased, but also skill-biased (Griliches 1969; Bresnahan et al. 2002; Autor et al. 2003).[17]

In particular, in a computerised work environment, advanced skills, related to information processing, become more valuable as there is a complementarity between the relative strength of the IT – such as, capacity for storage, communication and processing of information – and certain types of human

[17] There are, however, some claims in the recent literature that as at least early domains of IT applications reach maturity, knowledge related to them becomes codified and widely diffused eroding the initial comparative advantage of highly skilled workers (Consoli and Rentocchini 2015; Vona and Consoli 2015).

judgement and decision making (Bresnahan et al. 2002). As a result, the demand for more educated and higher skilled workers increase; also, more investments are directed towards (re)training current workers. The information overload bottleneck is particularly severe for workers at higher levels of the organisational hierarchy since 'what information consumes is […] the attention of its recipients' (Simon 1971, p. 40). As routinisation is one of the main mechanism producing polarisation in the labour market, this also implies increased wage differentials between low and highly skilled workers (Böckerman et al. 2016). Most prominent IT-using industries, particularly in the service sector, have seen these changes earlier (Wolff 2006) and to a greater extent (Autor et al. 1998) than others. And yet, all sectors of the economy were, in one or another way, affected by this process.

Task- and skill-biased character of IT-induced technological change has had important implications for the geography of job creation. The increased demand for skilled labour, employed in non-routine tasks, and the uneven distribution of technology-intensive industries, positing this demand, across regions has led to regions with higher skill endowments to become even more skill-endowed over time (Moretti 2012). In that respect, the diffusion of the IT, and the subsequent substitution of labour performing routine tasks by labour involved in more abstract tasks, have benefitted regions that were originally endowed with higher levels of human capital by boosting the job creation in these regions (Berger and Frey 2016).

7. Research setting: Sweden

7.1. Swedish economic growth and labour market trends, 1985-2010

Overall economic development of Sweden between 1985 and 2010 was characterised by a clear cyclical pattern as reflected in the GDP growth rate (Figure 4).

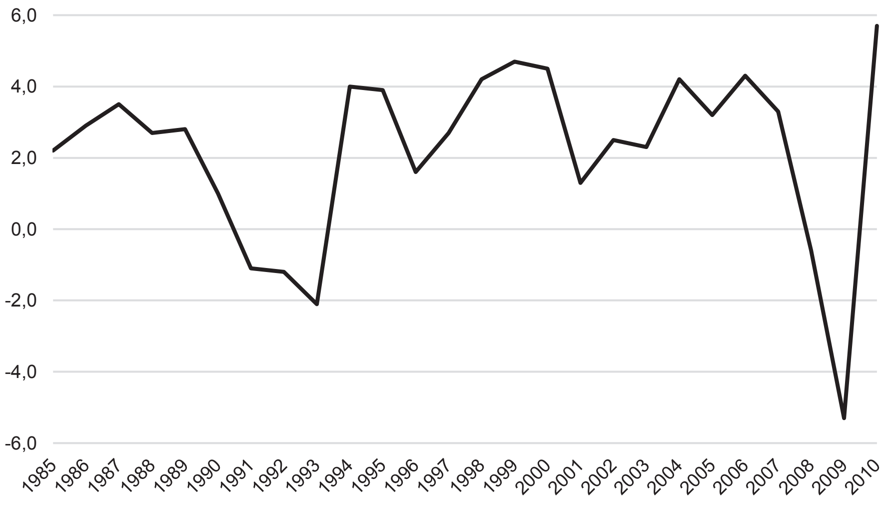


Figure 4. Economic growth in Sweden, 1985-2010 (annual GDP growth rate, fixed 2005 prices)

Over twenty-five years between 1985 and 2010, the Swedish economy experienced two periods of contraction. First, in the early 1990s, the Swedish demonstrated the negative growth rates for three years in a row (1991-1993) as an outcome of the crisis that started in the banking sector and spread out to the whole economy. Second, in the late 2000s, when the Swedish economy was hit by the repercussions of the global financial crisis of 2007-2008 and subsequent Great Recession. Between these two crises, the Swedish economy demonstrated a rather steady economic growth, averaging at 3.3 per cent per annum between 1994 and 2007. As a result, the recovery from the early 1990s crisis took approximately two years. By 1995, the Swedish economy returned to the pre-crisis level of GDP.

The recovery of the labour market from the early 1990s crisis went much slower (Figure 5).

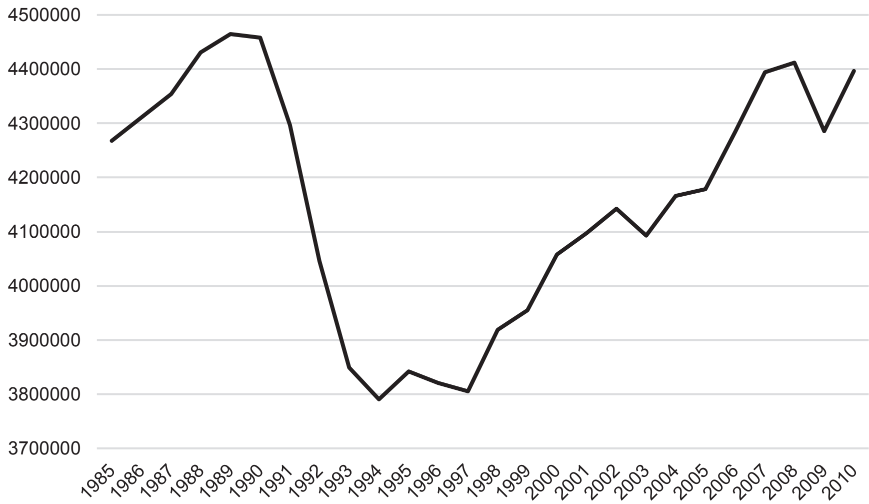


Figure 5. Total employment in Sweden, 1985-2010 (individuals aged 16-64)

Following the outburst of the crisis in the early 1990s, the total employment in Sweden contracted by more than 17 per cent. That is, almost each fifth job disappeared. The outcomes of job destruction were particularly pronounced in the manufacturing sector. Reaching the bottom level in 1994 and remaining there until 1997, the total employment demonstrated a steady recovery starting in 1998, when the employment growth rate averaged at approximately 1.5 per cent per year until 2008. It should be noted, however, the employment growth was slower than the expansion of the economy as a whole. In that respect, the GDP growth in the period between two major crises was driven, to a great extent, by the increases in labour productivity level. Nevertheless, the recovery of the labour market after the early 1990s crisis was never complete as the Swedish labour market never returned to the pre-1990s employment level.

At the same time, the aggregate labour market recovery statistics mask rather pronounced regional differences (Figure 6).

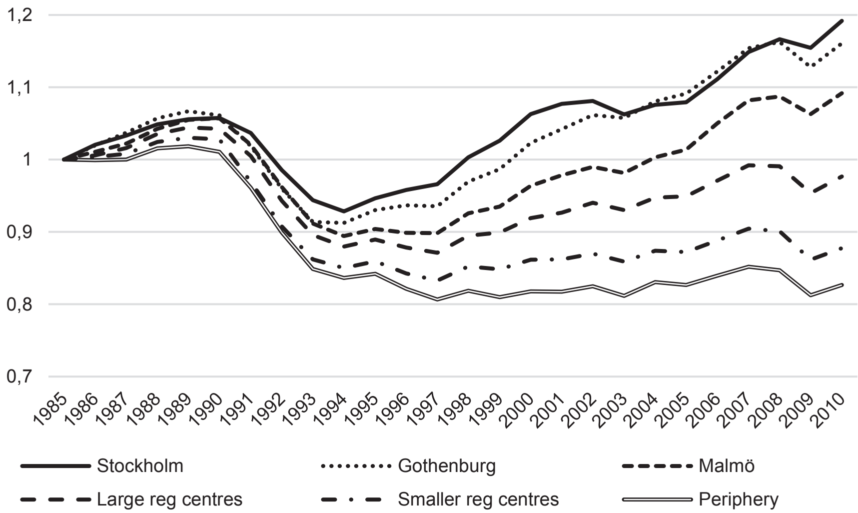


Figure 6. Employment growth across Swedish regions, 1985-2010 (1985=1)

The early 1990s crisis hit regions at all levels of the regional hierarchy. irrespective of the level of the regional hierarchy. However, effects of the crisis in more peripheral regions were more severe and longer lasting. The regional labour markets of Stockholm and Gothenburg labour markets began their recovery as early as 1995 and reached the pre-crisis employment by 2000 and 2003 respectively. In Malmö, the recovery process started later (1997), and the regional employment returned to the level of 1990 by 2006. While the recovery trend was observed in large regional centres, their labour markets never returned to the pre-crisis level. In smaller regional centres and most peripheral regions the employment stabilised after the fall and never recovered.

It is peculiar that by 2010 the performance of regions in terms of their recovery from the early 1990s crisis neatly corresponded to their position in the regional hierarchy. This manifested the divergence patterns across regional labour markets and continuing concentration of labour to the most dynamics regions at the top of the regional hierarchy. In that respect, this underlines the importance of accounting for the level of a region in the regional hierarchy when analysing regional labour market dynamics.

7.2. The IT in Sweden

Linux, Skype, Spotify, … The list of the Swedish IT start-ups, which shaped the evolution of the global IT, includes more widely-known names, and even more less famous ones. Over last 30 years, Sweden has become one of the world-leading knowledge economies with a strength in both providing and using the IT (Giertz et al. 2015), which is certified by the top positions of Sweden in various international rankings of the IT development (see Section 1.3.).

While it is rare in the world history that small economies are global leaders in the major sector, this is indeed the case with Sweden. In this section, a brief overview of the Swedish way towards the IT success as well as the current state of the IT sector in Sweden is performed.

The beginnings of the Swedish IT sector date back to the late 1940s.[18] As in the case with many other countries, the IT research was initiated by the state and remained in its domain for a long time. In 1948, the Swedish government, being among the first in Europe, established the Board for Computing Machinery (*Matematikmaskinnämnden*, *MMN*), whose task was to develop and produce the first Swedish computers. Already in 1950, the first computer – Binary Arithmetic Relay Calculator (BARK) – was completed, followed by the Binary Electronic Sequence Calculator (BESK) in 1953. The latter was primarily used for the national security purposes, but also for some civil applications, such as meteorological studies.

In 1954, MMN signed the contract with Saab (car and military planes manufacturer) that regulated the collaboration for the further development of BESK. The major stakeholders from the state side were the Swedish military and the central Swedish government that both were early adopters of computers in various agencies and divisions they comprised. This marked the start of the public-private collaboration in the IT development in Sweden.

18 Historical overview of the Swedish IT sector relies heavily on Giertz (2015).

By 1976, more than twelve thousand computers from Saab (later Datasaab) were sold. The problem was, however, that the demand for Saab computers remained mostly domestic. Because of particularities of the data processing architecture, most customers worldwide preferred more wide-spread IT systems developed by IBM. The opportunities for expanding the market of Saab-manufactured computers were limited, to a great extent, by the size of the domestic market.

The next era in the Swedish computer manufacturing began in the late 1970s, when Luxor AB – Swedish home electronics manufacturer that was founded in 1923 – entered the market of personal computers. In August 1978, the first Advanced BASIC Computer 80 (ABC 80) was launched. It became a success on the domestic market. Being originally designed and used for industrial automation, office and education purposes, it also managed to grasp a substantial share of the emerging Swedish PC market. Following the expansion of the PC market, Luxor introduced the successor of ABC 80 – ABC 800 – in 1981. It was a computer aimed at the home use market primarily. With a great performance and relatively low price, it soon reached 60 per cent of the Swedish PC market. The problem of both ABC 80 and ABC 800 was that they still employed their own data processing standards, which were not compatible with US-manufactured computers that dominated the global market. The inconvenience of this incompatibility increased as computers were used in continuously expanding range of applications. As a result, the Swedish companies started to buy computers from abroad; and by the end of the 1980s the US-based companies took over the Swedish computer market completely.

Beginning in the 1990s, the deregulation of IT sector and declining state support (Zaring and Eriksson 2009; Giertz 2015) as well as the increased international standardisation of the IT equipment led to the contraction of the IT manufacturing in Sweden. At the same time, the ongoing digitalisation of production processes in a wide range of industries boosted substantially the demand for provision of software and other IT-related services. This resulted in a rapid expansion of the services part of the IT sector. To provide a perspective on the reverse tendencies in growth of the IT manufacturing and IT services, Table 3 reports employment numbers in these two parts of the IT sector in Sweden between 1985 and 2010.

	1985	1990	1995	2000	2005	2010
IT manufacturing	25369 *57.87%*	27767 *45.22%*	25150 *38.13%*	28410 *23.73%*	18545 *16.72%*	17028 *13.79%*
IT services	18467 *42.13%*	33632 *54.78%*	40807 *61.87%*	91336 *76.27%*	92395 *83.28%*	106431 *86.21%*
Total	**43836**	**61399**	**65957**	**119746**	**110940**	**123459**

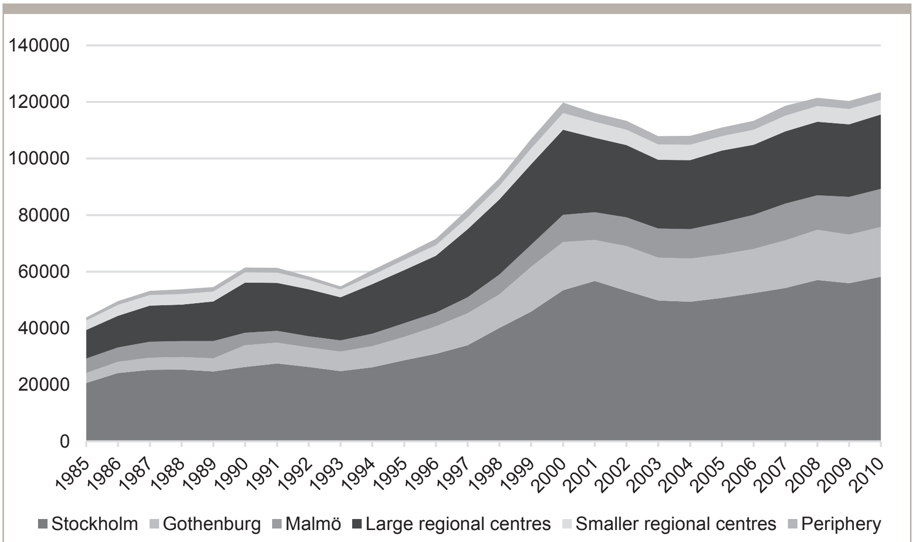
Table 3. IT employment in Sweden

Between 1985 and 2010, the total employment in the Swedish IT sector increased almost three times – from 43,836 to 123,459 workers. This corresponded to the increase of the sector's share in the national employment from 1.0 per cent to 2.8 per cent.

This growth was predominantly driven by the expansion of the IT services part of the sector, where employment increased almost six time – from 18,467 workers in 1985 to 106,431 workers in 2010. At the same time, over the considered time period the employment in IT manufacturing contracted by more than 8,000 workers. The contraction proceeded at the particularly fast pace in the aftermath of the 2001 dot-com crash, the result of which was, among other things, the global restructuring of the IT sector.

These tendencies led to the increase of the IT services employment share in the Swedish IT employment from 42.1 per cent in 1985 to 86.2 per cent in 2010. In that respect, the expansion of the Swedish IT sector was paralleled by its functional reorientation – from being primarily manufacturing-driven in the beginning of the time period to predominantly service-driven in the end.

This expansion of employment in the Swedish IT sector was unequally distributed across regions at different levels of the Swedish regional hierarchy (Figure 7). For instance, three Swedish metropolitan areas – Stockholm, Gothenburg, and Malmö – concentrated by far the largest share of IT employment. Over the considered time period, around 70 per cent of IT workers (on average) were employed at the local labour markets of these three regions. Stockholm alone concentrated around 45 per cent of IT employment. Moreover, while the IT sector expansion (in absolute numbers) took place in all regions, metropolitan areas of Sweden demonstrated faster growth than non-metropolitan regions. This implies the further concentration of the IT activities to the most dynamic regions at the top of the regional hierarchy.



Total employment growth over 1985-2010							
Stockholm	Gothenburg	Malmö	Large regional centres	Smaller regional centres	Periphery	**Metro**	**Non-metro**
181.43%	401.30%	163.30%	161.46%	53.16%	143.49%	**204.76%**	**135.05%**

Figure 7. IT employment across Swedish regions, 1985-2010

The outpacing expansion of the IT sector in metropolitan areas, coupled with its increased servicification, points to the fact that most IT-producing firms locate their businesses in large regions because the demand for IT services in these regions is particularly high due to scale effects – as these regions host more potential client companies – and higher demand for advanced (or, strategic) IT solutions that, as it was discussed in Section 6.1., tends to be higher in large regions.

7.3. The 'Swedish model' of the labour market

The Swedish labour market between the late 1960s and the early 1990s was characterised by a situation of full employment. In the aftermath of the deep economic recession in the first half of the 1990s, unemployment rose dramatically to levels, which were not observed since the 1930s (Bengtsson

2012). Even the subsequent decrease in the unemployment rate over the late 1990s and the 2000s, the Swedish economy never returned to the situation of full employment. In 2015, the unemployment rate among the work age population was 7.4 per cent (SCB 2016a).

Besides, for couple of decades prior to the 1990s there was a decline in the wage inequality among Swedish workers, both with regards to the overall wage dispersion and to its particular components, such as relative earnings advantage of highly educated workers, wage differences between men and women, etc. However, the trend for declining wage inequality was also broken in the aftermath of the early 1990s crisis (Edin and Holmlund 1995; Domeij and Floden 2010).

These trends, as well as their temporal congruence, may be related to the rise and demise of the 'Swedish model' of the labour market that is characterised by the solidarity wage policy – realised through the centralised bargaining mechanism – and a vast array of active labour market policies aimed at improving the efficiency of labour matching. In what follows, basic features of the model as well as its consequences for the functioning of the Swedish labour market are discussed.

The post-World War II labour market policy of Sweden traces back to works of Gösta Rehn and Rudolf Meidner – both economists in the Swedish Confederation of Trade Unions (*Landsorganisationen i Sverige*) – who developed a model that underlined the crucial role of labour market policy for achieving economic growth and price stability, on the one hand, and full employment, wage levelling, and union solidarity, on the other hand. Rehn-Meidner-inspired policies aimed at promoting the labour market flexibility through improved income and employment security (van den Berg et al. 1997). These policies combined three components, namely: a strict fiscal policy, solidarity wage policy, and active labour market policies.

First, the Rehn-Meidner model aimed at building a balanced economy with low inflation. Their fiscal policy was based on Keynesian principles and assumed that the excess demand should be addressed through fiscal policy, while admitting the possibility of high short-term structural unemployment. For instance, a high-tax policy was suggested to replace redundancies in the private sector with public employment (Bengtsson 2012).

Second, the Rehn-Meidner model promoted the solidarity wage policy, that is, a rational differentiation of wages within and across sectors that would result in the wage compression (Lundh 2005). The effect of this policy was that firms and sectors with low productivity and profitability levels – unable to withstand the international competition – would face downsizing as they would not be able to pay wages that were centrally bargained. More productive firms and industries would then get more opportunities for expansion, which, in its turn, would boost national productivity levels and the aggregate growth. In that respect, the job protection was replaced by the employment protection. In other words, according to the the Rehn-Meidner model, it was the national employment that should be defended, rather than particular job matches (Magnusson 2007). The mechanism of wage dispersion – traditionally used for the effective labour allocation – was replaced by mechanisms of job, industry, and regional mobility.

Finally, as the increased flexibility of the labour market would generate higher unemployment in the short run, the Rehn-Meidner model offered a wide range of active labour market policies that addressed this short-term mismatch on the labour market. Training as well as allowances for the worker mobility across jobs, industries, and regions were suggested as policy instruments aimed to help people to find jobs in more productive parts (in both sectoral and regional dimensions) of the economy (Bengtsson 2012).

Throughout the 1950s-1960s, the Rehn-Meidner model was accepted by actors on both supply-side (trade unions and other worker organisations) and demand-side (employer unions) of the labour market. By the late 1970s, however, the model began to lose its legitimacy, primarily with employers but also with some trade unions and local interest groups (Lundh 2005). Several factors contributed to that.

First, the Swedish society changed. The expansion of the public sector and increased number of white-collar workers facilitated the development of a white-collar union movement. Wage demands posed by workers, participating in that movement, exceeded those considered normal within the centralised bargaining system (Lundh 2005). Also, the policy of employment protection, that replaced the job protection policy, was undermined by the adoption of the 1974 Swedish Employment Protection Act and the 1976 Act on Employee Consultation and Participation in Working Life (Bengtsson 2012). Besides, the focus of active labour market policies shifted in the 1970s and 1980s towards interventions on the demand-side of the labour market, e.g., job creation schemes in the public sector as an alternative to the private sector employment.

Second, the demise of the mass production system and the IT-induced economic transformation pointed to the need for a functioning local wage formation. As the IT-induced technological change was skill-biased, skilled workers became increasingly important for firms' competitive performance. High costs of employing and (re)training such workers made employers search for options to tie workers to their jobs through, for example, higher relative wages, other non-monetary benefits, etc. At the same time, an oversupply of lower skilled workers and undersupply of jobs, which these workers could occupy, undermined employment protection mechanisms and resulted in smaller incentives for unskilled workers to change jobs. In other words, the flexibility mechanisms of the Rehn-Meidner model did not pay off for unskilled workers anymore. This resulted in the shift of the overall focus of firms from the worker collective to individual workers. On the policy side, there is now a stronger emphasis on qualifications and activities of particular job seekers and the individual provision of the labour market policies (Bengtsson 2012).

Both these factors intensified the firms' need for wage flexibility as an instrument to recruit and retain attractive workers. Under such circumstances, it was important for firms to deviate from centralised wage bargaining within the solidarity wage policy. Developments in the 1980s-1990s resulted in more opportunities for firms to influence wages based on their own prerequisites. The union agreements were increasingly the basis that was complemented with further wage negotiations in firms. By the end of the 1990s, about half of the latter were distributed to the local level (Lundh 2005).

This is, however, not to say that the trade unions lost their role on the Swedish labour market. Compared to the weakening of the trade union movement in other European countries throughout the 1980s-1990s, the degree of the trade union organisation as well as the extent of coverage of collective agreements in Sweden remained high in the international comparison (Lundh 2005).

In that respect, the consequences of the Rehn-Meidner model implementation may still be observed in Sweden. Even though there is an upward trend in overall wage inequality since the early 1990s (Domeij and Floden 2010), Sweden is still characterised by one of the most equal income distributions (OECD 2011). With this in mind, it comes as no surprise that studies of internal migration demonstrate that reallocation of labour in Sweden is driven primarily by the patterns of job availability rather than wage differentials. (Westerlund 1997, 1998; Fredriksson 1999; Gärtner 2014). In other words, geographical reallocation of workers is directed first and foremost to regions characterised by higher rates of job creation, while the effect of regional wage differentials is relatively minor.

Fredriksson (1999) shows that mobility of workers in Sweden is more responsive to national economic conditions and region-specific shocks in the demand for labour than in any other European country. In other words, the Swedish labour market is more responsive to the shifts in the macroeconomic situation than that of other European countries. In that respect, it is interesting that switching a job is a major response to job destruction for Swedish workers, compared to becoming unemployed or leaving the labour market. This, among other things, results in the regional reallocation of workers in Sweden to remain high by European standards.

8. Conclusion

This chapter provides an overview of the major findings from the articles included in this dissertation. It continues by synthesising these findings and presenting general conclusions and emergent topics.

8.1. Summary of the articles

Article I addresses the gap in the literature with respect to identifying the leading industries associated with technological change at various times and measuring their effects on functioning of the economy. This is performed by revisiting and empirically refining Perez' (1983, 2010) classification of key industries driving the technology-induced transformation process into motive, carrier, and induced branches.

By analysing the patterns of inter-regional worker reallocation in Sweden between 1985 and 2010, the following research question is addressed:

> *In what ways do spatial patterns of distribution of leading industries associated with a current wave of technological change shape inter-regional labour reallocation flows?*

It is hypothesised that a stronger regional presence of leading industries positively affects the ability of regions to attract and retain workers.

Results of the analysis confirm the hypothesis above. That is, the industrial structures of regions in general, and the presence of leading industries in particular, played an important role in shaping patterns of inter-regional reallocation of workers in Sweden over the considered time period. However, the decomposition of these effects in time demonstrated that there are several important qualifications to this result.

First, different groups of leading industries played different roles in attracting labour to and/or retaining labour in regions at different stages of the GPT diffusion process. The positive role of motive branches – comprising the activities that are paradigmatic to the recent wave of technological change – are only observed for the period between 1985 and 1998, but not at later stages of the GPT diffusion or over the whole time period. Rather, the locational patterns of carrier branches – the most visible and active users of the GPT – played the most pronounced role in shaping patterns of inter-regional worker reallocation. Induced branches were important in terms of generating gross flows of workers between regions, while their effect is not visible in the resulting net inter-regional labour reallocation.

Second, locational patterns of service branches are the major factor shaping the patterns of inter-regional labour mobility. Their role is particularly pronounced in terms of attracting workers to regions. The role of manufacturing branches is quite different. Their regional presence is a stabilising factor, helping regions to retain workers.

Third, the impact of diversification of regional employment mixes is different at different stages of the GPT diffusion process and, particularly, in regions at different levels of the regional hierarchy. At the early stages of GPT-induced transformation, the increased specialisation has a negative effect on the ability of regions to attract and retain labour. This effect becomes positive later. Negative effects of specialisation are especially strong in metropolitan areas. More peripheral regions benefit more from specialisation in terms of higher worker inflows, on the one hand. On the other hand, higher specialisation also generates larger worker outflows from these regions. This might explain why peripheral Swedish regions had problems with recovering from the early 1990s crisis with regards to labour market dynamics (see Section 7.1.).

All in all, the results of empirical analyses demonstrate that the presence of leading industries in regions has an impact on their ability to attract and retain labour. In that respect, the industrial restructuring, and the resulting structural change, induced by the diffusion of the IT as a GPT, affected the patterns of worker reallocation across regions. This provides the evidence for the role of the labour market as a response mechanism in the process of technology-induced adjustment. It is demonstrated, however, that the particular mechanisms of the labour market response change over time, as the GPT is diffused across wider spectrum of sectors, and in regions at different levels of the regional hierarchy.

Article II combines the insights from the industry dynamics literature with the labour market studies to investigate how the evolution of the knowledge-intensive IT services sector in Sweden was reflected in the dynamics of its labour force building in the period between 1991 and 2010. Two research questions are posited:

> *How did the skill and experience composition among incoming staff vary as the IT services sector evolved over time?*
>
> *How did previously acquired experience and skills affect entry wages of incoming workers, their propensity to stay in the sector and wage performance, reflecting the workers' measured value to the sector during different phases of its development?*

It is demonstrated that the development of the IT services sector was unequally distributed across regions at different levels of the regional hierarchy. Not only did metropolitan areas concentrate around 75 per cent of the total employment in the sector, the regional patterns of sectoral employment growth strengthened the differences across regions in favour of major metropolitan areas over time.

The results of empirical analyses suggest that while the sector was rather turbulent with regards to its labour market dynamics, the expectations, requirements, and valuations of skills of new entrants into the sector consolidated fairly early in the process of its expansion. In fact, the evolution of the sector was reflected not so much in *how employers in the sector valued* skills of inflowing individuals, but in *what kind of skills* employers in the sector tended to attract over time.

The labour dynamics around the sector suggests the evolution of an increasingly specialised structure over the considered time period. In other words, the recruitment in the sector appeared to rely increasingly on inflows from related industries as it matured. For instance, individuals with prior experience in related industries enjoyed better entry conditions as well as more lasting employment prospects. Interestingly, however, the benefits accruing from having related work experience in the past vanish rather quickly, to the benefit of on-the-job training and formal education.

With regards to the latter, there is a strong evidence that the higher education became an increasingly important entrance ticket to jobs in the sector. While this trend is observed for labour force in Sweden in general, it is much more pronounced in the IT services sector. Also, it appears that the sectoral core competences are not embedded in one dominant educational or occupational group, but are rather distributed and made operational across a range of skill backgrounds in combination. In that respect, it provides an important lesson for the educational policy: educational programmes should be tailored to provide workers not only with core competences related to the specialisation of the programme, but also with a wide range of complementary skills.

One of the findings is that sectoral crises are important periods of evolution of specialised labour market structures around the sector, as well as of sectoral consolidation more generally. While the sectoral labour market dynamics is substantial during crises, it is of a different nature. Individuals getting jobs in the sector in these periods constitute a more homogeneous group than during the boom years. In other words, in crisis times sectoral recruitment patterns are shaped in the way of increased consolidation towards narrower skill profiles.

Finally, labour sourcing process manifests itself differently in regions at different levels of the regional hierarchy. Stockholm (and later Gothenburg and Malmö), being the hotspots of the sectoral employment, provided the highest wage benefits for workers relocating from other regions. What is interesting, while the wage premium for local entrants in metropolitan areas is realised through higher entry wages, while regional movers to metropolitan areas tend to enjoy better post-entry wage performance. Also, regional movers tend to be less entrenched in the sector as they demonstrate the lower probability to remain employed in the sector over time.

On a more general level, Article II suggests that the labour market dynamics in the core sector, associated with the GPT diffusion, develops towards a higher specialisation of its employment mix. While at the early stages of the GPT diffusion process the availability of relevant skills is limited, employers in the sector, nevertheless, develop the vision of relevant skill profiles rather early. This relevance is reflected in the entry conditions and employment prospects of individuals. Over time, as the availability of skills increases, these valuation structures do not change much. However, the ‘content’ of worker inflows with regards to skills embedded in workers increasingly resembles early defined relevant skill profiles. This implies that the availability, overall and particularly regional, of workers possessing certain skills is an important enabler for the evolution of GPT-related sectors.

The findings in Article II resonate nicely with those in **Article III** that investigates the distribution and reallocation of workers in the IT occupations across different industries and regions in Sweden over 2001-2010 with the aim of exploring the patterns of diffusion of IT-related competences in the Swedish economy. Particular emphasis in the article is made on the expansion of IT employment outside of the IT sector.

The research questions in the article were formulated in the following way:

> *To what extent does the distribution of the IT workforce between the IT and non-IT sectors reflect the quality of IT workers' human capital?*
>
> *In what way does the position of a region in the regional hierarchy affect the regional distribution of the IT workforce between the IT and non-IT sectors?*
>
> *How are the dynamics of the IT workers reallocation conditioned by sectoral and regional factors?*

It is demonstrated that the labour market for IT workers expanded rapidly during the 2000s. What is interesting, this expansion was primarily driven by the outpacing growth of IT employment outside the IT sector. Out of 30,000 new IT jobs generated in the economy 75 per cent were created in non-IT sectors. This resulted in the decrease of a share of the IT sector in the total IT employment.

This expansion was coupled by the qualitative upgrade of the IT workforce in both IT and non-IT sectors. It realised through the increased share of workers with higher education and the substitution of technical IT labour by relatively higher skilled IT workers (professionals and managers).

In that respect, the diffusion of the IT manifested itself in the spread of (increasingly advanced) IT competences beyond the core IT sector. Thus, pervasiveness of the IT as a GPT implies not only the increased investment in the IT capital (computers and related equipment) but also the expansion of the labour market for IT workers within and beyond the core, GPT-related, sector.

It appears, however, that the pervasiveness is not universal in the sense that IT workers may easily switch IT jobs across different industries. There are rather rigid structures of worker reallocation as individuals switch IT jobs predominantly within the same industry they were previously employed in. This suggests that the pervasiveness characteristic of the IT as a GPT should be qualified further as specialised pervasiveness. That is, the IT, indeed, possesses the capacity to generate IT-related jobs in all sectors of the economy (thus, pervasiveness). At the same time, the existing clusters of worker reallocation in the industry space point to the increasing specialisation of IT workers that may limit employment opportunities for them in terms of finding an IT job in another industry (thus, specialised).

In that respect, the tendency towards an increasingly specialised labour market structure around the IT services sector, observed Article II, may also be extended to the case of the labour market for IT workers in non-IT sectors.

The results of analysis also point that the rapid expansion of the labour market for IT workers was accompanied by changes in the organisation of the market with respect to the reinforcement of regional hierarchies. For instance, compared to regions at lower levels of the regional hierarchy, metropolitan areas are characterised by larger, more IT-intensive, and more specialised labour markets for IT workers. The issue of regional availability of specialised IT competences is, therefore, highlighted. On the one hand, the share of non-IT sectors in regional IT employment mixes increased at lower levels of the regional hierarchy. A possible explanation to that is a limited supply of IT-related activities by specialised IT firms in regions at lower levels of the regional hierarchy which forces firms in these regions to develop IT competences internally. On the other hand, firms in more peripheral regions tend to employ workers with less specialised skill profile as well as workers from outside their immediate surroundings.

With regards to this dissertation, two important conclusions arise from Article III. First, the GPT diffusion requires not only investment in the GPT-related physical capital, but also hiring workers to perform GPT-related tasks. These workers are instrumental for making the best use of the GPT-related capital being rolled out. In that respect, hiring workers, possessing specialised human capital, is a mechanisms of establishing the innovation complementarities between the activities of firms and new technology being diffused.

Second, increasingly specialised patterns of worker reallocation imply that limits in availability of specialised human capital may constrain the opportunities for GPT-enabled development. Structures of supply of and demand for the GPT-related skills on regional labour markets may impose barriers to the successful diffusion of a new technology, particularly to more peripheral regions.

Finally, **Article IV** focuses on entrepreneurship as a potential mechanism of the IT diffusion from metropolitan areas to more peripheral regions. By investigating the spatial biographies of individuals, performing entrepreneurial entries in the IT sector in Swedish non-metropolitan regions between 1991 and 2010, the paper addresses two research questions:

> *In what way does prior locational behaviour of individuals influence their propensity to become entrepreneurs?*
>
> *In what way is the post-entry performance of new firms affected by pre-entry locational behaviour of their founders?*

The results of analysis suggest that entrepreneurship in the Swedish IT sector is characterised, to a great extent, by the locational inertia. Between 1991 and 2010, more than 75 per cent of entrepreneurial entries in non-metropolitan regions were performed by local individuals. Local individuals were more likely to prefer an entrepreneurial option to paid employment. Also, firms established by local entrants tended to survive longer.

At the same time, the results also suggest that the spatial origin of entrepreneurs should be considered beyond the local/non-local dichotomy. It is not just the location of individuals immediately prior to performing entrepreneurial entry, but also their extended spatial biographies that matter for their entrepreneurial activities. It is demonstrated that in certain cases individuals with broad spatial careers are more likely to start successful businesses than local entrants.

One of the more interesting results concerns the role of metropolitan areas in shaping the entrepreneurial dynamics in regions at lowers levels of the regional hierarchy. It is demonstrated that having prior work experience in metropolitan areas increases the probability of an individual to start a new firm, and a successful one, in a non-metropolitan region. In that respect, it is suggested that metropolitan areas are learning hotspots for individuals willing to obtain sector-specific knowledge in a dynamic urban context. This is particularly emphasized for individuals relocating to metropolitan areas for a while, but returning to their home regions to start a business. In this case, they are both embedded locally in a region where they perform an entrepreneurial entry, but also embedded in broader knowledge networks at the sectoral level.

The effect of the metropolitan employment tenure is, however, mostly observed in the 1990s. This points that the relationship between spatial biographies of individuals and their entrepreneurial activities is related to the evolution of the sector itself and the environment, in which it operates.

For instance, the rapid expansion of IT-related activities in non-metropolitan areas, adaptation of educational systems to the digital paradigm, as well as the overall diffusion of IT as a GPT improved the opportunities for obtaining IT-related knowledge beyond the metropolitan areas' boundaries. This results in the decreasing importance of metropolitan areas as learning regions and source of IT entrepreneurs for more peripheral regions.

Article IV, therefore, suggests that the patterns of regional distribution of GPT-related activities in regions at different levels of the regional hierarchy have important implications for diffusion of the GPT over time. At the early stages of the GPT diffusion, the regions at the top of the regional hierarchy are hotspots for GPT-related activities, as it is predicted in the literature. Therefore, they act as learning regions for individuals willing to obtain work experience related to the GPT. As time goes by, the GPT-related activities diffuse across a wide range of regions, which manifests itself in the decreasing role of large regions as the only locomotives of GPT-induced transformation process.

All in all, Articles II-IV imply that considering the labour market only as a response mechanism to the GPT-induced structural change is an oversimplification. Availability of workers possessing certain skills has important implications for how, when, and where the technology-induced economic transformation takes place. In that respect, the labour market should also be seen as an enabler and/or restrictor for the opportunities of the economy to respond to transformation pressures generated by the introduction and diffusion of the GPT.

Table 4 below provides a brief overview of four articles with respect to their aim, theoretical framework and main findings.

Table 4. Overview of the articles

Article number and title	Aim	Theoretical framework	Main findings
Article I. Technological Change and Geographical Reallocation of Labour: On the Role of Leading Industries	To assess the effects of technology-induced structural change on an ability of regions to attract and retain workers	Evolutionary economic geography Neo-Schumpeterian economics Labour economics	Stronger regional presence of leading industries, associated with the GPT-induced structural change, positively affects the ability of regions to attract and retain workers. Different functional groups of leading industries play different roles at different stages of the GPT diffusion process. Manufacturing branches act as a stabilising factor, helping regions to retain workers; service branches are the factor of attracting workers to regions. The degree of diversification of regional employment mixes has a different impact on the ability of regions to attract and retain workers: • in regions at different levels of the regional hierarchy; • at different stages of the GPT diffusion process.
Article II. Labour force building in a rapidly expanding sector	To investigate structures of labour sourcing in the Swedish knowledge-intensive IT services sector during the period of its rapid expansion between 1991 and 2010	Evolutionary economic geography Industry studies Employer-employee matching theory Skill-relatedness	Expectations, requirements, and valuations for skills of new entrants into the IT services sector consolidated fairly early in the process of its expansion The evolution of the sector is reflected not so much in how employers value the skills of incoming workers, but rather in what kind of skills individuals, hired into the sector, possess. For instance, the increasingly specialised structure with regards to importance of industry experience evolved around the sector over the period of investigation. Also, the increased role of higher education as an entrance ticket to jobs in the sector is underlined. Crises are important periods for the sectoral consolidation and restructuring. The labour sourcing process has a strong geographical component, which is reflected in both entry conditions for workers becoming employed in the sector and the probability of them to remain employed in the sector.

Table 4 (continued). Overview of the articles

Article III. Specialised pervasiveness: Diffusion of IT competences in the Swedish economy	To explore the patterns of diffusion of IT-related competences in the Swedish economy in the period between 2001 and 2010	Evolutionary economic geography GPT theory	Pervasiveness of the IT as a GPT realises, among other things, through the increased employment of IT workers in both IT providing and IT using sectors in regions at all levels of the regional hierarchy. This pervasiveness is, however, specialised. That is, the IT has the ability to generate IT-related jobs in all sectors of the economy but with an increasing degree of specialisation and subsequent segmentation of the labour markets for IT workers. The degree of specialisation of the IT workforce is higher in regions at higher levels of the regional hierarchy.
Article IV. Local or not? Spatial biographies of Swedish IT entrepreneurs	To investigate the extent to which spatial biographies of individuals, that is their histories of prior relocation, have an impact on their propensity to become entrepreneurs in the knowledge-intensive IT services sector and post-entry performance of firms they establish.	Evolutionary economic geography Entrepreneurship studies Population geography	Entrepreneurs in the knowledge-intensive IT services sector exhibit locational inertia. That is, individuals tend to start IT firms in the region where they previously lived and worked. Also, entries by such individuals tend to survive longer. However, in certain cases individuals with broad spatial biographies are more likely to start successful businesses than local entrants. The role of metropolitan areas goes beyond providing the most fertile ground for knowledge-intensive sectors. Having work experience in metropolitan areas increases the probability of an individual to start a new firm (and a more successful one) in a non-metropolitan region. The importance of metropolitan work experience, however, decreases over time.

8.2. Synthesis of results

The aim of this dissertation is to investigate the intertwined dynamics of the industrial restructuring and labour market evolution induced by the introduction and diffusion of a GPT. It is hypothesised that the labour market played a dual role in this process: on the one hand, the response mechanism smoothing the transition to the new technological paradigm; and, on the other hand, a mechanism which itself enables or restricts the dynamics of industrial restructuring at different stages of the GPT diffusion process and across regions at different levels of the regional hierarchy. The particular focus is made on identifying the linkages between the micro-level processes of GPT-induced transformation with the macro-level determinants and outcomes of these processes through the meso-rules that ensure the translation of the former into the latter.

The analyses in four articles, included in this dissertation, provide a rather strong support for the hypothesis about the dual role of the labour market as it was discussed in the previous section. In what follows, the results of individual articles are synthesised and several emergent topics are presented.

The main finding of this dissertation is that the co-evolutionary dynamics of industrial restructuring and labour market evolution in the process of the GPT diffusion followed the meso-trajectory that may be described as the *transition from the GPT-centred story to the GPT-related story*.

At the early stages of the diffusion of the IT as a GPT, the core GPT-related sector – the knowledge-intensive IT services sector – played the most important role in generating the labour market dynamics across and within regional labour markets. For instance, regional presence of the sector was one of the main factors of attracting labour to regions (Article I). This period was characterised by the rapid expansion of the sector itself. The employment growth was fuelled by hiring workers with rather diverse backgrounds from a rather open pool of potential employees (Article II). At the same time, the concentration of the sector to large regions at the top of the regional hierarchy made these regions learning hotspots for individuals willing to obtain GPT-related skills. Employment experience in these regions provided individuals with superior learning opportunities which became a precondition for establishing successful businesses in the GPT-related sector in more peripheral regions (Article IV). Thus, the GPT-centred story.

As time went by, there were notable changes in the development of the GPT-related sector itself as well as in the labour market dynamics around it. For instance, the sector lost its role as the major factor of attraction of workers to regional labour markets. Rather, this role was delegated to the industries that became the most active and visible users of the GPT (Article I). Later stages of the GPT diffusion are characterised by the increased spread of GPT-related competences in a wide range of sectors and regions (Article III). At the same time, more specialised labour market structures evolved around both GPT-providing and GPT-using sectors with respect to sourcing GPT-related human capital (Articles II and III). This suggests that the GPT-related competences become less generic and more specific to the sector where they are applied. Also, large regions at the top of the regional hierarchy lost their monopoly as superior learning regions (Article IV). In that respect, the locus of GPT-induced transformation shifted both in industry and regional spaces to the wider range of industries and regions. Thus, the IT-related story.

These dynamics reflect nicely the predictions of the GPT and TEP literatures with their focus on the long-term aspect of the technology diffusion process. Indeed, the early GPT diffusion is an uncertain process of realising the potential of a new technology and making required complementary investments. At this stage, the GPT diffusion is conditional upon the dynamics of GPT-related sector as well as behaviour of early adopters in other sectors. Therefore, the core GPT-related sectors is at the centre of the transformation story. With time, the GPT pervasiveness potential and emergence of innovation complementarities between old and new technologies across a wide range of sectors – located far from each other in the technological dimension – ensures that the benefits of the GPT are recognised by the increased number of economic agents in the economy. This is reflected in the shifting roles of various actors in the GPT-induced transformation. Thus, the identified meso-trajectory manifests in the increased role of the GPT as the emergent complement to already existing activities (Verspagen 2004) and the platform for transformation for the economy as a whole (Castellacci 2008).

The transition from the GPT-centred to the GPT-related story underlines the importance of considering the temporal dimension of the GPT diffusion process. It is no longer possible to assume that it proceeds linearly in time. To study the impact of technological change on the evolution of the economy, one should acknowledge the existence of particular points in time – some of which may be driven by chance events – that characterise the shifts in the technology diffusion process.

> Nobody can hope to understand the economic phenomena of any, including the present, epoch who has not an adequate command of the *historical facts* and an adequate amount of *historical sense* or of what may be described as *historical experience*. (Schumpeter 1954, pp. 12-13; emphasis in the original)

For instance, with regards to the diffusion of the IT as a GPT, the shifts in empirical patterns observed in individual articles took place simultaneously – around the turn of the millennium. Peculiarly, these changes coincided in time with the 2001 dot-com crash that was the crisis specific to the IT sector.

It is well possible that this crisis boosted the transition from the GPT-centred to the GPT-related story, or that it didn't. Nevertheless, it was the milestone that marked the beginning of the transformation of the IT sector itself (Article II) and of the increased accumulation of the IT competences by non-IT sectors (Article III), which resulted in the changing roles of various sectors in shaping the patterns of inter-regional worker reallocation (Article I) as well as shifting roles of regions at different levels of the regional hierarchy, at least with respect to their roles as learning regions (Article IV). Without accounting for these trends, and identifying the points in time when they occur, one cannot arrive at any satisfactory explanations of the impact of technology-induced transformation on the economy.

This is, however, not to say that any GPT will necessarily follow the same temporal patterns, or have as easily identifiable time points of fundamental shifts in the diffusion process. On the contrary, this points to the necessity to acknowledge that each GPT develops in its historical time and there is a myriad of micro-level processes and macro-level factors that interact in complex ways to shape its diffusion path.

Another important meso-rule that is identified through the analyses underlines the importance of spatial factors for the diffusion of the GPT. It may be formulated in the following way: a position of a region in the regional hierarchy determines both the micro-level processes of GPT-induced transformation at the regional level as well as the regional outcomes of this process and contribution of the region to the aggregate transformation dynamics at the macro-level of the economy.

Again and again, investigations in individual articles pointed that the extent of and opportunities for GPT-induced transformation, and its impact on regional labour market dynamics, are conditioned by the position of a region in the regional hierarchy.

On the one hand, it is demonstrated that large regions at the top of the regional hierarchy are characterised by larger scale of the GPT-related activities expansion, not only in absolute terms (total employment in GPT-related occupations) but also with regards to the degree of emerging complementarities to the GPT – reflected in, in the case of this dissertation, in the IT intensity of regional employment mixes (Articles II and III). Regions at lower levels of the regional hierarchy, even though demonstrating positive dynamics in the GPT-related activities over time, lagged far behind.

On the other hand, the importance of the position of a region in the regional hierarchy goes beyond the mere scale effects. It also defines the opportunities for GPT-induced transformation of regional labour markets. The ability of regional labour markets to adjust to the changing patterns of demand for labour is shown to be limited for regions at lower levels of the regional hierarchy (Article I). The extent of labour markets in such regions restricts the opportunities for hiring specialised labour possessing the GPT-related human capital (Article III). Also, the concentration of GPT-related activities to regions at the top of the regional hierarchy limits the ability of more peripheral regions to provide learning opportunities of the comparable qulity (Article IV). While the differences between regions at different levels of the regional hierarchy are, to some extent, mitigated over time – as the GPT is increasingly diffused to a wider range of industries and regions – they still remain quite persistent.

The significance of regional hierarchies in understanding the dynamics of technology-induced transformation has important implications for further research and regional policies. Traditionally, economic geography focused on understanding the uneven patterns of regional development. More recently this paradigm has all but disappeared due to 'an academic obsession […] with the study of 'successful' regions' (Martin 2015, p. 21). It appears, however, that these successful regions are characterised by completely different dynamics than regions lagging behind (often found at lower levels of the regional hierarchy). Therefore, one cannot simply copy the same instruments which worked in the context of successful regions and expect that they will work in the same way in more problematic contexts. One-size-fits-all approach is likely to fail. In that respect, research in economic geography should revive its interest in the properties of regions lagging behind in economic transformation to provide a more informed input to the design of regional development policies.

All in all, the dissertation contributes to the literature in economics, economic history, and economic geography by demonstrating that the dynamics of technological change as well as its implications for functioning of the economy should be approached through the prism of the technology diffusion process which *unfolds in time and space*. It suggests that investigations of technology-induced transformation dynamics should acknowledge four intertwined dimensions: *what* kind of technology is being diffused, *how* it is diffused, *when* it is diffused as well as *where* it is diffused at different points in time.

With regards to labour market dynamics, the dissertation suggests that the role of the labour market in the technology-induced transformation is far from the smoothly operating mechanism of adjustment to economy-wide economic shocks, as it is often assumed in mainstream approaches to economic theorising. By demonstrating that the technology-induced labour market transformation is not only characterised by emerging non-linearities and divergent trends across different regions, but also has repercussions for the technology diffusion process itself, the dissertation provides a reference point for studies of labour market evolution beyond the standard equilibrium approach.

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Article I

Lund, November 2, 2016

To whom it may concern,

The authors hereby certify that the paper entitled 'Technological Change and Geographical Reallocation of Labour: On the Role of Leading Industries' is based on 75%/25% contributions by the respective authors Martynovich/Lundquist.

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Technological Change and Geographical Reallocation of Labour: On the Role of Leading Industries

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MARTYNOVICH M. and LUNDQUIST K.-J. Technological change and geographical reallocation of labour: on the role of leading industries, *Regional Studies*. This paper analyses inter-regional labour reallocation in Sweden over the period 1985–2008 and assesses the effects of technology-induced structural change on the ability of regions to attract and retain workers. The findings suggest that (1) the regional presence of leading industries associated with technological change has a significant effect; (2) the importance of leading industries is of dynamic character as various functional groups of leading industries play different roles at different stages of the technology-induced transformation process; and (3) while manufacturing branches act as a stabilizing factor, i.e. helping regions to retain workers, service industries drive labour reallocation in terms of attracting workers to regions.

Technological change   Industrial restructuring   Adjustment   Labour reallocation   Leading industries   Sweden

MARTYNOVICH M. and LUNDQUIST K.-J. 技术变革与劳动的地理再配置：先导产业的角色，*区域研究*。本文分析瑞典在1985年至2008年期间的跨区域劳动再配置，并评估由技术引导的结构变迁，对于区域吸引并留住劳工之能力的影响。研究结果显示：（1）与技术变革有关的先导产业存在于区域中，具有显着的效应；（2）先导产业的重要性，具有强而有力的特徵，因先导产业的各种功能团体，在技术引导的转变过程的不同阶段中，扮演不同的角色；以及 (3) 当製造部门作为稳定的因素时，例如协助区域留住劳工，服务业则是在吸引劳工至该区域方面，驱动劳动的再配置。

技术变革   产业再结构   调节   劳动再配置   先导产业   瑞典

MARTYNOVICH M. et LUNDQUIST K.-J. La mutation technologique et la redistribution géographique du travail: à propos des industries phares, *Regional Studies*. Cet article cherche à analyser la redistribution interrégionale du travail pour la période allant de 1985 à 2008 et évalue l'impact de la mutation structurelle stimulée par la technologie sur la capacité des régions à recruter et à maintenir des travailleurs. Les résultats suggèrent que (1) la présence dans la région des industries phares associées à la mutation technologique a un impact non-négligeable; (2) l'importance des industries phares s'avère dynamique parce que divers groupes fonctionnels jouent des rôles différents à diverses étapes du processus de transformation qui est stimulé par la technologie; et (3) alors que les établissements industriels servent de facteur de stabilisation, à savoir en aidant les régions à maintenir l'emploi, les industries des services déterminent la redistribution du travail en termes de l'attrait des travailleurs vers les régions.

Mutation technologique   Restructuration industrielle   Ajustement   Redistribution du travail   Industries phares   Suède

MARTYNOVICH M. und LUNDQUIST K.-J. Technischer Wandel und geografische Neuverteilung von Arbeitsplätzen: die Rolle der führenden Branchen, *Regional Studies*. In diesem Beitrag untersuchen wir die interregionale Neuverteilung von Arbeitsplätzen in Schweden im Zeitraum von 1985 bis 2008 und die Auswirkungen des technisch bedingten Strukturwandels auf die Fähigkeit von Regionen zur Anwerbung und Beibehaltung von Arbeitskräften. Aus den Ergebnissen geht hervor, dass (1) die regionale Präsenz von führenden mit dem technischen Wandel verknüpften Branchen eine signifikante Auswirkung hat; (2) die Bedeutung der führenden Branchen einen dynamischen Charakter aufweist, da verschiedene Funktionsgruppen der führenden Branchen in den verschiedenen Phasen des technisch bedingten Veränderungsprozesses unterschiedliche Rollen spielen; und (3) während produzierende Branchen als stabilisierender Faktor wirken, d. h. Regionen bei der Beibehaltung von Arbeitskräften unterstützen, Dienstleistungsbranchen die Neuverteilung von Arbeitskräften vorantreiben, indem sie Arbeitnehmer in Regionen anziehen.

Technischer Wandel   Branchenumstrukturierung   Anpassung   Neuverteilung von Arbeitsplätzen   Führende Branchen   Schweden

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MARTYNOVICH M. y LUNDQUIST K.-J. Cambio tecnológico y reasignación geográfica del trabajo: el papel de las industrias líderes, *Regional Studies*. En este artículo analizamos la reasignación laboral interregional en Suecia entre 1985 y 2008 y evaluamos los efectos del cambio estructural inducido por la tecnología en la capacidad de las regiones de atraer y mantener a los trabajadores. Los resultados indican que (1) la presencia regional de industrias líderes asociadas al cambio tecnológico tiene un efecto significativo; (2) la importancia de las industrias líderes tiene un carácter dinámico porque diferentes grupos funcionales de las industrias líderes desempeñan papeles diferentes en distintos estadios del proceso de transformación inducido por la tecnología; y (3) mientras las ramas manufactureras actúan como un factor estabilizador, es decir, ayudan a las regiones a conservar trabajadores, las industrias de servicios impulsan la reasignación laboral atrayendo a los trabajadores a las regiones.

Cambio tecnológico Reestructuración industrial Ajuste Reasignación laboral Industrias líderes Suecia

JEL classifications: J61, N14, O33, R11

INTRODUCTION

This paper analyses inter-regional labour mobility patterns in Sweden over 1985–2008 with the aim of assessing effects of technology-induced structural change on an ability of regions to attract and retain workers. Provided the widely acknowledged role of human capital for regional growth and competitiveness (BARRO, 2001; BADINGER and TONDL, 2003; COHEN and SOTO, 2007), understanding the factors helping regions to attract workers is of high theoretical importance.

Aggregate outcomes of technological change are continually (re-)defined by changes in the industrial composition of the economy (SAVIOTTI and PYKA, 2004; METCALFE *et al.*, 2006; HANUSCH and PYKA, 2007). In particular, heterogeneous response of regions to aggregate shocks is mediated, to a large extent, by their economic composition and industrial organization (ESSLETZBICHLER, 2007; ROBSON, 2009). In that respect, what has been missing in the literature is a method to identify leading sectors associated with technological change at various times and measure dynamically their effects on functioning of the economy (SILVERBERG, 2007). The paper addresses this gap by revisiting and empirically refining PEREZ's (1983, 2010) classification of key sectors driving technological change and analysing their role as factors of attracting and retaining workers in regions.

The following research question is asked: In what ways do spatial patterns of distribution of leading industries associated with a current wave of technological change shape inter-regional labour reallocation flows? Equivalently: In what way does a stronger presence of leading industries in a region contribute to its ability to attract and retain workers?

Previous attempts to identify and quantify the role of leading sectors in economic development (ROSTOW, 1960; THOMPSON, 1990) were confined to the national level. Literature on labour mobility as a response to structural change was primarily addressing the inter-sectoral reallocation dimension (GREENAWAY *et al.*, 2000; ELLIOTT and LINDLEY, 2006; BACHMANN and BURDA, 2010). Studies of regional industrial composition effects on the patterns of inter-regional labour reallocation (BÖCKERMAN *et al.*, 2004; ESSLETZBICHLER, 2007) have not taken technology-induced structural change into the consideration.

The paper is built upon insights from macro-evolutionary economic geography and labour economics' perspective on labour mobility as a response mechanism to economic shocks. Taking a macro-perspective allows the analysis of labour mobility patterns across all elements of a regional system while conceptualizing structural change in its time-dependent, regional and industrial dimensions.

The paper focuses on the latest wave of technological change induced by diffusion of information and communication technology (ICT)-related products and services. Using a unique combination of Swedish datasets 3 403 978 worker moves across 92 local labour markets over 1985–2008 are detected and analysed.

The paper is organized as follows. The second section summarizes the theoretical framework integrating the literature on technological change, its regional aspect as well as labour market response. The third section discusses employed data and methodology. It is followed by a summary of leading industries' development over time which provides estimates on the effects of their presence on regional labour markets. The fifth section concludes.

TECHNOLOGICAL CHANGE, LEADING INDUSTRIES AND REALLOCATION OF LABOUR

Dynamics of industrial restructuring and spatial transformation

Contemporary theorizing of economic growth is increasingly based on SCHUMPETER's (1939) idea that long-term fluctuations in the rhythm of economic growth are rooted in the discontinuities brought by the introduction of new interrelated and pervasive radical technologies (often referred as general purpose technologies), and subsequent structural adjustment of the economy to newly opening technological opportunities (VERSPAGEN, 2004; METCALFE *et al.*, 2006;

LOUÇA, 2007; SILVERBERG, 2007). This deep structural transformation has been referred to in the literature as a shift in the technological paradigm (DOSI, 1982), a technological revolution (PEREZ, 1983), or a technology shift (SCHÖN, 1998).

Although outcomes of this transformation are visible at the macro-level, they cannot be analysed at that level as sources of qualitative changes shaping the transition to the new technological paradigm are defined by industry dynamics at the meso-level (CARLSSON and ELIASSON, 2003; SAVIOTTI and PYKA, 2004; HANUSCH and PYKA, 2007). While industrial sectors, whose technological base is closely related to new general purpose technologies, are exposed to broader opportunities and experience more dynamic development, industries less connected to emerging technological paradigm may be forced to move along less dynamic paths (NELSON and WINTER, 1982; CASTELLACCI, 2008). Changes in the industrial composition of the economy induced by growth and decline in various sectors are then continually redefining the economy-wide relations between productivity, employment and output growth as well as the contributions that each industry makes to these aggregates (METCALFE *et al*., 2006).

At the same time, processes of an economy's adjustment to the new technological paradigm are not equally distributed across space. A contemporary view of regional economic growth builds upon the principle of increasing returns derived from internal- and external-scale effects, the size of a local market, transaction costs and the comparative advantages from production factors (KRUGMAN, 1991; FUJITA *et al*., 1999). The principle of increasing returns might be further connected to an endogenous capacity of regions to generate innovation as well as to receive and exploit ideas, innovations, technology, and market changes from the outside world (JAFFE *et al*., 1993; BOSCHMA and LAMBOOY, 1999). This capacity is dynamic in nature and defines the ability of a region to translate growth forces of the technology shift into competitive performance. As receiver capacities, roles and relations between regions are changing over time, it has been claimed that technology shifts are essentially geographical in character (LUNDQUIST *et al*., 2008a, 2008b; LUNDQUIST and OLANDER, 2009).

Spatial and sectorial outcomes of adjustment to newly emerging technological opportunities are then dependent on a range of interlinked mechanisms and channels connected to internal organizational structures of firms and industries, pure imitation by new and existing competitors, emerging complementarities between new and old parts of the economy, possibilities for decomposition and fragmentation of value chains, as well as opportunities grown from processes of standardization, price competition and falling transaction costs.

In particular, in the beginning of the adjustment process, industries making an early use of new technological opportunities are mainly located in markets at the top of a regional hierarchy as these provide sufficient economies of scale when transaction costs are high. Beginning gently and experimentally in these sites, new activities take time to become visible. Mature businesses initially dominating the scene gradually decrease in size and importance offering space and resources to newly emerging activities. Regions at lower levels of a regional hierarchy, lacking sufficient locational advantages and receiver capacity, cannot attract new industries resulting in a slower aggregate growth in output, productivity and employment.

With time, new general purpose technologies start shaping new production configurations outside industries of their origination through industrial interactions, demand pressures and technical competition (CANTNER and VANNUCCINI, 2012). This allows a wider spectrum of industries to benefit from opportunities offered by new technologies. At the same time, as transaction costs gradually fall and large regional markets become strained on a resource side, industries drawing upon new technologies or incorporating them into their core activities start to disseminate regionally leading to an accelerated growth in value added, productivity and employment in a wider set of regions.

All in all, the literature suggests that processes of adjustment following the introduction of new general-purpose technologies are determined by complex patterns of changing roles of various industries and regions. In that respect, any attempt to analyse economic outcomes of shifts in technological paradigms requires an understanding of the underlying dynamics of industrial restructuring and spatial transformation.

Structural change and reallocation of labour

As people follow jobs (STORPER, 2013), patterns of labour mobility are driven by those of job availability. In that respect, in the economy experiencing an ongoing structural change, flexible labour markets smooth an adjustment to new industrial systems by ensuring that changing labour demand patterns between expanding and declining sectors meet a response in the form of worker reallocation (GREENAWAY *et al*., 2002; AGHION *et al*., 2006; BACHMANN and BURDA, 2010; PASTORE, 2013).

In particular, industrial restructuring in the economy (i.e., relative or absolute decline in some sectors as well as growth or emergence of others) implies changes in profitable opportunities across sectors resulting, among other things, in different rates of job creation and destruction between expanding and declining sectors (GREENAWAY *et al*., 2000). Old jobs are destroyed when new technologies arrive, but are replaced by updated employment opportunities in existing sectors or completely new jobs in emerging ones (MORTENSEN and PISSARIDES, 1998). The consequence of these processes is a reallocation of workers across occupations and sectors. In that respect, mobility of labour is a mechanism facilitating an adjustment to economic shocks.

There is an agreement in the literature that regions differ in their capacity to reabsorb redundant labour from declining industries into new sectors, which leads to different extents of spatial labour market imbalances (CAROLEO and PASTORE, 2010). Here, aggregate shocks have asymmetric effects across regions through their non-neutral effects on industries (NEUMANN and TOPEL, 1991). ROBSON (2009) distinguishes three sources of these effects: (1) in the short run, regions with concentration of employment in 'cyclically sensitive' industries are more vulnerable to aggregate labour demand shocks; (2) long-term shifts in labour demand across industries generate stronger reallocation pressure on workers in regions with a high concentration of declining industries; and (3) labour market performance is affected by a degree of specialization/diversification with a more diverse industry employment mix providing regions with a higher capacity to reabsorb displaced workers through facilitating matching process in times of idiosyncratic shocks (MORETTI, 2011). As industrial development has uneven spatial patterns, inevitable emergence of imbalances across regional labour markets calls for redistribution of labour across not only sectors but also regions, which affects inter-regional labour mobility patterns.

Hypothesizing a role of leading industries in labour reallocation

Establishment of ICT as a cluster of new general purpose technologies leads to a vast reorganization in industrial structure of the Swedish economy through the emergence of new industries, the revitalization of growth in some existing industries, as well as a decline and phasing out of others. Such restructuring has a long-term impact on labour markets through shaping new demand for labour as there is an explosive growth in employment in new and renewed industries, while labour is displaced from declining ones. Changes in demand patterns are met with the reallocation of labour as a response mechanism to disparities across sectors. As there are uneven spatial patterns in location of growing and declining industries at various stages of the adjustment process, there are additional pressures for workers to be mobile not only across sectors but also regions.

In Sweden, labour mobility across regions was shown to be a major response to changes in economic conditions when compared with participating in labour market programmes, turning unemployed or leaving labour market (FREDRIKSSON, 1999). Besides, institutional factors such as centralized bargaining and the 'solidarity wage policy' have for a long time kept very compressed wage dispersion across regions (EDIN and HOLMLUND, 1995; ELIASSON *et al.*, 2003). As a result, earlier studies of internal migration in Sweden (WESTERLUND, 1997, 1998; FREDRIKSSON, 1999) demonstrated that labour mobility was driven mainly by *job availability* so that workers migrated primarily to regions where employment growth took place with no or minor effects on regional wage differentials. GÄRTNER (2014) showed that, even controlling for wage differentials, increased job availability has a strong effect on inter-regional worker reallocation.

Locational patterns of leading industries associated with technological change are, therefore, hypothesized to play an important role in reshaping Swedish local labour markets in general, and in determining the direction of inter-regional worker flows, in particular. The reasons are twofold. First, these industries are expected to be ones with higher-than-average job creation rates and more pronounced growth in employment. In that respect, they act as employment anchors helping a region to attract and retain labour. Second, as these industries are not isolated and become embedded in existing regional industrial landscapes through, among other things, input–output linkages (CANTNER and VANNUCCINI, 2012; LIND, 2014), a stronger presence of leading industries should sustain/reinforce output and employment growth in other industries present in a region.

All in all, as previous studies show that internal mobility of workers in Sweden is primarily driven by job availability, and the latter is expected to be enhanced by locational patterns of leading industries, it is hypothesized that a *stronger regional presence of leading industries results in an increased inflow of workers into and decreased outflow of workers from a region resulting in a positive rate of net employment change*.

DATA AND METHODOLOGY

Data employed in the analysis are a compilation of two datasets: the Longitudinal Integration Database for Health Insurance and Labour Market Studies (LISA) provided by Statistics Sweden; and the Database of Evolutionary Economic Geography in Lund (DEVIL).

LISA is a linked employer–employee database covering all individuals registered in Sweden. For each individual it contains an in-depth set of background information including region, industry and firm of employment, which allows one to trace the employment history of an individual and construct a very precise measure of labour flows. Annual data are available for 1985–2011.

DEVIL is a longitudinal establishment-level database providing information on an establishment's municipality of registration, number of employees, value added, etc. It is used to model industrial profiles of Swedish regions with respect to regional employment mixes. Data cover the period between 1968 and 2008.

Data from LISA and DEVIL are merged at the municipality level and further aggregated to 92 local labour market areas (as of 1999). This specification of spatial units is chosen as it is defined in the way that maximizes homogeneity of within-region mobility patterns while sustaining cross-regional heterogeneity. The resulting dataset includes observations over 1985–2008 across 92 spatial units.

Identifying leading industries

PEREZ (1983, 2010) suggested that in the adjustment process following a technology shift key industries might be divided into groups with respect to their functional relation to technological transformation process, namely:

- *Motive branches* producing key factors and other inputs directly associated with them and creating, therefore, conditions for development of a new technological paradigm; growth of these industries is dependent on the rhythm of the penetration of new technologies to other industries.
- *Carrier branches* being the most visible and active users of new inputs and best adapted to a new organization of production; they induce a great variety of investment opportunities, thus having a great influence on a general rhythm of economic growth.
- *Induced branches* that may have existed before but which are modernized and take on a different role. Their development is both a consequence of and complementary to the growth of motive and carrier branches, and is indispensable for facilitating the maximum diffusion of new industries.

Identification of the leading sectors driving technological transformation of regional economies was performed in two steps. First, using the methodology suggested by LUNDQUIST *et al.* (2005, 2008a, 2008b), all industries present in the Swedish economy were divided into 30 actor branches with respect to productivity trajectories, price and volume development as well as their functional specialization. In the second step, most salient industries driving the transformation of the economy were identified with respect to total value-added growth patterns in each of 30 actor branches. Five manufacturing actor branches and eight service actor branches were then selected and further divided into three functional groups – motive, carrier and induced – following Perez's classification. For the more detailed information regarding the classification process, see Appendix A in the Supplemental data online.

Dependent variables: worker flow rates

Worker moves are observed when individuals switch region of employment between two consecutive years. In practice, the measure of worker flows was constructed according to the following procedure.

First, for each year *t* a sample of individuals aged 15–74 years was selected, which corresponds to the current Statistics Sweden definition of the labour force.[1] Second, an assumption of 'contracted' mobility – that is, labour mobility as an outcome of a successful job search process – was made. Given that all individuals of working age are potential job searchers in all regions at time $t-1$, it implies that switching a region was considered as a worker move if: (1) an individual was employed at time *t*; and (2) a region of employment at time *t* was different from a region of residence (for previously unemployed) or employment (for previously employed) at time $t-1$. Finally, to minimize the probability of including workers participating in short-term employment, who are less likely to contribute to the 'true' labour reallocation, the sample was further restricted to individuals who were employed directly at the moment of data collection (not just at some point over a year). As a result, 3 403 978 worker moves were identified.

Consequently, for each local labour market total worker inflows (WIFs) and outflows (WOFs) were calculated. Finally, to deal with potential scale issues (as bigger regions would always tend to have higher in- and outflows), worker flows were transformed into worker flow rates:

$\mathrm{WIFR}_{jt} = \mathrm{WIF}_{jt}/N_t$ – gross worker inflow rate for region *j* at time *t*[2]

$\mathrm{WOFR}_{jt} = \mathrm{WOF}_{jt}/N_t$ – gross worker outflow rate for region *j* at time *t*

$\mathrm{NETR}_{jt} = \mathrm{WIFR}_{jt} - \mathrm{WOFR}_{jt}$ – net worker flow rate for region *j* at time *t*

Including gross worker flow rates into the analysis is motivated by two reasons: (1) net worker flow rates alone often mask substantial labour market dynamics behind net employment change (DAVIS and HALTIWANGER, 1995; ESSLETZBICHLER, 2007); and (2) estimations for gross flow rates might demonstrate push and pull factors resulting in the net reallocation of workers.

Explanatory variables

Principal explanatory variables are regional employment shares in three groups of leading industries (separately for manufacturing and services):

$$\mathrm{LI}_{f\,jt} = \frac{x_{f\,jt}}{\sum_{i=1}^{n} xi_{jt}}$$

where $x_{f\,jt}$ is the employees in group *f* in region *j* at time *t*; x_{ijt} is the employees in industry *i* in region *j* at time *t*; and *n* is the number of industries. Changes in this variable are supposed to capture long-term shifts in demand for labour and, in that respect, reflect the effect of adjustment process following the technology shift.

As long-term shifts in labour demand are not the only source of variation in regional labour market performance (ROBSON, 2009), two more variables are introduced. First, annual growth in regional per capita value added in the productive sector (*GROWTH*) is included to capture effects of short-term fluctuations in business activity. Second, following WREN and TAYLOR (1999) and ROBSON (2009), the coefficient of absolute regional specialization (*CARS*) is added to control for possible effects of specialization/diversification in a regional employment mix:

$$CARS_{jt} = \frac{[\sum_{i=1}^{n}(x_{ijt} - \bar{x}_{jt})^2/(n-1)]^{1/2}}{\bar{x}_{jt}}$$

where x_{ijt} is the employees in actor branch i in region j at time t; and n is the number of actor branches:

$$\bar{x}_{jt} = \sum\nolimits_{i=1}^{n} xi_{jt}/n$$

CARS reflects an employment dispersion across actor branches present in a region. A higher value of CARS points to a more concentrated regional employment mix.[3]

As there are reasons to expect heterogeneous effects of specialization on labour market performance in regions of different size (LUNDQUIST and OLANDER, 2009), an additional estimation is performed, where CARS is interacted with dummy variables for various levels of the Swedish regional hierarchy. These levels are defined by conducting breaks analysis of a population distribution across regional labour markets. Seven hierarchy levels are then distinguished: three metropolitan areas (Stockholm, Gothenburg and Malmo) as well as large, medium-sized, small and micro-regions.[4]

Control variables include the size of regional labour markets, proxied by logged regional population (*POPULATION*), and average regional productivity (*PRODUCTIVITY*). Including the latter is motivated by findings according to which productivity level might be associated with a positive impact on employment in growing establishments so that high-productivity regions are able to create more jobs (BARTELSMAN and DOMS, 2000). Descriptive statistics for the variables considered in the analysis are provided in Appendix B in the Supplemental data online.

Estimation strategy

In the most general form, the estimated dynamic panel model is:

$$\begin{aligned}\mathrm{WFR}_{jt} = \alpha_0 \sum_{k=1}^{P} \alpha_k \mathrm{WFR}_{jt-k} + \sum_{k-1}^{P} \beta_k \mathrm{LI}_{jt-k} \\ + \sum_{k=1}^{P} \gamma_k \mathrm{CARS}_{jt-k} \\ + \sum_{k=1}^{P} \mu_k X_{jt-k} + \delta_j + \theta_t + u_{it}\end{aligned}$$

where WFR_{jt} is the selected measure of worker flow rate; LI_{jt} is a vector of regional employment shares in leading industries; CARS_{jt} is the coefficient of absolute regional specialization; and X_{jt} is the control variables. The term δ_j accounts for regional fixed effects controlling for time-invariant unobservable regional characteristics; θ_t represents region-invariant unobservable time effects; and u_{jt} captures the remaining disturbances.

A dynamic panel approach is used since it allows one to deal with (1) autocorrelation problems induced by including the lagged depending variable (making it possible to account for chain migration); and (2) simultaneity bias propelled by potential reverse causality relationships between dependent and independent variables (GÄRTNER, 2014). The equation is estimated by employing an instrumental system-generalized method of moments (GMM) estimator (ARELLANO and BOVER, 1995).

Such an approach requires distinguishing between exogenous and endogenous variables as they are instrumented with different lags (ROODMAN, 2009). In the specifications presented in the next section, regional shares of leading industries as well as per capita value-added growth are treated as endogenous variables correlating with current errors. As the specification of instrumented endogenous variables and their lags adversely affects the test of over-identifying restrictions (ROODMAN, 2009), the number of instrumented lags is restricted. This allows one to deal with potentially poor performance of asymptotic results when the number of observed time periods is large (CAMERON and TRIVEDI, 2010).

RESULTS

Employment growth in leading industries

Table 1 summarizes employment growth across groups of leading industries and levels of the Swedish regional hierarchy. Growth patterns are indicated for the whole time period under consideration as well as for two sub-periods (1985–98 and 1999–2008) to demonstrate the changing roles of different groups in a long-term restructuring of the Swedish economy.

In both motive manufacturing and services (Table 1 (a)), employment growth was relatively faster in the first sub-period. Here, while growth in service branches was almost evenly spread across regions,[5] employment generation in manufacturing was more pronounced in metropolitan areas. In the second sub-period, employment growth in manufacturing turned into a decline, which was also more visible in bigger regions (except Gothenburg). As for the service branches, employment growth continued in all but micro-regions, resulting in almost as many jobs created in the second sub-period (40 723 jobs) as in the first one (41 531 jobs).

Overall, between 1985 and 2008 motive branches were the only group where employment growth in

Table 1. Employment growth in motive, carrier and induced branches

(a) Motive branches

	Motive manufacturing			Motive services		
Annual employment growth rates	1985–98 (%)	1999–2008 (%)	1985–2008 (%)	1985–98 (%)	1999–2008 (%)	1985–2008 (%)
Stockholm	3.89	−3.26	0.78	9.99	5.58	8.07
Gothenburg	3.71	3.59	3.66	9.93	5.60	8.05
Malmo	6.75	−0.39	3.65	8.04	10.04	8.91
Large	1.23	−4.12	−1.10	11.91	3.96	8.46
Medium	1.38	0.26	0.89	9.20	3.34	6.65
Small	0.80	−0.86	0.07	8.64	5.25	7.17
Micro	1.84	0.86	1.41	21.75	−10.81	7.60
Whole Sweden	2.43	−1.72	0.62	9.92	5.37	7.94
Jobs created	31 784	−18 558	13 226	41 531	40 723	82 254

(b) Carrier branches

	Carrier manufacturing			Carrier services		
Annual employment growth rates	1985–98 (%)	1999–2008 (%)	1985–2008 (%)	1985–98 (%)	1999–2008 (%)	1985–2008 (%)
Stockholm	−2.50	2.22	−0.44	5.22	3.24	4.36
Gothenburg	0.39	1.35	0.81	6.46	3.95	5.37
Malmo	0.72	−0.90	0.02	6.44	5.04	5.83
Large	−0.53	0.37	−0.14	5.50	5.78	5.62
Medium	−0.63	0.27	−0.23	4.25	5.19	4.66
Small	−0.78	0.79	−0.10	6.34	5.77	6.09
Micro	−1.44	−2.09	−1.72	7.78	8.21	7.97
Whole Sweden	−0.69	0.59	−0.14	5.41	4.35	4.95
Jobs created	−24 906	16 049	−8857	89 240	96 175	185 415

(c) Induced branches

	Induced manufacturing			Induced services		
Annual employment growth rates	1985–98 (%)	1999–2008 (%)	1985–2008 (%)	1985–98 (%)	1999–2008 (%)	1985–2008 (%)
Stockholm	−2.53	−0.47	−1.63	0.68	−1.96	−0.47
Gothenburg	−0.95	−1.70	−1.28	1.44	0.20	0.90
Malmo	0.29	−3.32	−1.28	1.24	0.25	0.81
Large	−0.84	−1.79	−1.25	1.08	1.03	1.06
Medium	−1.33	−0.94	−1.16	0.74	0.81	0.77
Small	−1.12	−1.20	−1.15	1.79	1.07	1.48
Micro	−2.51	−1.28	−1.97	1.11	2.31	1.63
Whole Sweden	−1.19	−1.41	−1.29	0.95	−0.33	0.40
Jobs created	−28 847	−22 553	−51 400	18 786	−5183	13 603

absolute numbers was observed in both manufacturing and services resulting in a total of 95 480 jobs created.

Carrier branches exhibit a different pattern (Table 1 (b)). In manufacturing, the first sub-period was characterized by job destruction with employment decreasing by almost 25 000 jobs. The shift to increased employment in the second sub-period could not compensate for the decline in the first, resulting in almost 9000 jobs being lost over 1985–2008. In both sub-periods, metropolitan areas seem to outperform more peripheral regions.

Carrier services are characterized by fast employment growth in both sub-periods. In contrast to motive services which tended to grow faster in metropolitan areas, some convergence is observed in the second sub-period in carrier services as the latter grew somewhat faster in peripheral regions. Besides, contrary to motive services, carrier services demonstrated higher absolute employment growth in the second sub-period, potentially indicating that they intensified their development by adapting to new technological opportunities. In total, over 1985–2008 employment in carrier services increased by 185 415 workers.

Finally, induced manufacturing demonstrated negative developments in employment in both sub-periods resulting in 51 400 jobs being lost (Table 1(c)). An overall increase in value added between 1985 and 2008, which classified them as one of the leading industries, came, therefore, mainly from increased productivity.

Employment in induced services increased overall in the first sub-period. However, negative developments in Stockholm in the second sub-period outweighed growth in other regions to end up with 5183 jobs lost in 1999–2008. In total, over 1985–2008, increased employment in services did not compensate for the employment fall in manufacturing branches, resulting in 37 797 job being lost in induced branches in total.

All in all, a total of 234 241 jobs were generated in leading industries over 1985–2008, of which 281 272 jobs were created in service branches and 47 031 jobs were lost in manufacturing. This is of particular interest as the total employment growth in the economy over the considered time period equalled 220 675 jobs. That implies that the remaining elements of the Swedish industrial structure were (in general) characterized by job destruction.

Effects of leading industries on inter-regional worker flow rates

The results of the estimation for worker in-, out- and net flow rates are presented for the whole time period (1985–2008) as well as for two sub-periods (1985–98 and 1999–2008) to capture the potentially varying effects of different groups of leading industries over time. In what follows, the regression output for each dependent variable is summarized, followed by a discussion of the results.

Worker inflow rate (WIFR)

The first striking feature in the regression output is that none of functional groups of manufacturing has a significant effect on the ability of regions to attract labour (Table 2). This holds for the whole time period as well as for both sub-periods. When it comes to service branches, estimated coefficients suggest that different industry groups play different roles in attracting workers to a region at various times.

In the first sub-period (models I and II), it is motive services that play the most important role in attracting workers, which underlines their early role in the transformation of the economy. There is additional (although, weak) evidence for regions having higher inflows due to wider representation of induced services. This effect, however, disappears as soon as specialization at various levels of the regional hierarchy is included (model II). When it comes to effects of specialization/diversification in the regional employment mix, while CARS is included as it is, it shows no significant impact on WIF. However, controlling for levels of the regional hierarchy suggests that specialization might be beneficial (or, at least, less harmful) for more peripheral regions, but potentially harmful for bigger ones (negative, but insignificant coefficient for general CARS).

An interesting observation comes from considering the interplay between CARS and regional population. Model I – with no spatial differentiation in CARS – returns a strongly significant (though, surprisingly negative) coefficient for population variable. Accounting for differences across regional levels in model II makes the population variable turn insignificant. This result suggests that industrial structure of a region with respect to its specialization/diversification is a more important explanatory factor for region's ability to attracting labour than its size.

In the second sub-period (models III and IV), the roles are changing: motive and induced services no longer demonstrate a significant impact, while carrier services become highly significant and positive. These switching roles between various functional groups underlines once again the fact that outcomes of technology-induced structural change are defined by industrial dynamics. Specialization is now demonstrated to have a positive effect on the ability of regions to attract workers irrespective of position in the regional hierarchy. This is, to a great extent, predicted by theory: as new technologies are spread through the whole industrial system and developed into standardized applications, it is possible to expect more benefits coming from Marshall–Arrow–Romer (MAR)-type agglomeration externalities (Lundquist and Olander, 2009).

The resulting pattern for the whole time period (models V and VI) is that while motive services do not have any significant effect on inflow rates, positive and significant coefficients for carrier and induced service branches imply that their stronger presence in a region increases its attractiveness for potential employees manifesting in higher WIF. No evidence for motive branches to make a region more competitive in terms of attracting labour might point to the fact that their role is confined to an initial spark in the first sub-period, while, in general, the role of economy transformers is delegated to carrier branches, which becomes particularly visible in the second sub-period. This is confirmed by the fact that over 1985–2008 there were more than twice as many jobs generated in carrier than in motive services.

The insignificant coefficient for CARS with no differentiation across regional levels (model V) suggests that it is not possible to make any reasonable conclusions regarding its effect on the WIF rate. However, introducing spatial differentiation (model VI) returns an interesting result. Large regions, in particular the metropolitan areas of Stockholm, Gothenburg and Malmo, tend to benefit more from diversification in their employment mix (negative and significant coefficient for Stockholm, with no significant differences for Gothenburg and Malmo tiers). In that respect, the urbanization externalities thesis is supported. At the same time, in smaller regions this effect is mitigated and eventually turns positive for regions at the very bottom of regional hierarchy, suggesting that small regions may benefit from becoming more specialized and forming clusters of particular industries.

Table 2. Estimated effects on worker inflow and outflow rates

	Worker inflow rate						Worker outflow rate					
	1985–98		1999–2008		1985–2008		1985–98		1999–2008		1985–2008	
Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Dependent_{t-1}	0.49***	0.45***	0.31***	0.57***	0.620***	0.581***	0.29***	0.30***	0.60***	0.50***	0.552***	0.496***
Dependent_{t-2}							0.20**	0.20***			0.181***	0.147***
$\text{Motive man}^{+}_{t-1}$	31.21	−73.33	−207.05	−224.76	19.737	16.883	134.72	217.88	5.72	123.62	110.973	114.71
$\text{Motive serv}^{+}_{t-1}$	4986.28**	4924.97**	−228.9	−132.46	242.035	270.369	−1812.73	−2905.64	756.91	637.56	−98.4	−42.854
$\text{Carrier man}^{+}_{t-1}$	93.45	−73.33	105.87	−109.65	−70.424	−88.956	73.72	104.89	−136.29	−248.66**	−178.525***	−205.800***
$\text{Carrier serv}^{+}_{t-1}$	−748.99	−1212.49	1052.21***	625.95*	190.214*	200.041*	35.23	−188.44	−74.56	−151.29	−245.214**	−201.902*
$\text{Induced man}^{+}_{t-1}$	69.34	30.07	74.03	−137.02	21.466	16.598	−414.71**	−406.97**	−151.93	−226.39**	−131.827*	−71.954
$\text{Induced serv}^{+}_{t-1}$	1371.07*	999.3	−706.04	−90.12	570.113***	576.694***	647.35	−69.3	451.29*	684.56	180.394	332.955***
CARS_{t-1}	32.8	−204.95	72.44***	119.89***	17.017	−250.218**	29.12	32.1	56.58**	66.80**	48.829***	−32.275
$\text{CARS\_Gothenburg}_{t-1}$		80.81*		12.93		188.112		0.45		46.54		45.061
CARS_Malmö_{t-1}		73.82		15.53		195.53		19.21		35.1		35.769
CARS_Large_{t-1}		119.41*		−9.58		254.051**		0.71		28.11		67.768**
CARS_Medium_{t-1}		113.93		−45.3		217.574**		29.71		−24.9		68.366**
CARS_Small_{t-1}		163.91*		−55.46		253.239**		41.43		−32.13		76.163**
CARS_Micro_{t-1}		227.30**		11.33		281.490**		102.89		10		93.914*
Population_{t-1}	−69.18***	−19.61	3.16	−66.06**	−29.547***	−7.896	−49.10*	−9.39	−66.96***	−87.41***	−10.643*	−7.366
$\text{Productivity}_{t-1}$	−0.14	0.03	−0.03	0.12	0.045	0.265	−0.07	−0.18	0.01	0.18*	−0.113	−0.036
Growth^{+}_{t-1}	33.14	8.4	−98.29	−101.21	18.502	36.792	−34.63	−23.45	83.41	23.1	−1.49	1.516
SARGAN	0.79	0.605	0.842	0.794	0.246	0.18	0.162	0.138	0.401	0.796	0.104	0.049
AR(2)	0.478	0.582	0.876	0.9	0.755	0.854	0.15	0.13	0.526	0.404	0.543	0.763
WALD	0	0	0	0	0	0	0	0	0	0	0	0
N of observations	1104	1104	920	920	2024	2024	1012	1012	920	920	1932	1932
N of instruments	91	97	85	91	296	302	88	94	85	91	290	296

Notes: Results correspond to one-step estimates. The superscript '+' indicates that a variable is generalized method of moments (GMM)-style instrumented. SARGAN is a test for the over-identifying restrictions. AR(2) is a statistic for the presence of autocorrelation in the level equation. WALD is a test for the joint significance of explanatory variables. All test statistics are reported as *p*-values. Region and year dummies as well as a constant are included in all models, but not reported. Estimations are performed with xtabond2 package (Roodman, 2009).

***Parameter estimate is statistically significant at the 1% significance level; **parameter estimate is statistically significant at the 5% significance level; *parameter estimate is statistically significant at the 10% significance level.

Worker outflow rate (WOFR)

Estimating the same models for WOFRs produces quite different results, suggesting that the presence of various groups of leading industries has different effects as push and pull factors (Table 2).

In the first sub-period (models VII and VIII), induced manufacturing industries seem to contribute to retaining workers in the region. In this turbulent period of competition between old and new parts of the economy these industries might, therefore, play a role of stabilization factor. As manufacturing facilities are difficult to relocate, their ongoing functioning in a region might contribute to a lower job destruction rate, increasing the ability of a region to keep workers. Neither other functional groups of leading industries nor diversification/specialization patterns have any significant effect on WOFRs in this sub-period.

The situation changes completely in the second sub-period (models IX and X). While the models are quite unstable, there is some evidence that induced manufacturing still contributes to retaining workers. But this effect is now supported by the presence of carrier manufacturing as well. In that respect, there is a further evidence that manufacturing branches might play a stabilizing role by helping regions to retain workers.

A quite surprising observation here is that a higher share of induced services in regional employment tends to increase the WOF (positive and significant coefficient in model IX). One possible explanation is that this effect might reflect a strong connection of induced services to other parts of regional economies. LUNDQUIST and OLANDER (2009) claimed that actor branches constituting the induced services functional group had strong elements of industry-related activities. This implies that the captured effect might be indicative of developments in those sectors of the economy that are not considered in the model. Another possible explanation is a high turnover of workers in these industries, which might result in a positive impact on the outflow rate.

Regions with higher specialization in their employment mix tend to experience a higher WOF (positive and significant coefficients for CARS), irrespective of their position in the regional hierarchy. Besides, bigger regions seem to be more successful in retaining workers.

Models for the whole time period (XI and XII), in general, confirm results obtained for sub-periods: there is a negative effect from the stronger presence of induced and carrier manufacturing on the WOFRs and some evidence for a positive effect of induced services. What is different, however, is that now the effect of carrier services becomes visible: a stronger regional presence of these branches tends to decrease the outflow of workers. What is also observed is that specialization tends to increase the WOF (model XI), but this effect is more pronounced in smaller regions (model XII). When it comes to the interplay between CARS and regional size, the same pattern is observed for the whole time period as in the case of WIF models, that is, specialization/diversification in the regional employment mix seems to provide a better explanation for the WOF than a size of the region.

Net rate of employment change (NETR)

The dynamic effects of various functional groups of leading industries on gross worker flow rates are visible in models for the net worker flow rates, illustrating the outcome of worker reallocation across regions (Table 3).

In the first sub-period (models I and II), motive and induced services have a positive effect on the net flow, which is a manifestation of their role in attracting workers to a region (see inflow rate models). At the same time, induced manufacturing has a positive effect through its ability to help regions to retain labour (see outflow models). Puzzling is the significant and negative coefficient for carrier services. One possible explanation is that the sector's strong growth could be a result of outsourcing/spin-off trends from manufacturing (BAINES *et al.*, 2009). Services included in this functional group (marketing, design, advertising, security, and research and development (R&D) services) were mainly produced in-house in manufacturing firms before, but are now outsourced to independent service units that probably employ the same labour force as before and are still located close to the old 'parent' firm. This might produce a negative effect on the WIF rates as this process is likely to take place within the region. Specialization is shown to have a negative effect irrespective of the regional hierarchy level.

In the second sub-period (models III and IV), it is carrier services that exhibit a significant and positive effect, which confirms their role in attracting labour in WIF models. This might indicate a switch from employment growth in the carrier through spin-offs/outsourcing to self-generated growth within these sectors. There is some evidence that induced services have a negative impact. Potential explanations for that were discussed when presenting results for WOF models. The second period shows a shift from a positive role of diversification to a positive role of specialization for the ability to attract a labour force.

All in all, for the whole time period (models V and VI) there is a strong positive effect coming from a presence of carrier service industries. This is not surprising as carrier services is the only industry group which over the whole time period provided a consistent positive influence on regional labour markets in terms of attracting (inflow models) and retaining (outflow models) labour. Coefficients for other functional groups of industries are not significant.

When it comes to the effect of specialization/diversification in regional employment structure, the increased degree of specialization makes a region unable to attract

Table 3. Estimated effects on net worker flow rate

Variable	Net worker flow rate					
	1985–98		1999–2008		1985–2008	
	I	II	III	IV	V	VI
Dependent$_{t-1}$	−0.05	−0.06	0.31***	0.24**	0.050	0.049
Motive man$^{+}_{t-1}$	−296.58	−335.90	−207.05	−46.22	30.126	29.747
Motive serv$^{+}_{t-1}$	3632.52*	4199.13*	−228.90	−789.84	−37.925	−151.128
Carrier man$^{+}_{t-1}$	−8.64	−20.64	105.87	18.14	94.345	91.440
Carrier serv$^{+}_{t-1}$	−1423.74*	−1703.77**	1052.21**	941.78**	354.100**	315.042**
Induced man$^{+}_{t-1}$	448.20***	428.81***	74.03	38.52	121.854	115.355
Induced serv$^{+}_{t-1}$	1336.18*	1084.17	−706.04	−987.39**	−286.345	−285.913
CARS$_{t-1}$	−73.84**	−91.71**	72.45**	135.28***	−31.340*	−77.777**
CARS_Gothenburg$_{t-1}$		32.89		−34.94		−0.520
CARS_Malmö$_{t-1}$		8.93		−29.44		6.052
CARS_Large$_{t-1}$		41.75		−81.35		−5.131
CARS_Medium$_{t-1}$		48.29		−75.75		12.714
CARS_Small$_{t-1}$		86.35		−97.38		30.309
CARS_Micro$_{t-1}$		107.06		−51.67		49.021
Population$_{t-1}$	12.67	41.38	3.16	−0.87	8.177	22.640***
Productivity$_{t-1}$	0.05	0.05	−0.03	−0.09	0.014	−0.003
Growth$^{+}_{t-1}$	74.84	74.53	−98.29	−73.17	59.541	65.213
SARGAN	0.245	0.230	0.842	0.739	0.165	0.171
AR(2)	0.140	0.127	0.876	0.928	0.451	0.450
WALD	0.000	0.000	0.000	0.000	0.000	0.000
N of observations	1104	1104	920	920	2024	2024
N of instruments	139	145	85	91	296	302

Note: See Table 2.

labour, which is reflected in negative signs of estimated coefficients for CARS. Moreover, as indicated by model II, there are no significant differences in this effect across regions of different size. Contrary to gross flows models, accounting for differences in specialization/diversification effects across regions, the effect of population remains significant and positive, implying that larger regions are beneficiaries of the inter-regional labour reallocation.

DISCUSSION

In general, the results suggest that an industrial structure of a region, and, particularly, a presence of leading industries, associated with structural change induced by the introduction of ICT, played an important role in shaping patterns of inter-regional labour mobility in Sweden since 1985. More particular results are discussed below.

First, by distinguishing between manufacturing and services within each of the leading industry functional groups, it is demonstrated that service branches seem to be a major driver behind shaping patterns of labour reallocation, while manufacturing plays a different role, mostly by helping to retain workers in a region. This suggests that only service branches had job creation rates high enough to be a factor in attracting workers into a region. This is supported by findings in Table 1 regarding a regional distribution of employment growth in leading industries. This is fully in line with the idea of the increasing service orientation of advanced economies, which is, more or less, taken for granted in the literature (PENEDER *et al.*, 2003; SCHETTKAT and YOCARINI, 2006).

Second, it is shown that there are important differences across functional groups of leading industries, that is, motive, carrier and induced branches, when it comes to their effect on attracting labour into and/or retaining labour in a region in different phases of technology-induced transformation process.

In particular, the role of motive industries, which are expected to generate the initial impulses for transition to new industrial structures, is only visible in the beginning of the adjustment process, but not in the later stages or for the whole time period. This relates to the findings of VERSPAGEN (2004) who claimed that while ICT-related industries (which constitute the motive branches) have substantial effects on the structure of the economy, ICT is an important complement to rather than a substitute for older technologies, which continue to play an important role in the economy. Therefore, rather than being primary drivers of change, these sectors provide a growth platform for other industries as a new technological paradigm is emerging (CASTELLACCI, 2008).

In that respect, the role of major mobility-shaping actors is 'delegated' to carrier branches, which by incorporating ICT into their existing routines become the most visible and active users of new inputs. These industries are demonstrated to be the largest group when it comes to total employment as well as a group with the most jobs created over the considered time period. Therefore, it comes as no surprise that carrier branches (particularly, services) consistently generated significant effects on labour mobility across most of the model specifications. Induced branches are demonstrated to be important actors in terms of generating gross flows of workers, while their effect is not visible in the resulting net reallocation of workers across regions.

Third, specialization/diversification in the regional employment mix tends to exhibit various effects in time and across space. When comparing evidence from models for two sub-periods it is observed that specialization seems to have a negative impact in the beginning of the adjustment process, while is more positive in the later stages. It points to the fact that in the early stages of adjustment regions benefit more from diversified environment as it allows for a recombination of knowledge across old and new parts of the economy. As the new technologies are standardized and spread widely through a wider set of industries, it becomes possible for regions to benefit from more specialized structures. Models for the whole period, however, still point to the negative effect of an increased specialization in the long run.

When it comes to regional variation, increased specialization is shown to have negative effects in metropolitan areas and large regions supporting, in that respect, the urbanization externalities thesis and the importance of diversification related to Jacobs' externalities. Regions at lower levels of the regional hierarchy, however, seem to benefit more (in terms of inflow of workers), but, at the same time, lose more (increasing outflow of workers) from specialization and MAR externalities. As a result, these effects for smaller regions cancel each other out, leading to the same negative influence of specialization as in metropolitan areas, which are demonstrated in net flow models. This leaves particularly regions lower down in the hierarchy in a tricky dilemma: a way to increase inflow of labour seems to be increased specialization, but this will at the same time generate even higher outflows of workers generating a negative cumulative process of shrinking local labour markets, increasing specialization and fewer possibilities to diversify into related industries. Processes of this kind could provide an additional explanation about why small Swedish regions had such severe problems in catching up with other regions after the latest technology shift (LUNDQUIST and OLANDER, 2009).

Finally, some evidence has been obtained that an employment structure in a region plays a greater role than its size in terms of attracting/retaining workers in a region. In particular, accounting for regional differences in specialization/diversification in the whole-period gross-flow models made the regional size variable become insignificant. This might be because the interpretation of gross in- and outflow rates is qualitatively different from that for a net flow rate. Particularly, while the net rate is indicative of true labour reallocation, gross flow rates are more a measure of labour market flexibility, that is, how employers adjust their demand for labour, and employees – their labour supply (GREENAWAY *et al.*, 2000, 2002; ELLIOTT and LINDLEY, 2006). Since there is no reason to believe that it is the size of a labour market per se that has an effect on its flexibility but rather its employment mix, such an interplay between employment structure and regional population variables seems to be reasonable. Net flow models, in their turn, reflect the resulting reallocation of labour across regions. Here, even when accounting for regional differences in employment structure, a regional size variable is still significant, which may be attached to the tendency of larger regions to have higher net job-generation rates, and thus attracting more workers from outside of a region.

CONCLUSIONS

This paper aimed at analysing the role of leading industries associated with technology shifts as factors of attracting and retaining workers in regions experiencing an ongoing structural change. This was performed by revisiting and empirically refining PEREZ's (1983, 2010) classification of key sectors driving technological change into motive, carrier and induced branches. It was hypothesized that a stronger regional presence of leading industries would positively affect the ability of a region to attract and retain labour.

All in all, the results provide evidence supporting the hypothesis, that is, leading industries are shown to affect WIF positively and to have a negative impact on WOFs. However, the underlining dynamics suggest that this effect is far from linear. It has been demonstrated that various functional groups of leading industries: (1) played different roles at different stages of technology-induced transformation; and (2) differently affected the ability of regions to attract labour when compared with an ability to retain labour. Also, the role of manufacturing and service branches has been shown to be different. While the former primarily act as a stabilizing factor, helping regions to retain workers, the latter are shown to be real drivers behind worker reallocation in terms of attracting workers to a region.

In order to strengthen the claim of the importance of leading industries for local labour market dynamics, however, some other issues might be addressed in further analysis. First, the influence of leading industries might be not confined to themselves: while 234 241 new jobs were created in these branches, the total amount of inter-regional worker moves exceeded 3.4 million. It would be interesting to analyse further whether this is a multiplicative effect of leading industries establishing their position on regional labour markets or individual developments in these industries.

Apart from labour mobility across regions it is also important to analyse the role of leading industries in generating labour market dynamics within regions. Besides, there are reasons to believe that labour mobility is not only a response mechanism, which follows the development of new industries (and, thus, spreading of general purpose technologies associated with the current growth cycle), but also a mechanism that shapes and enhances these developments. In that respect, analysing cross-sectoral mobility patterns (with respect to how, at what pace and in which form do leading industries enter existing industrial structures) would make it possible to look at mechanisms facilitating the establishment and regional diffusion of a new general purpose technology as a core driver of economic growth. Finally, the role of leading industries in labour reallocation (in both regional and sectoral dimensions) might be considered from the point of view of labour market outcomes, such as income and unemployment convergence/divergence patterns as well as regional resilience.

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NOTES

1. Sensitivity checks were performed by considering individuals aged 16–64 (to exclude those in retirement age) and 20–64 (to exclude those in the 'career shopping' stage of their lives and/or are likely to relocate with their parents). As estimations based on these samples produced the same output, the broadest sample was included in the final version of the paper.
2. Where $N_t = E_{jt} + E_{jt-1}/2$, where E_{jt} is employment in region j at time t.
3. CARS was preferred as a measure of concentration to the more conventional Hirschman–Herfindahl index (HHI) since the latter tends to overemphasize the presence of highly concentrated industries. As the Swedish regional system includes some highly specialized regions (e.g., small regions in northern parts of the country, where up to 70% of employment is concentrated in one industry), using the HHI might have induced estimation bias for those regions.
4. Using a demographic criterion for differentiating between levels of the regional hierarchy is motivated by findings in the literature demonstrating that regional size is an important predictor of regional development (Eriksson and Hansen, 2013). In the case of this paper, it also appeared that regional population is highly correlated with patterns of industry penetration across regions. That is, the lower a region is in the regional hierarchy, the fewer industries tend to be represented.
5. The outstanding growth rate for micro-regions (21.75% on average over 1985–98) can be explained by the low base effect because in 1985 there were only 23 employees in motive services at this level of the regional hierarchy.

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APPENDIX A. ACTOR BRANCHES. SUPPLY- AND DEMAND-DRIVEN INDUSTRIES

Division of manufacturing industries into actor branches is performed in three steps (LUNDQUIST et al., 2005, 2008b).

First, industry groups exhibiting similar patterns in their value added growth in different temporal phases of the growth cycle are identified. Second, industry groups are divided into sub-groups based on similarities in labour productivity growth patterns. A matrix with cells corresponding to various combinations of value added and productivity growth patterns is constructed.

After that, two theoretically stylised industry groups are introduced: supply- and demand-driven industries. Supply-driven industries are the first ones to be affected by transformation as they adopt new technologies before other industries in order to create new products (thus, forming the new demand in the economy). Demand-driven industries are affected by transformation later and act as providers of raw materials and intermediate goods for supply-driven industries (therefore, expanding the new demand in the economy).

In the third stage, relative price and relative volume development for industries is used to distinguish between those within the cells/subgroups that could be assumed to be more supply-driven in their development and those that could be assumed to be more demand-driven. Finally, theoretically stylised industry groups are linked to those matrix cells that contain actual industries. Groups of industries in each cell then form the so called actor branches reflecting their assumed roles in the technology shift process. In the end, nine actor branches are identified. Their division between supply- and demand-drive group is presented below.

Supply-driven manufacturing industries	*Demand-driven manufacturing industries*
1. new/renewed	5. induced I
2. transformed	6. induced II
3. early followers	7. contracting
4. late followers	8. obsolete I
	9. obsolete II

For the service sector a slightly different logic is applied (LUNDQUIST et al., 2008a). In the first stage, service industries are divided into three groups based mainly on their user orientation. In the second stage, these user-oriented groups are classified into two sub-groups according to value added development (but also controlling for productivity dynamics): 'strong to medium growth'; and 'medium to weak growth'. Because of the absence of the relative price series for service industries for the time period under consideration, service industries within the sub-groups cannot be classified into supply- and demand-driven following the price/volume rationale. It is, therefore, the growth and productivity dynamics together with the user-orientation of an industry that determine whether it should be classified as supply- or demand-driven. The final classification of service industries is presented below.

Producer services	
Supply-driven	*Demand-driven*
10. ICT services	14. financial and legal services
11. MAD services	15. leasing of manufacturing equipment
12. R&D laboratories	16. technical and engineering consultancy
13. security services	17. industry-related wholesale
Consumer and general services	
Mainly demand-driven	
18. retail of food	25. transport and communication
19. supermarkets and shopping malls	26. hotels and restaurants
20. retail of consumer durables	27. cleaning, waste management, recycling
21. retail-directed wholesale	28. retail/services of cars and fuel
22. recreation, culture and sports	29. electricity, gas, water
23. other consumer services	30. construction
24. specialised retail sale	

Aggregated growth can thereby be dismantled and followed for industry groups affected by the technology shift in various ways. This classification is used as a guide for selection of those industries that could be used as indicators of the economic transformation, when it comes to estimate its impact on labour markets.

After identifying 30 actor branches, most salient industries driving the transformation of the economy were identified with respect to total value added growth patterns. Five manufacturing actor branches and eight service actor branches were then selected and further divided into three functional groups – motive, carrier and induced – following (PEREZ, 1983) classification. Division of selected actor branches across functional groups is presented in the Table below.

Leading industries functional groups	**LUNDQUIST and OLANDER (2009, 2010) actor branches**	
	Manufacturing	*Services*
Motive	New/renewed industries	ICT services
Carrier	Transformed industries Early followers	MAD[1] services R&D laboratories Security services Technical consulting
Induced	Induced I industries Induced II industries	Financial/legal services Leasing of manufacturing equipment Industry-related wholesale

Note: It is necessary to mention that to some extent PEREZ' (1983, 2010) functional groups are used rather as a useful metaphor than direct guidance for classification. While she considers motive branches to include only producers of cheap inputs with pervasive applicability (semiconductors in our case), in present classification these also include paradigmatic industries associated with the current structural change cycle (ICT/electronics manufacturing and ICT-services). Otherwise, the classification employed in this paper corresponds to a great extent follows that of Perez.

[1] Marketing, advertisement, and design

APPENDIX B. VARIABLES DESCRIPTION AND STATISTICS

Variable	Description	Mean	St. dev.	Min	Max
WIFR	Gross worker inflow rate	460,4512	153,7388	172,5905	1381,108
WOFR	Gross worker outflow rate	499,855	168,1501	148,9822	1840,748
NETR	Net worker flow rate (net rate of employment change)	-39,40384	109,3795	-1533,351	480,7586
Motive man	Share of motive manufacturing industries in a regional employment mix	0,0358588	0,0489737	0	0,355844
Motive serv	Share of motive service industries in a regional employment mix	0,0101056	0,0152764	0	0,1545564
Carrier man	Share of carrier manufacturing industries in a regional employment mix	0,1663791	0,1221209	0	0,6827586
Carrier serv	Share of carrier service industries in a regional employment mix	0,045262	0,0356546	0,0026212	0,3396501
Induced man	Share of induced manufacturing industries in a regional employment mix	0,0918433	0,0746915	0	0,4387363
Induced serv	Share of induced service industries in a regional employment mix	0,0395723	0,0240426	0	0,3031414
CARS	Coefficient of absolute regional specialisation	1,487538	0,4821554	0,8409394	3,890135
Population	Logarithm of regional population	10,45615	1,327333	7,913155	14,70561
Productivity	Average productivity of a worker in a productive sector	512,0748	100,044	157,2072	1010,337
Growth	Annual growth in per capita value added in a productive sector	0,0182784	0,0993165	-0,5661153	1,041716

Article II

Lund/Göteborg, November 1, 2016

To whom it may concern,

The authors hereby certify that the paper entitled 'Labour force building in a rapidly expanding sector' is based on 60%/40% contributions by the respective authors Martynovich/Henning.

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Labour force building in a rapidly expanding sector

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Abstract: Between 1991 and 2010, employment in the knowledge-intensive IT services sector in Sweden increased from about 30,000 to 104,000 workers. Building on recent theoretical insights suggesting that the skill composition of worker inflows is an indicator of knowledge relevant to employers, we investigate the labour inflows into the sector. Who were people getting jobs in this expanding sector? And, how were their skills valued by employers as the sector evolved? Our findings suggest that the sectoral evolution was reflected not in *how the skills* of incoming workers *were valued*, but rather *who was hired* into the sector. The paper suggests that the analysis of worker inflows is a tool for investigating the evolution of sectors and their knowledge bases. It provides some lessons for industrial and educational policies regarding technologically turbulent industries, and takes the first step towards developing an approach integrating industry dynamics with labour force sourcing and evolution.

Keywords: industry dynamics; evolution; labour sourcing; labour mobility; human capital

JEL codes: J23, J24, J44, L86

1. Introduction

In 1995 five guys in southern Sweden diverged from their pastime interest in role-play gaming and started a web design consultancy business. Catching the wave of skyrocketing demand for its services, *Framtidsfabriken* (The Future Factory) expanded, nationally and internationally, to around 3,000 employees five years after its foundation. However, with the dot-com crash in 2001 fortunes changed quickly, and the share price dropped by 98% bringing the company on the verge of bankruptcy. In modified form and drastically reduced in size, it survived and eventually merged with others (Åsenlund 2001).

Framtidsfabriken's story is spectacular, but neatly illustrates the dramatic expansion of the IT services sector in the 1990s. It heralded a new digital era of development and manifested an increasingly important role of IT firms as providers of vital inputs necessary to enhance performance of firms in other sectors of the economy (Miozzo and Grimshaw 2005; Doloreux and Muller 2007). In Sweden, considering the knowledge-intensive IT services only, employment increased from about 30,000 workers in 1990 to over 104,000 in 2010. In the aftermath of the dot-com crash, sectoral employment shrank by 11 per cent, or 10,000 workers, only to return to the steady growth path afterwards. These developments were not unique to Sweden, but reflected global employment trends in the IT sector (OECD 2010).

The history, growth, international success and transformation of the Swedish IT sector has been extensively analysed from various perspectives elsewhere (e.g., Johansson 2001; Dahlin 2007; Giertz et al. 2015). To our knowledge, however, no study has systematically investigated the labour sourcing aspect of the 'boom and bust' pattern described above. Who were the people entering the IT services sector? Was it all about inexperienced enthusiasts rushing in, or did the sector draw also from the competences already existing in the economy? Who enjoyed lasting employment prospects? And did the sectoral labour market calm down eventually to become that of just any other sector?

Answers to these questions could carry important implications, going beyond the labour market dynamics of one particular sector. In the labour market literature, there is a plethora of studies on workers displaced from declining industries (Pinch and Mason 1991; Bruce C. Fallick 1996; Shuttleworth et al. 2005; Oesch and Baumann 2015). Although the complementary question of how new and rapidly expanding industries build their labour force is not entirely novel (Freeman et al. 1982), only a few empirical studies on labour sourcing in such industries have been conducted (Bruce Chelimsky Fallick 1996; Neumark and Reed 2004; Warhurst et al. 2006; Mukkala and Tohmo 2013).

Recent theoretical arguments suggest that this should be changed. As labour flows are fundamentally an indication of skills and experiences carried to new applications (Neffke and Henning 2013), how industries build their labour force is a prime determinant of their knowledge formation as well as a manifestation of the relationship between new knowledge requirements and formerly accumulated competences. Evolving skill structures of industries may be seen as both causing and being affected by changing industrial regimes based on the generation, adaptation and diffusion of useful knowledge (Consoli and Rentocchini 2015). Therefore, an inflow of labour into an industry at any point in time is indicative of required competences, and how these are valued and put into productive use. How this plays out in surging industries is of vital importance to the renewal of the economy.

Using data on the inflows of labour into the knowledge-intensive IT services sector in Sweden between 1991 and 2010, this paper focuses on entry conditions and post-entry performance of workers in the sector addressing, in particular, the questions of:

- how the skill and experience composition among incoming staff varied as the sector evolved over time;
- how previously acquired experience and skills affected entry wages of incoming workers, their propensity to stay in the sector and wage performance, reflecting the workers' value to the sector during different phases of its development.

Even though the IT services sector was turbulent over the considered time period, the paper indicates that expectations, requirements and valuations of skills of new entrants into the sector consolidated fairly early. In that respect, evolution of the sector was reflected not so much in *how employers valued* the skills of inflowing individuals over time, but change in *who was hired*.

Perhaps most notably, higher education was becoming an increasingly important 'entrance ticket' to the sector. Also, the results emphasize the striking importance of workers educated with a main profile in the social sciences. Besides, we find strong evidence that, over time, an increasingly specialised labour market was growing around the sector, in related sectors, and that the collapse of the dot-com bubble played a particularly pronounced role for sectoral consolidation and restructuring.

The remainder of the paper is organised as follows. Section 2 summarises the research design behind the paper. In Section 3, a brief overview of the development of the Swedish knowledge-intensive IT services sector over 1991-2010 is provided, with a particular focus on the labour market aspect of its expansion. Section 4 presents the results of regression analyses. Section 5 discusses the observed labour market dynamics through the prism of the sector's evolution. Finally, Section 6 concludes.

2. Industry dynamics and labour inflows: research design

2.1. Data and sampling

The data employed in this paper comes from the Longitudinal Integration Database for Health Insurance and Labour Market Studies provided by Statistics Sweden. For each individual registered in Sweden it contains a set of personal attributes as well as a linkage to establishment of her main employment for which a type of employment, location, and industry affiliation are known.

Our sampling frame is the complete set of individuals and firms in the knowledge-intensive IT services sector. According to the Swedish Standard Industrial Classification, it comprises five 5-digit industries under the activity code 72 'computer and related activities' which we include in our study: (1) hardware consultancy, (2) software consultancy, (3) software supply, (4) data processing, and (5) database activities.[1]

1 We exclude two 5-digit industries also classified as computer and related activities, namely (1) maintenance and repair of office, accounting and computing machinery, because this industry has a different functional focus from our selected industries, and (2) other computer related activities, because this industry collects a vast number of heterogeneous activities. Besides, contrary to other 5-digit industries, the latter industry changed its classification code when the industrial classification system in Sweden changed in 2002, which would make it difficult to follow it up over the whole period that we study.

For each year between 1991 and 2010 a sample of individuals employed in the sector was derived. It was restricted to individuals in the full working age, 18-64 years old. Besides, to minimize the probability of including workers participating in short-term or project employment, we restricted the sample further to individuals who were employed directly at the moment of data collection (not just at some point over a year). All in all, 1.41 million worker-firm-year matches were identified, of which 365,552 were associated with an industry switch and were included in the final dataset.

2.2. Dependent variables and estimation strategy

Three dependent variables are included in the empirical analyses. First, we define entry conditions of an individual getting a job in the sector as her entry wage relative to the median industry wage at the year of entry:

$$wage\_ind_{ij}^{t} = \frac{\mathrm{wage}_{\mathrm{ij}}^{\mathrm{t}}}{\mathrm{med\_wage}_{\mathrm{j}}^{\mathrm{t}}}$$

where *t* is the year of entry, $\mathrm{wage}_{\mathrm{i}}^{\mathrm{t}}$ – yearly wage of an individual *i* in a 5-digit industry *j* at year *t*; $\mathrm{median\_wage}_{\mathrm{j}}^{\mathrm{t}}$ – median yearly wage in a 5-digit industry *j* at year *t*. The relationship between entry conditions and individuals' backgrounds is then modelled using pooled OLS regression.

The estimation output is reported for the year of entry ($wage\_ind_{ij}^{t}$) and the succeeding year ($wage\_ind_{ij}^{t+1}$). We do so for two reasons. First, we control for a possible situation when a large part of the registered income during the year of entry accrues from the previous job. Second, this allows us to check whether estimations for the year of entry reflect the effects of individuals' backgrounds accurately, or also include some temporary negotiation component in the recruitment process.

Second, as we are interested in the stability of job matches, we estimate the probability of individuals to remain employed in the sector three years after the entry. Formally, we define a binary variable:

$$Stay_{i}^{t+3} = \begin{cases} 1, \text{if an individual is employed in the IT services sector at t} + 3 \\ 0, \text{otherwise} \end{cases}$$

where *t* is the year of entry. The propensity of individuals to remain employed in the sector is then estimated as discrete-time event history models using logistic regression. Such specification is expected to expose differential patterns of individuals' post-entry performance dependent on the overall industry performance at the moment of entry as well as observed stay/exit. While estimating this model, we additionally restrict our sample to individuals aged 18-61 at the year of entry to avoid including individuals who are likely to retire at the age of 65. One reservation needs to be made here. As it is possible that individuals deliberately self-select out of the sector – e.g., leave for in-house IT positions in other industries – estimated effects should be treated as correlations rather than causalities.

To add another perspective on the post-entry performance of individuals, we also estimate a model assessing the probability of a worker to perform better in terms of wage growth than an industry average over three years after the entry. The dependent variable is defined in the following way:

$$Wage\_growth_{ij}^{t+3} = \begin{cases} 1, \text{if } \Delta\text{wage}_{\text{ij}} \geq \Delta\text{med\_wage}_{\text{j}} \\ 0, \text{if } \Delta\text{wage}_{\text{ij}} < \Delta\text{med\_wage}_{\text{j}} \end{cases}$$

where *t* is the year of entry; $\Delta\text{wage}_{\text{ij}} = \ln(\text{wage}_{\text{i}}^{\text{t+3}}) - \ln(\text{wage}_{\text{i}}^{\text{t}})$; $\text{wage}_{\text{i}}^{\text{t}}$ – yearly wage of an individual *i* employed at an industry *j* at year *t*; $\Delta\text{med\_wage}_{\text{j}} = \ln\left(\text{med\_wage}_{\text{j}}^{\text{t+3}}\right) - \ln\left(\text{med\_wage}_{\text{j}}^{\text{t}}\right)$; $\text{med\_wage}_{\text{j}}^{\text{t}}$ – median yearly wage in a 5-digit industry *j* at year *t*.

As the wage performance is only observed for the subset of individuals, who are employed in the sector at *t+3*, estimation results may be inconsistent if staying in the sector and having a faster wage growth are not independent phenomena. Indeed, individuals with more suitable backgrounds are less likely to be systematically selected out of the sector. To correct for this selection bias, a Heckman-probit model is specified.

Formally, this model includes an outcome (wage growth) equation and a selection (stay) equation, as follows:

$$Wage\_growth_{i}^{t+3} = \begin{cases} \beta_o \boldsymbol{I_i} + \beta_1 \boldsymbol{C_i} + \varepsilon_i, \ \text{if } \text{y}_{\text{i}}^{*} > 0 \\ \text{not identified, if } \text{y}_{\text{i}}^{*} \leq 0 \end{cases}$$

$$Stay_{i}^{t+3} = \begin{cases} 1, \ \ if\ y_i^* > 0 \\ 0, \ \ if\ y_i^* \leq 0 \end{cases}$$

where $y_i^* = \beta_o \boldsymbol{I_i} + \beta_1 \boldsymbol{C_i} + \beta_2 \boldsymbol{S_i} + \theta_i$ represents a latent variable measuring the differential in new entrants' utility between staying or leaving the sector; $\boldsymbol{I_i}$ – vector of individuals' background characteristics; $\boldsymbol{C_i}$ – vector of control variables; $\boldsymbol{S_i}$ – vector of selection variables.[2] By allowing the error terms ε_i and θ_i to be correlated, it is possible to correct for non-randomness of the sample of individuals remaining employed in the sector. While such specification doesn't allow us to control fully for self-selection of individuals out of the sector, it helps to come closer in terms of establishing causal relationships between individuals' backgrounds and their performance. As in the case of estimating models for a propensity to stay in the sector, the sample is restricted to individuals aged 18-61.

2.3. Independent variables: Operationalising individuals' backgrounds

We develop three principal background indicators operationalising knowledge, skills and experiences that individuals bring with them when becoming employed in one of IT service industries: entry mode, educational background, and regional experience.

For the entry mode, we distinguish between job-to-job, unemployment-to-job, and non-participation-to-job transitions.[3] Such distinction allows tracking the value and quality of previous experiences flowing into the sector.

Individuals, employed at a year before getting a job in one of IT service industries, are registered as performing direct job-to-job switches. Such transitions are likely consequences of active decisions to participate in a new industry (March and Simon 1958). They signal, in that respect, a 'perceived desirability of movement' and reflect an attractiveness of individuals on the labour market. Given that, the industry background of individuals may also be expected to matter. Neffke and Henning (2013) argue that switching jobs is easier between industries in which activities draw upon similar skills (or, skill-related industries) as in that case individuals can re-use parts of their previously acquired human capital. In that respect, individuals performing job-to-job switches from skill-related industries will be of a higher value for destination industries than individuals switching directly from just any job.

2 Our selection variable is the sectoral employment growth over three years after the entry. We expect it be positively associated with a probability of an individual to remain employed in the sector.

3 An entry into one of IT service industries is observed at a particular point in time, implying that individuals can appear several times in the data set during the period.

To detect such skill transferability, we distinguish between job-to-job entries from other IT service industries[4] and from outside the IT services sector.

An individual is considered entering from non-participation if she was not connected to any firm by employment for three years prior to the entry, or was below full working age the year before the entry. In practice, such entries fall into two categories: young people entering labour market directly from education, and those older who for some reason have been inactive on the labour market and then get a job in the sector. To capture this distinction, we divide the group of entrants from non-participation into those older than 30 years old, and those younger than 30 years old. Although we cannot ascertain this with completely accuracy given the structure of our data, we find it likely that many of the individuals in the latter group are fresh graduates.

Individuals of working age, not categorised into the groups above, are considered entering from unemployment. Previous research has repeatedly found that spells of unemployment are detrimental to individuals' position on the labour market, particularly in the longer run. This may be related to the deterioration or loss of human capital, and the fact that employers may take previous performance as a sign of the future (Eliason and Storrie 2006). At the same time, individuals may engage in training programs during unemployment to upgrade or even re-direct their human capital, which may have a positive impact on their future performance (Kluve 2010). We believe that the industry background of individuals entering from unemployment may play a role just as in the case of direct job-to-job switches. We, therefore, distinguish between those who enter with experience in the IT services sector prior to unemployment, and those without.

Formally the entry mode variable is defined in the following way:

$$Entry\_mode_i^t = \begin{cases} Fresh\ graduate, \text{if NTJ switch, individual younger than 30 y. o.} \\ Non-participant, \text{if NTJ switch, individual older than 30 y. o.} \\ Unrelated\ UTJ, \text{if UTJ switch from an unrelated industry} \\ Related\ UTJ, \text{if UTJ switch from a related industry} \\ Unrelated\ JTJ, \text{if JTJ switch from an unrelated industry} \\ Related\ JTJ, \text{if JTJ switch from a related industry} \end{cases}$$

where *NTJ* – a non-participation-to-job switch; *UTJ* – an unemployment-to-job switch; *JTJ* – a job-to-job switch.

[4] 5-digit industries at *t-1* and *t* should be different.

The second experience variable we construct is educational background. As a baseline, we expect a traditional positive correlation between education length and on-the-job performance (Card 1994). In young industries, in particular, demand may be strong for skills that did not exist to a large extent in the labour force before (Freeman et al. 1982). In other words, we can expect that there will be a shortage of people with formal skills directed towards those industries as it takes time for educational systems to respond to newly emerging skill demands (Vona and Consoli 2015). Therefore, firms will be prone to recruit people with a broader set of general, or 'conventional' skills (reflected by education level) in dramatic expansion phases, and will be willing to pay rather well to do so (Freeman et al. 1982). Formally, our education level variable (*Edu_level*) includes five categories: (1) pre-gymnasial education; (2) gymnasial education; (3) post-gymnasial education shorter than 2 years; (4) post-gymnasial education longer than 2 years; (5) doctoral education.[5]

Over time, however, adaptation of the educational system may to an increasing extent be expected to provide industries with more tailor-suited competences. Thus, apart from the education level, we also record the education track (*Edu_track*), where we specifically distinguish between educational background in (1) social sciences, (2) natural sciences, mathematics, data and computing, and (3) engineering and technology. Although this division does not capture all the subtleties of educational specialisation (for example, social science tracks may include some technical courses, while engineering degrees may include courses in management or marketing), it does point to a core focus of an educational program pursued by an individual.

Finally, based on the previous location affiliation of an individual's workplace (for previously employed) or municipality of residence (for previously unemployed/non-participating) we record whether getting a job in one of the IT service industries is associated with a regional move (*Regional move*).[6] The literature points to two possible effects. On the one hand, recruiting an individual from outside the immediate surrounding may be

5 Post-gymnasial education is predominantly university education, but could also include other forms. Gymnasium is the highest level of secondary education in Sweden.

6 Here, regions are local labour markets defined by patterns of commuting between municipalities in the way that maximises homogeneity of mobility patterns within a region while sustaining cross-regional heterogeneity. This definition of a region allows distinguishing between 'real' movers and commuters in the most efficient way.

beneficial for firms in terms of obtaining knowledge and skills which are not locally available (Boschma et al. 2009). Besides, when firms are in the need of highly-skilled individuals they tend to expand their spatial search (Russo et al. 1996). From that perspective, a regional move may be associated with better employment prospects for an individual. On the other hand, moving implies that an individual has to give up some of the localised personal networks that she has accumulated, which leads to monetary and social costs (Eriksson et al. 2014). Besides, specific practices or routines develop in regions over time (e.g., Rigby and Essletzbichler (1997) demonstrated regional variations in production technologies). Therefore, a regional move may cause an individual to become 'out of place' until sufficient knowledge about regional routines is accumulated and networks are built again (Eriksson et al. 2014), which may lead to a negative impact on individual's value to employers as well as her employment prospects.

Besides the experience variables discussed above, we include a variable for the size of a firm in which an individual becomes employed as the literature reports that not only entry wages and post-entry performances (Fackler et al. 2015), but also responses to cyclical dynamics (Fort et al. 2013) are different for firms of different sizes. Also we control for the demographic variables (age and sex). Appendix A1 provides a detailed description of the variables presented above.

3. The knowledge-intensive IT services sector in Sweden

3.1. Expansion of the sector between 1991 and 2010

Over two decades between 1991 and 2010 employment in the knowledge-intensive IT services increased from 30,287 to 104,059 employees (Figure 1), corresponding to more than a threefold increase of a sector's share in the national employment (from 0.68 per cent to 2.37 per cent).

Over this period, however, employment growth patterns varied considerably. Stagnant period in the early 1990s, *1991-1993*, marks our first sub-period. Explosive growth of employment was particularly pronounced in the 1990s and culminated in 2001. We divide this into two sub-periods, *1994-1997* and

1998-2001. During this period, the expansion of small firms was essential. Characterizing the growth if IT firms in Sweden between 1993 and 1998, Johansson (2004) found that growth emanated nearly exclusively from small and medium-sized firms. Following this expansion, the dot-com crash resulted in a dramatic consolidation of the IT services sector as the number of workers in the sector reduced by more than 10,000 until 2004. Separate estimates are provided for this period. Thereafter, employment growth recovered, but demonstrated a steadier pace during the last two sub-periods, *2005-2007* and *2008-2010*. In fact, by 2007 number of employees exceeded the peak of 2001.

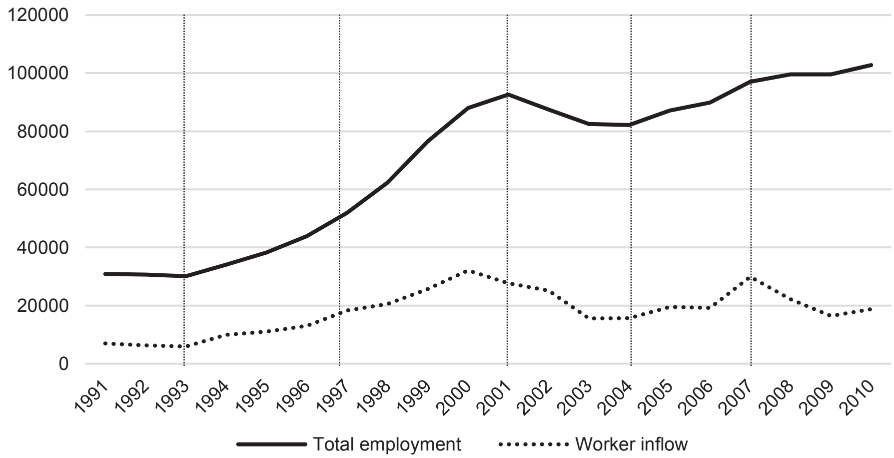
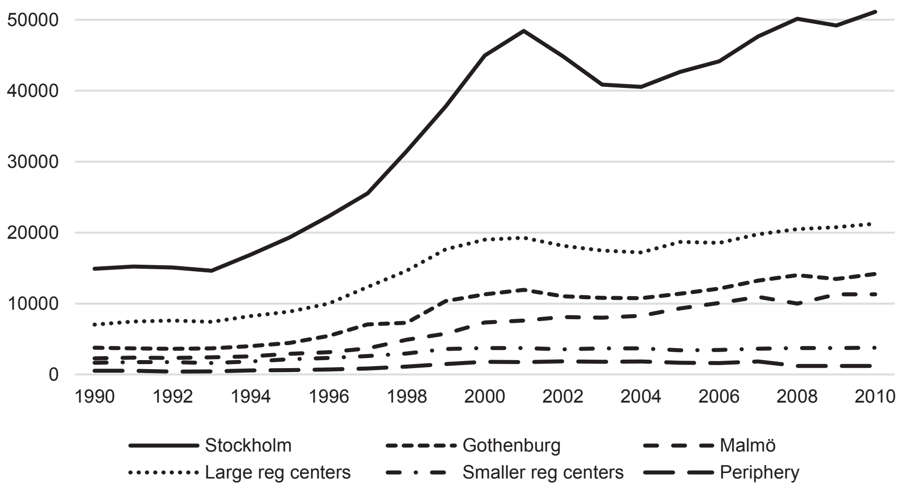


Figure 1. Employment in the knowledge-intensive IT services sector

Notably, the worker inflow into the sector appears to be correlated to its growth phases. Overall, the periods of rapid expansion corresponded to higher inflows (and vice versa) implying their pro-cyclical nature. Nevertheless, even in the period of contraction, there were still around 20,000 workers getting a job in the sector every year.

3.2. Regional aspects of IT services expansion

We know that some regions act as hotspots for early industry development, serving as places of attraction for labour from other regions (e.g., Mukkala and Tohmo 2013). Large, dense regions offer advantages in terms of knowledge flows and knowledge spillovers as they combine the localisation of clusters in specific industries with industrial diversity (Karlsson et al. 2010). In particular, the literature has frequently emphasised that the role of knowledge-intensive business services is particularly pronounced in metropolitan regions (Simmie and Strambach 2006; Chadwick et al. 2008). Figure 2 clearly shows that this is the case also for Sweden.



Total employment growth over 1985-2010							
Stockholm	Gothenburg	Malmö	Large regional centres	Smaller regional centres	Periphery	**Metro**	**Non-metro**
242,77%	277,49%	397,88%	202,38%	126,85%	132,57%	**265,81%**	**184,80%**

Figure 2. Regional distribution of the knowledge-intensive IT services employment

Metropolitan areas (Stockholm, Gothenburg and Malmö)[7] concentrated around 75 per cent of IT services employment throughout the observed time

7 We introduce six regional groups (or families) according to the methodology suggested by the Swedish Agency for Economic and Regional Growth (NUTEK 2004): metropolitan areas (Stockholm, Gothenburg and Malmö), large regional centres, smaller regional centres and peripheral regions. Criteria involved in the definitions of these groups include population size and density, business dynamics, share of individuals with higher education as well as access to higher education institutions.

period. This location tendency goes not only for the selection of industries reported here, but also for other ICT-related industries. For a larger selection of ICT industries, Giertz (2015) found that nearly half of all employees could be found in Stockholm.

Moreover, while Lundmark (1995) documented a tendency for spatial decentralisation of Swedish IT services employment in the 1980s, the metropolitan regions outperformed non-metropolitan areas in terms of employment growth dynamics during the period that we study. The former managed to combine internal sources of growth with attracting workers from more peripheral regions. This supports previous claims that growth in knowledge-intensive services is likely to strengthen differences across regions in favour of major metropolitan areas (Wood 2005; Corrocher and Cusmano 2012).

3.3. Labour inflows into the knowledge-intensive IT services sector

Returning to the core questions of this paper, Figure 3 summarises the distribution of worker inflows into the sector by the entry mode.

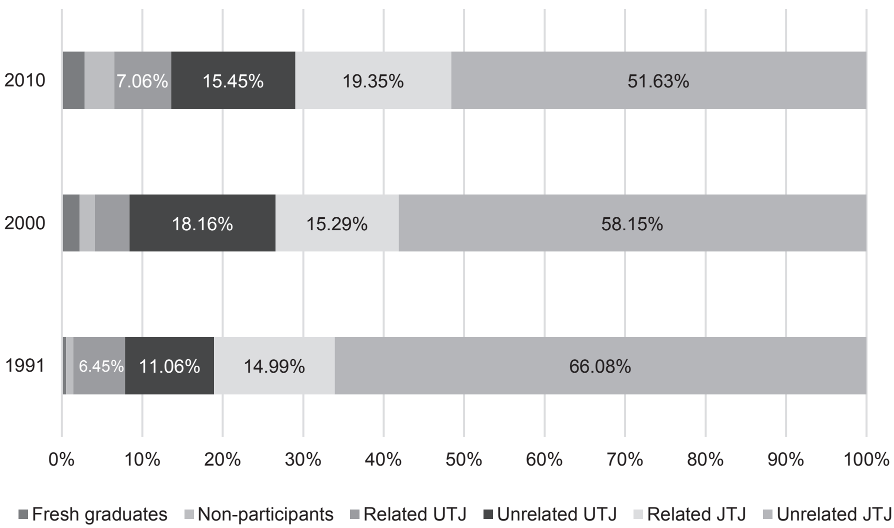


Figure 3. Worker inflows by entry mode

By far, the highest number of entries was performed directly from a previous job, but from outside the sector. Their share, however, decreased over time: from 66.0 per cent in 1991 to 51.6 per cent in 2010. On the contrary, the fraction of job-to-job switches within the sector increased from 15.0 per cent to 19.4 per cent respectively. Nevertheless, direct switches as a whole lost their importance in favour of other modes of entry: entries from unemployment reached 22.5 per cent of inflows in 2010 (17.5 per cent in 1991), from non-participation – 3.7 per cent (0.9 per cent in 1991), while fresh graduates increased their share from 0.5 per cent in 1991 to 2.8 per cent in 2010.

Two conclusions can be made based on these trends. On the one hand, there are indications of an increasingly dynamic labour market *within* the sector. This recalls findings of Maliranta and Nikulainen (2008) who documented worker inflows into the Finnish IT service industries and emphasized an increasingly important role of worker reallocations within the IT sector. Partly, this might be attributed to the dramatic expansion of the sector over time, which improved the availability of workers with the specialised human capital. At the same time, this might also point to the increased value that employers in the sector put on the relevant prior experience.

On the other hand, there is evidence for a diversification of sectoral recruitment strategies through employment of individuals unemployed/non-participating prior to the hire. This should not be interpreted as a falling demand for skilled labour possessing specialised human capital. First, unemployed individuals do not necessarily possess less skills than those performing a direct job-to-job switch. Second, even if the latter holds true, the recruitment of less skilled and/or specialised workers surged during the years of the most rapid expansion of the sector when the labour market was running scarce of relevant competences and employers in the sector were forced to expand the search for suitable workers. An increasing share of unrelated unemployment-to-job entries during the 1990s as well as its decrease in the aftermath of the dot-com crash are a clear indication of that. Third, a surge in the share of fresh graduates and non-participants may point to a growing interest of firms in the sector for individuals who can be hired at a relatively low cost and trained on-the-job, alternatively for individuals instructed in the latest applications of knowledge relevant to the sector.

With regards to the education level of workers (Figure 4), one can observe a great surge in the share of entrants with higher education[8] over time: from 37.4 per cent in 1991 to 53.9 per cent in 2010. While this trend reflects a general tendency towards an upgrade of the education level in the Swedish workforce (for instance, the corresponding numbers for employees in service sectors (excluding IT) are 25.4 and 37.6 per cent respectively), the absolute numbers suggest that having a higher education is a particularly strong prerequisite for IT jobs. Other education level categories lost their shares considerably, pointing to an increasing role of higher education as an 'entrance ticket' to the sector.

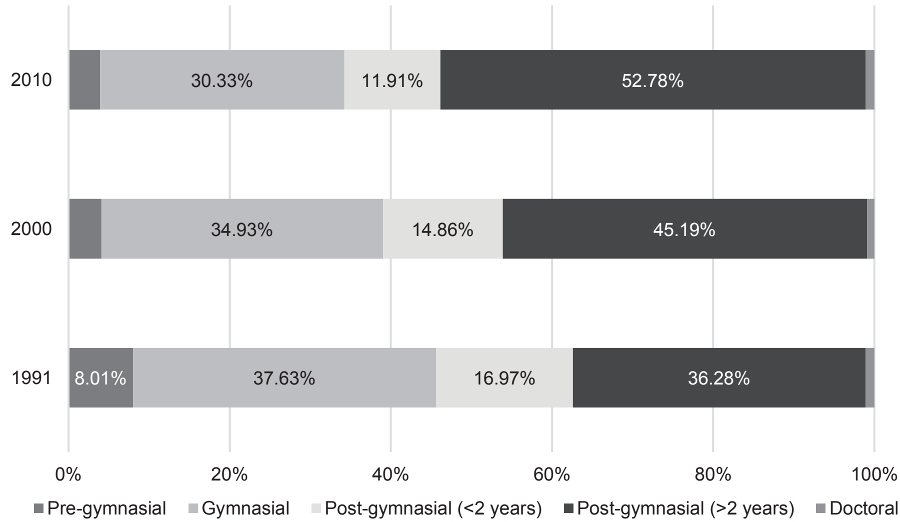


Figure 4. Worker inflows by education level

The similar tendency is observed by Warhurst et al. (2006) who claim that a higher education, relevant experience, and computing interest have increasingly become important factors for getting advanced IT jobs. While this may be assigned to a growing competition for jobs and an increased complexity of tasks in the process of sectoral evolution, it would probably not be possible without an adaptation of the educational sector through an

8 Here, defined as having at least two years of post-gymnasial education (including individuals with doctoral degrees).

improved availability of specialised educational programs providing individuals with knowledge and skills relevant to the sector.

In that respect, it is interesting that education in data and computing not only fell behind education in social sciences and technology and engineering over the whole time period, but also somewhat lost its share over time: from 19.4 per cent in 1991 to 16.4 per cent in 2010 (Figure 5).

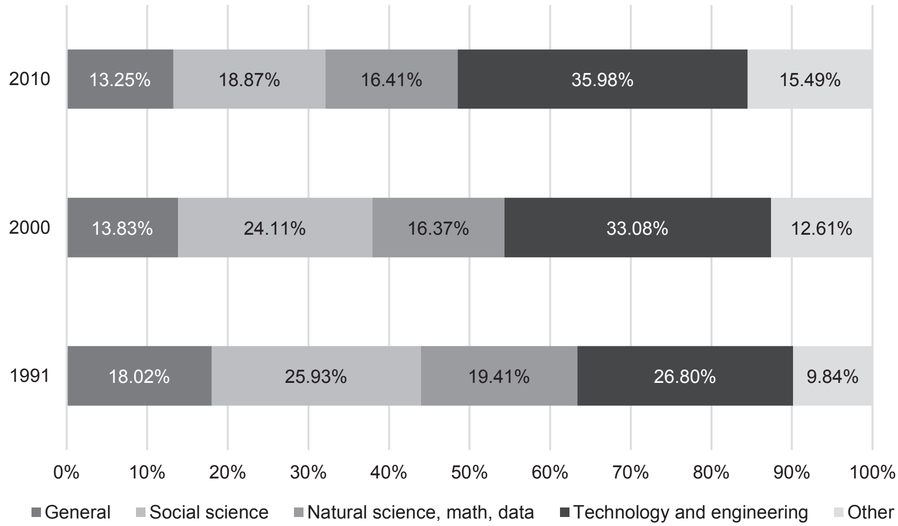


Figure 5. Worker inflows by education track

While this might seem surprising at first, one should consider the specificity of the sector with regards to services it provides. The latter involve an intensive interaction between providers of services and their clients (Strambach 2001). In order to match clients' needs, employees in the sector are required, beyond their technical tasks, to obtain an in-depth understanding of clients' business and production processes (Valenduc 2008), which increases the demand for education in social sciences and engineering. More generally, recent developments in the demand for IT workers emphasize that they should embody a mixture of technical, organisational, business, and management skills (Hawk et al. 2012). In that respect, a representation of an IT worker as a 'technical nerd' has become misleading over time, resulting among other things in a widening variety of education tracks opening doors to IT jobs.

Given the descriptive evidence presented above, an intriguing question is whether overall background profiles of incoming workers demonstrated any tendency towards convergence as the sector matured. On the one hand, evolution of the sector could lead to an increased need for broader skill portfolios as sectoral niches emerged as well as a range of possible applications widened. On the other hand, standardisation of a sectoral technological core, routinisation of tasks and a maturing educational system around the sector could increase the demand for rather narrow skill profiles of incoming individuals. To investigate this, we have calculated an entropy measure combining workers' background characteristics over time (Figure 6).[9]

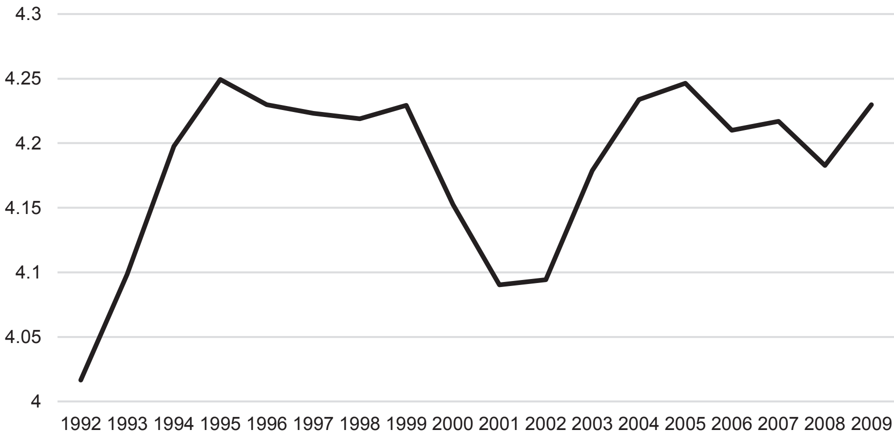


Figure 6. Dispersion of incoming workers' background characteristics (3-year moving average)

Background profiles of incoming workers appeared to be narrower when the sector faced difficult times: during the Swedish banking crisis in the early 1990s, in the aftermath of the dot-com crash in the early 2000s, and, to some extent, during the outbreak of the global economic downturn in the late 2000s.

9 An entropy measure is calculated as a joint entropy of four characteristics: education level, education track, type of the job switch (job-to-job, unemployment-to-job, non-participation-to-job), and previous background in the sector: $H(X_1, X_2, X_3, X_4) = -\sum_{X_1}\sum_{X_2}\sum_{X_3}\sum_{X_4} p(x_1, x_2, x_3, x_4) \log p(x_1, x_2, x_3, x_4)$, where $p(x_1, x_2, x_3, x_4)$ is the observed probability of each possible combination of background characteristics. Higher values of an entropy index imply higher dispersion of background characteristics.

In these periods, firms within the sector tended to hire individuals with narrower background profiles, which points to the consolidation of their expectations regarding new employees. Alternatively, this might point to narrowing of the scope of firms' operations to those which are crucial for firms' survival as compared to times of sectoral expansion.

In that respect, while during the crisis periods the number of individuals getting jobs in the sector still remained high (see Figure 1), they constituted a more homogeneous group than during the boom years. During the latter, however, firms might be expected to generate higher profits, making them care less about cost minimisation and be able to hire less experienced individuals with broader skill profiles to provide them with the relevant training and experience at the workplace.

4. Regression analysis

4.1. Entry conditions

Table 1 reports the results of estimating pooled OLS regressions relating entry conditions of individuals becoming employed in the sector to their background characteristics. Appendix A2 provides a sample summary as well as a correlation table for variables included in the analysis.

One striking feature of the estimation results is that, overall, the relationship between various aspects of workers' backgrounds and their entry wage remained fairly stable over time. Nevertheless, there are some notable changes which are discussed below.

We find a well-documented positive association between the education level of a worker and her wage. There are, however, two qualifications to that result. First, the education premium was decreasing along the evolution of the sector as a substantial compression of coefficients' magnitude is observed in later sub-periods. A possible explanation to that is an increased availability of workers possessing specialised human capital over time. Indeed, during the early stages of sectoral expansion one can expect a limited supply of workers with relevant experience as compared to the demand for them. In such situation, education level of a worker is a signal about her ability level to a potential employer, which would then be ready and willing to offer higher

Wage index; Pooled OLS	1991-2010		1991-1993		1994-1997		1998-2001		2002-2004		2005-2007		2008-2010	
	Wage_i_t	Wage_i_{t+1}	Wage_i_t	Wage_i_{t+1}	Wage_i_t	Wage_i_{t+1}	Wage_i_t	Wage_i_{t+1}	Wage_i_t	Wage_i_{t+1}	Wage_i_t	Wage_i_{t+1}	Wage_i_t	Wage_i_{t+1}
Edu_level (pre-gym)														
Gym	0.0354***	0.0513***	0.0817***	0.0847***	0.0642***	0.0799***	0.0327***	0.0337***	0.0198*	0.0426***	0.0074	0.0215	-0.0009	0.0108
After-gym (<2 years)	0.1037***	0.1434***	0.1085***	0.1408***	0.0925***	0.1565***	0.1086***	0.1288***	0.1241***	0.1539***	0.0781***	0.1006***	0.0602***	0.0686***
After-gym (≥2 years)	0.1831***	0.2179***	0.2293***	0.2627***	0.2297****	0.2563***	0.2179***	0.2225***	0.1839***	0.2409***	0.1199***	0.1477***	0.0863***	0.1070***
Doctoral	0.2785***	0.3268***	0.3764***	0.4449***	0.3699***	0.3611***	0.3156***	0.3051***	0.3340***	0.3807***	0.1443***	0.2663***	0.1634***	0.2020***
Edu_track (other)														
Social science	0.0863***	0.0883***	0.0790***	0.0715***	0.0643***	0.0738***	0.0917***	0.0928***	0.0827***	0.0837***	0.0974***	0.1149***	0.1093***	0.1041***
Natural science, data	-0.0078*	-0.0047	0.0380***	0.0013	0.0100	0.0148	0.0017	0.0249***	-0.0169*	-0.0278***	-0.0242**	-0.0205*	-0.0013	-0.0157
Technology	0.0666***	0.0567***	0.0690***	0.0581***	0.0652***	0.0570***	0.0733***	0.0719***	0.0530***	0.0467***	0.0589***	0.0561***	0.0800***	0.0495***
Entry (unrelated JTJ)														
Fresh graduate	-0.2855***	-0.1065***	-0.2678***	-0.1327*	-0.3075***	-0.1400***	-0.3318***	-0.1316***	-0.2627***	-0.0815***	-0.2541***	-0.0542***	-0.2344***	-0.0749***
Non-participant	-0.4913***	-0.2829***	-0.4728***	-0.2518***	-0.5120***	-0.3177***	-0.6027***	-0.3656***	-0.3828***	-0.2211***	-0.4488***	-0.2197***	-0.4506***	-0.2401***
Unrelated UTJ	-0.3182***	-0.2001***	-0.2498***	-0.1632***	-0.2421***	-0.1782***	-0.3060***	-0.1918***	-0.3815***	-0.2325***	-0.3476***	-0.2053***	-0.3271***	-0.2061***
Related UTJ	-0.3657***	-0.1626***	-0.2928***	-0.1443***	-0.3551***	-0.1599***	-0.4101***	-0.1832***	-0.3632***	-0.1807***	-0.3386***	-0.1325***	-0.3184***	-0.1325***
Related JTJ	0.0931***	0.0699***	0.0832***	0.0327**	0.0931***	0.0636***	0.0716***	0.0456***	0.0615***	0.0613***	0.1432***	0.1113***	0.0989***	0.0685***
Regional move	0.0293***	0.0432***	-0.0128	0.0595***	0.0051	0.0330***	0.0330***	0.0434***	0.0626***	0.0624***	0.0355***	0.0256*	0.0307**	0.0414***
Reg. family (large reg. centres)														
Stockholm	0.1939***	0.2110***	0.1236***	0.1591***	0.1500***	0.1695***	0.2192***	0.2225***	0.2286***	0.2483***	0.2028***	0.2171***	0.1794***	0.2130***
Gothenburg	0.0557***	0.0637***	-0.0125	-0.0179	0.0582***	0.0684***	0.0684***	0.0723***	0.0714***	0.1009***	0.0868***	0.0643***	0.0304***	0.0490***
Malmö	0.0582***	0.0667***	-0.0115	-0.0045	0.0040	0.0120	0.0419***	0.0319***	0.0858***	0.1169***	0.0890***	0.0790***	0.0791***	0.1168***
Smaller reg. centres	-0.0491***	-0.0673***	-0.0494***	-0.0670***	-0.0442***	-0.0855***	-0.0633***	-0.0803***	-0.0109	0.0048	-0.0855***	-0.1170***	-0.0625***	-0.0809***
Periphery	-0.0349***	-0.0583***	-0.0856***	-0.1045***	-0.0659***	-0.0435*	-0.0373***	-0.0758***	0.0192	-0.0094	-0.0230	-0.0671***	-0.0423*	-0.0305***
Reg. move*Reg. family (large reg. centres)														
Stockholm	-0.1421***	-0.0953***	-0.0759***	-0.0851***	-0.0961***	-0.0636***	-0.1426***	-0.0881***	-0.1970***	-0.1489***	-0.1468***	-0.0885***	-0.1481***	-0.1065***
Gothenburg	-0.0087	-0.0038	0.0944*	0.0019	0.0066	0.0156	-0.0139	-0.0075	-0.0100	0.0066	-0.0628***	-0.0252	0.0001	-0.0137
Malmö	0.0051	0.0088	0.1508***	0.0522	0.0300	0.0213	0.0264	0.0389**	-0.0416	-0.0340	-0.0100	0.0292	-0.0259	-0.0608*
Smaller reg. centre	0.0068	0.0168	0.0589	0.0313	0.0158	0.0304	0.0061	0.0151	-0.0332	-0.0372	0.0539*	0.0623**	-0.0160	0.0272
Periphery	-0.0243*	-0.0202	-0.0521	-0.0496	0.0309	0.0360	-0.0218	-0.0262	-0.0853***	-0.0536*	-0.0177	-0.0107	-0.0140	-0.0208
Firm size (2-10 emp)														
1 emp	-0.4174***	-0.5027***	-0.3300***	-0.3540***	-0.3755***	-0.4533***	-0.4091***	-0.5066***	-0.4353***	-0.5199***	-0.4284***	-0.5284***	-0.4131***	-0.4936***
> 10 emp	0.1535***	0.1724***	0.1092***	0.1070***	0.1330***	0.1615***	0.1139***	0.1354***	0.2121***	0.2386***	0.1876***	0.1857***	0.1717***	0.2024***
R^2	0.3584	0.3027	0.4109	0.2976	0.4372	0.3287	0.3465	0.2894	0.3464	0.3326	0.3612	0.2919	0.3493	0.3166
N	351982	256832	18633	13895	51828	41595	103637	76560	54242	41499	67728	52704	55914	30579

Note: Demographic controls (sex and age), industry and year dummies as well as a constant are included in the models but not reported. Standard errors are robust and clustered at the individual level. ***(**,*) indicate significance at 0.1% (1%, 5%) level

Table 1. Workers' backgrounds and entry conditions

wages to those with higher education level. With the development of a more specialised labour market and educational system around the sector, education level *per se* might be expected to lose in importance in comparison to other background characteristics of workers, such as education specialisation and relevant work experience. This, in its turn, would have a downward pressure on the wage premium from education level.

Second, in the aftermath of the dot-com crash the education premium remains observable only for individuals with at least some education at the post-gymnasial level. This supports the claim made above that higher education was becoming an 'entrance ticket' to good (at least, better paid) jobs in the sector.

Another interesting observation is that in all time periods the magnitude of coefficients for education level increases somewhat a year after the entry. One implication is that the association between entry conditions and education level remains quite persistent, that is, individuals with higher levels of education not only enjoy better entry conditions, but also faster wage growth, at least over the first year of employment.

With regards to the education track, it is the background in social sciences which tends to yield the highest wage premium in entry wage closely followed by that in engineering and technology. Surprisingly, education in natural science, computing and data did not have any significant impact on entry conditions in most time periods. What might be behind this is the relative ease with which general skills in programming can be obtained (Østergaard and Dalum 2011) and a rapid obsolescence of technical IT skills (Prabhakar et al. 2005). This would make it less strategically valuable to hire workers with purely technical education, and increase the value of education tracks which include complementary applied skills. Moreover, the premium for education in social sciences and engineering and technology tends to increase over time, which supports the explanation provided for compression of coefficients for education level.

The association between entry conditions and the entry mode is very consistent over the whole time period. The best entry conditions are, unsurprisingly, experienced by individuals performing a direct switch from a job in another IT service industry. These are closely followed individuals performing a job-to-job switch from outside the sector. Among the rest, it is fresh graduates who might expect better entry conditions. Thereafter follow entrants from unemployment with only minor difference between those with and without experience in the sector.

It is interesting that performing an unrelated job-to-job switch tends to yield better entry conditions than having employment history in IT services but being unemployed before getting a new job. This might have two, potentially complementary, explanations. On the one hand, employers in the sector may consider unemployment periods detrimental to individuals' human capital and, thus, to their potential performance. On the other hand, individuals performing a direct switch, even from outside the sector, might have a better position for negotiating entry wages while previously unemployed individuals might tend to accept lower ones.

Another peculiar observation is that, contrary to education level and track, the magnitude of coefficients for various entry modes reduces considerably a year after the entry, which feasibly points to a faster wage growth for those with worse entry conditions. Potential explanation is a very fast accumulation of specialised human capital through on-the-job learning process. If the latter claim is correct, the importance of general human capital (reflected by education level and track) would be more persistent than that of having relevant work experience.

Individuals becoming employed in metropolitan areas (Stockholm, Gothenburg and Malmö), unsurprisingly, may expect higher entry wages than individuals getting jobs in more peripheral regions, which is predicted by the literature on the urban wage premium (Glaeser and Maré 2001; Yankow 2006). This wage premium increases somewhat over time, peaking in the aftermath of the dot-com crash.

At the same time, there is a difference between metropolitan areas with regards to entry conditions for individuals, for whom a job switch is associated with a regional move. In particular, individuals relocating to Stockholm tend to find themselves in a worse position than those performing a local job switch. Potential explanation to that is that incoming workers may not be acquainted with a relevant wages level in Stockholm, which pushes their expectations lower than those of local workers. This is partly confirmed by the fact that the year after entry the difference between local entrants and region switchers is somewhat mitigated (but does not completely disappear).

Individuals performing a regional move to regions other than Stockholm appear to enjoy a slight wage premium over local entrants, which is not significantly different between secondary metropolitan areas of Sweden and more peripheral regions. Possible explanation to that is that the entry conditions of regional switchers are pushed up by individuals relocating from Stockholm. Indeed, once the regional movers from Stockholm are excluded, the association between entry conditions and regional relocation becomes insignificant.[10]

Finally, larger firms tend to provide better entry conditions. This tendency is more pronounced in the aftermath of the dot-com crash. Particularly in the period of sector's contraction, one can expect the reallocation of workers to the most productive and resistant firms, with a higher probability of survival, which are likely to be the largest firms in the sector.

4.2. Probability to stay in the sector

Table 2 reports the estimation output of logistic regressions relating individuals' probability to remain employed in the sector three years after the entry to their background characteristics. Appendix A3 provides a sample summary as well as a correlation table for variables included in the analysis.

With exception of individuals with a doctoral degree, higher level of education tends to be positively associated with the propensity of individuals to stay employed in the sector when the whole time period is concerned. There is, however, a huge variation in the coefficients for different sub-periods. In the periods, when the stay/exit is observed in the times of rapid expansion (entry in 1991-1993 and 1994-1997), there is no systematic tendency in the coefficients. However, when the stay/exit is observed during and in the aftermath of the dot-com crash (remaining sub-periods), importance of education tends to be more pronounced. As in the case with entry conditions, by the end of the considered time period it is only higher education which tends to yield a higher probability to stay in the sector. This puts another perspective on the importance of education level as a background characteristic.

Education track tends to be related with the propensity of individuals to remain employed in the sector. However, the observed magnitude of coefficients is completely reversed compared to entry conditions regressions.

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[10] These models are not reported but are available from the authors upon request.

Staying in the sector; Pooled logistic regression	1991-2010	1991-1993	1994-1997	1998-2001	2002-2004	2005-2007
Edu_level (pre-gym)						
Gym	0.0758***	0.0258	-0.0124	0.1566***	0.0617	0.1054
After-gym (<2 years)	0.2171***	0.2001*	0.1140*	0.3034***	0.2338***	0.1015
After-gym (≥2 years)	0.2827***	0.2270**	0.0914	0.3356***	0.3529***	0.3389***
Doctoral	0.0111	0.1805	-0.1713	0.0804	0.0240	0.0689
Edu_track (other)						
Social science	0.0667***	-0.0689	0.0839**	0.0986***	0.0242	0.0202
Natural science, data	0.5917***	0.6728***	0.6307***	0.5881***	0.4770***	0.5762***
Technology	0.2999***	0.1923***	0.2318***	0.3121***	0.2632***	0.4386***
Entry (unrelated JTJ)						
Fresh graduate	-0.0398	-0.2435	-0.0771	-0.1126	0.1083	0.0106
Non-participant	-0.2410***	-0.4784*	-0.2556**	-0.3611***	-0.1572	-0.0916
Unrelated UTJ	0.1171***	0.0224	0.1437***	0.1006***	0.1127**	0.0568
Related UTJ	-0.0693***	-0.1310**	-0.0762**	-0.0819***	-0.1032***	-0.0696*
Related JTJ	0.6025***	0.4132***	0.5011***	0.4810***	0.6694***	0.7119***
Regional move	-0.0476*	-0.1157	-0.0894*	0.0916**	-0.2209***	-0.3161***
Reg. family (large reg. centres)						
Stockholm	0.0087	-0.0251	-0.2188***	0.1639***	-0.1128***	-0.1536***
Gothenburg	0.2152***	0.0880	0.0588	0.2580***	0.3540***	-0.1029*
Malmö	0.0901***	-0.2570***	-0.1003*	0.3170***	0.0996***	-0.1994***
Smaller reg. centres	0.0691**	0.1149	0.0570	0.3715***	-0.3629***	0.0897
Periphery	-0.1790***	-0.0492	-0.1663	-0.0043	-0.1299	-0.6949***
Reg. move*Reg. family (large reg. centres)						
Stockholm	-0.0641*	0.0302	0.0348	-0.2432***	0.1100	0.1974**
Gothenburg	-0.1369***	-0.3156*	-0.1078	-0.1638**	-0.1688	0.1903*
Malmö	-0.1229***	-0.1745	-0.0095	-0.3839***	0.0821	0.3684***
Smaller reg. centre	-0.1321**	-0.3437	-0.2165*	-0.3443***	0.2010	-0.0413
Periphery	-0.2194***	-0.9347***	-0.0868	-0.3576***	-0.0792	0.2508
Firm size (2-10 emp)						
1 emp	0.0327	0.0995	0.0745	0.1284***	-0.0324	-0.0861*
> 10 emp	0.2114***	0.3440***	0.3699***	0.1666***	0.0933***	0.2430***
Pseudo-R^2	0.0491	0.0512	0.0393	0.0364	0.0578	0.0639
N	294020	18514	51605	103185	53812	47788

Note: Demographic controls (sex and age), industry and year dummies as well as a constant are included in the models but not reported. Standard errors are robust and clustered at the individual level. ***(**,*) indicate significance at 0.1% (1%, 5%) level

Table 2. Workers' backgrounds and propensity to stay in the sector

That is, having more technical education is strongly and positively associated with the probability of staying (being the highest for individuals with education in natural sciences, data and computing). Coefficients for education in social sciences are quite unstable in different time periods. One possible explanation is that individuals with education in social sciences (and, to some extent, engineering) perform tasks and develop skills which are easier to transfer to other sectors, while individuals with education in natural sciences, data and computing have a higher tendency to be 'locked-in' in the sector.

Also, entry mode co-varies extensively with the probability to remain employed in the sector. For instance, it is the highest for individuals performing related job-to-job moves followed by individuals performing unrelated direct switches and fresh graduates. The lowest propensity is observed for entrants from non-participation. Quite surprisingly, individuals performing unrelated unemployment-to-job switches are more likely to stay in the sector than those entering from unemployment with their last job in another IT service industry. Possible explanation is that the latter make several attempts to find a job in the sector, and, failing, move on to jobs elsewhere.

There is, however, an interesting time dynamics. First, the tendency for individuals performing related job-to-job switches to stay longer in the sector becomes stronger over time, pointing to the increased stability of job matches for this category of workers. Second, the difference between other groups of workers becomes less pronounced with the evolution of the sector, virtually disappearing in the latest observed sub-period.

Regional relocation is negatively associated with the propensity to stay in the sector in all regions when the whole time period is taken into consideration. With exception of large regional centres, this tendency is particularly pronounced for individuals, for whom stay/exit is observed right in the aftermath of the dot-com crash. One possible explanation to that is that relocating individuals might find it difficult to fit into labour markets of destination regions. In that respect, it is interesting that probability of remaining employed in the sector is in most sub-periods the lowest in the most peripheral regions. Another possible reason is that some workers could use a job in the sector as the 'entry platform' to a new region (as there would be lots of job opportunities due to sectoral expansion), being ready to move to jobs in other sectors as they become more embedded in regional labour markets.

With regards to the firm size, the largest probability to stay in the sector is observed for individuals becoming employed in large firms. This tendency, however, becomes weaker during and after the dot-com crash. What might be behind this is that, as the sector matured, its labour market was becoming less turbulent (reinforced by the consolidation of the sector in the aftermath of the dot-com crash), leading to the mitigation of differences between firms of different sizes in terms of providing stable employment opportunities. While it is only a speculation at this point, the dot-com crash may also have put severe pressure on relatively large firms in the sectors that we study, just as it did in other ICT sectors in Sweden. For example, Ericsson had over 40,000 employees in Sweden in 2000, decreasing to about 21,000 in 2004 (Giertz 2015).

4.3. Wage growth after the entry

Table 3 reports the results of estimating the Heckman-probit selection model for the wage performance of individuals provided that they stay employed in the sector three years after the entry. Appendix A4 provides a sample summary as well as a correlation table for variables included in the analysis. Selection equation estimates are reported in Appendix A5.

As in the models discussed above, education level has a positive and strictly hierarchical association with a probability of individuals' wage growth above industry average over the whole time period. Education premium with respect to wage growth is particularly pronounced in years of sectoral expansion (1994-1997 and 2005-2007). What's interesting here, while individuals with doctoral education do not exhibit any outstanding pattern in propensity to remain employed in the sector, they are the ones to expect the fastest wage growth provided that they stay.

Individuals with social sciences education background appear to not only enjoy the best entry conditions, but may also expect the highest wage growth when the whole time period is considered. This tendency is particularly observed after the dot-com crash. Individuals with more technical education perform worse. This points once again to the importance of 'soft' skills for performance in the sector. Besides, as individuals with technical education might have a higher risk to be 'locked-in' in the sector (as suggested by the propensity to stay regressions) they might also be in a relatively worse position when it comes to wage negotiations.

Wage growth; Heckman probit	1991-2010	1991-1993	1994-1997	1998-2001	2002-2004	2005-2007
Edu_level (pre-gym)						
Gym	0.0741***	-0.0875	0.0836*	0.0505	0.0454	0.0991*
After-gym (<2 years)	0.1221***	-0.0148	0.2341***	0.0921*	-0.0430	0.0865
After-gym (≥2 years)	0.1239***	0.0459	0.1511***	0.0646	0.0614	0.1141*
Doctoral	0.2323***	0.0320	0.3043**	0.1582**	0.2068**	0.2279**
Edu_track (other)						
Social science	0.0309**	-0.0087	0.0111	0.0336	0.0113	0.0706**
Natural science, data	-0.0214	-0.0493	0.0170	-0.0436	-0.1301***	-0.0054
Technology	-0.0343**	0.0668	-0.0286	-0.0576**	-0.0491*	-0.0735**
Entry (unrelated JTJ)						
Fresh graduate	0.4255***	0.0453	0.2103*	0.6891***	0.0581	0.4556***
Non-participant	0.4450***	0.7120**	0.4457***	0.7200***	0.0514	0.4849***
Unrelated UTJ	0.2938***	0.2286***	0.2230***	0.2853***	0.3266***	0.3075***
Related UTJ	0.5766***	0.3234***	0.4783***	0.6719***	0.4364***	0.6071***
Related JTJ	-0.1117***	-0.0770*	-0.0881***	-0.1228***	-0.1573***	-0.1818***
Regional move	-0.0012	0.0967	0.0473	0.0232	0.0062	-0.0491
Reg. family (large reg. centres)						
Stockholm	-0.0237*	-0.0466	0.0316	-0.0531**	-0.0296	-0.0132
Gothenburg	-0.0570***	-0.0212	-0.0630*	-0.0787***	-0.0666*	-0.0614*
Malmö	-0.0286*	0.0074	0.0267	-0.0136	0.0086	-0.1080***
Smaller reg. centres	-0.0637**	-0.1101	-0.2029***	0.0006	0.0842	-0.0945*
Periphery	-0.0440	-0.0513	0.0320	-0.0010	-0.1466*	0.1510
Reg. move*Reg. family (large reg. centres)						
Stockholm	0.1746***	0.1979*	0.1343*	0.1624***	0.1385**	0.1613**
Gothenburg	0.0876**	-0.0309	0.0445	0.0478	0.0492	0.1683*
Malmö	0.0611	-0.0462	-0.0377	-0.0198	0.0391	0.1464*
Smaller reg. centre	0.0316	0.0023	0.0550	-0.0001	0.0792	-0.0618
Periphery	0.0609	0.0748	-0.0717	0.0264	0.1941	-0.1169
Firm size (2-10 emp)						
1 emp	-0.7355***	-0.5241***	-0.7359***	-0.6747***	-0.7155***	-0.7191***
> 10 emp	0.1049***	0.1283***	0.1678***	0.1380***	0.0107	0.0469*
Prob. (ρ=0)	0,0000	0,0055	0,0000	0,0000	0,0001	0,0000
N censored	128167	7942	19978	51407	22872	17324
N uncensored	165853	10572	31627	51778	30940	30464

Note: ρ≠0 indicates that selection and outcome equations are dependent (i.e., that Heckman specification is correct). Demographic controls (sex and age), industry and year dummies as well as a constant are included in the models but not reported. Standard errors are robust and clustered at the individual level. ***(**,*) indicate significance at 0.1% (1%, 5%) level

Table 3. Workers' backgrounds and post-entry wage performance

With regards to the entry mode, it is somewhat surprising that individuals performing a direct switch from employment within the sector are less likely to enjoy a better-than-industry-average performance when compared to other modes of entry. Possible explanation is that these workers have the best negotiation position for the entry wage, so that a better performance of individuals with other modes of entry may just be a realisation of the 'low-base' effect. If the latter is true, then it comes as no surprise that while initial wage premium for direct switchers increases over time, their post-entry performance in terms of wage growth becomes worse over time.

While performing a regional move is negatively associated with a probability to remain employed in the sector three years after entry, it has no significant impact on individuals' wage performance. There are, however, regional differences. That is, individuals moving to and remaining employed in Stockholm (in the later sub-periods, also Gothenburg and Malmö) enjoy a significant wage growth premium.

Employees in large firms tend to have the best wage performance as compared to medium-sized firms and individual consultancies. However, this wage growth premium decreases over time, pointing once again to the increasing importance of medium-sized firms in the sector.

5. Discussion

Due to the international success of the Swedish ICT sector, especially in the 1990s, previous investigations covered a range of issues concerning its historic growth, firm structure, and innovation system characteristics over time. Yet, to our best knowledge, no studies have taken an explicit interest in the sources of labour supply for these expanding activities. This is not particular to Sweden, or to the IT industries. In the international literature, few efforts have been devoted to a fruitful integration of the literatures on industry dynamics and labour market dynamics (Mamede 2009).

We think, however, there are a couple of reasons to pursue this integration. From the perspective of industry dynamics, economic sectors could be regarded as constantly evolving bundles of activities, execution of which entails the application of specific knowledge. Sectoral evolution is, therefore, necessarily shaped by the dynamics of knowledge creation (Krafft et al. 2014). This knowledge is brought into and formed within industries by employees. Changes in the workforce composition of an industry over time is, in that respect, a reflection of its evolution. The study of labour sourcing processes may provide insights into how various types of knowledge are formed, combined and valued in an industry over time, also in particular localities. It may also shed light on relationships with and knowledge diffusion between other related industries (Neffke and Henning 2013), indicating how independent expanding industries are, or not, from previously established structures in the economy.

From the perspective of the labour market dynamics, employment structures and worker turnover can be considered as coordinating devices which ensure a coherence between what is required from the workforce, and the pool of skills and capabilities that are available in the economy. The skill composition of a workforce is an indicator of knowledge relevant to employers in an industry at any point in time (Consoli and Rentocchini 2015). Understanding the labour sourcing processes over time may, therefore, provide insights into which types of labour demand, as well as opportunities for labour, are created in industries at different stages of maturity. Such understanding may then inform training initiatives, education policies and human capital policies, aiming at promoting growth and development of both new and maturing sectors.

We have observed several tendencies in the labour sourcing strategies of employers in the knowledge-intensive IT services sector in Sweden, which may be manifestations of evolution of the sector as a whole, as well as its demand for labour in particular. First, dynamics of worker reallocation around the sector suggest the evolution of an increasingly specialised structure over the period that we study. In other words, the more mature the sector turns, the more it relies on the internal labour market dynamics. In particular, individuals moving into an IT services job from a related industry tend to increase their share among labour inflows, enjoy better entry conditions as well as more lasting employment prospects throughout the whole period under consideration. In that respect, one can point out that the knowledge relevant to an industry is not only tenured in the industry itself, but also in other, related, industries. This provides important qualifications to recent claims that industries cannot be meaningfully studied as isolated units. Rather, their evolution is shaped in a mutual exchange with related industries (Frenken and Boschma 2007; Neffke et al. 2011). But while people moving from closely related sectors are attractive and initially rewarded, they quickly need to adapt to new circumstances and contexts to sustain their perishable mover advantages. The benefits accruing from work experience in related industries vanish rather quickly, to the benefit of experience (on-the-job training) and formal education.

Second, the results strongly suggest that higher education becomes an increasingly important ‘entrance ticket’ to jobs in the IT service industries. In that respect, job opportunities become increasingly restricted over time (Warhurst et al. 2006), at least for ‘better jobs’ in the sector. While this is a tendency which the IT services sector shares with the Swedish labour market in general, this is also in line with Østergaard and Dalum (2011) who argue that even if the human capital entry barriers have been low historically for IT, they seem to have increased. Higher education level also tends to be associated with more lasting employment prospects in the sector as well as better post-entry wage performance. Even though we are inclined to argue that the growth of specialised IT education tracks in Swedish higher education institutions has contributed to pushing the ‘entrance ticket’ upwards, we cannot rule out that fiercer competition for IT service jobs was behind this. Nevertheless, evolution of the sector seems instead to lead to an increasing need for, and in particular reward to, the most educated workers.

Third, complementary to the latter finding, our investigations also indicate that qualified industry experience, or even industry-specific skills (Neffke and Henning 2013), of great value to the sector can be attained by people with very diverse educational backgrounds. Sectoral core competences seem not to be embedded in one dominant educational or occupational group, but are rather distributed and made operational across a range of skill backgrounds in combination. An example in our investigation is the striking importance of workers educated with a main core in social sciences. We believe that this reflects the broad scope of competences needed in today´s advanced service industries. These workers are also highly appreciated in the sector, and the status of their work is recognised in the wage. However, they seem to have a lower tendency to stay on, compared to workers with specialised technical backgrounds. The latter rather seem to become ‘locked-in’ in their existing positions and conditions.

Fourth, one of our most interesting findings is how sectoral crises, in our case the dot-com crash, become important periods for both building linkages to other industries (Eriksson and Boschma 2013), and general sectoral consolidation and restructuring. During severe crises, sectoral labour dynamics is substantial but of a very different character. That is, while labour inflows into industries remain rather high, the group of workers getting jobs in the sector in these periods is more homogeneous than in times of rapid expansion. The implication is that dedicated specialists have an easier time in periods of crisis, and the ones hurt are those who do not fit the narrower skill profile. In other words, crises are periods of an increased consolidation of sectoral activities as reflected, among other things, in the sectoral demand for labour. Because crises also seem to be dynamic periods, we would find it interesting to further study how labour reallocation during crisis affects industry evolution in the longer run.

Finally, labour sourcing processes have important geographical components. The hotspot for the knowledge-intensive IT services sector in Sweden has always been the capital region of Stockholm, which not only concentrates around half of the sectoral employment but also hosts employers providing the best conditions for their workers in terms of wages. Stockholm's particular strength is also reflected in the wage benefits for workers relocating to Stockholm from other regions. With time, two other Swedish metropolitan areas (Gothenburg and Malmö) caught up on Stockholm to demonstrate the similar developments. In that respect, it is interesting that different types of spatial entries are differently associated the entry conditions and post-entry performance of workers in the sector. While for local entrants in metropolitan areas urban wage premium is realised through higher entry wages, regional movers tend to demonstrate better post-entry wage performance. One tentative explanation for this is that (at least some of) regional movers are quite footloose, and, therefore, more inclined to move on to other jobs unless they enjoy a solid wage growth over the first couple of years of employment. Indeed, complementary to that finding, it appears that regional movers are less entrenched in the sector as they demonstrate lower probability to remain employed in the sector. What might be behind this is that such workers may use an entry to a job in expanding industries as stepping stones to other types of work in a region of arrival. One important thing to mention is that, even though the sector demonstrated the fastest expansion in metropolitan areas, it also enjoyed substantial dynamics even in the most peripheral regions of Sweden.

6. Conclusion

This paper investigated structures of labour sourcing in the Swedish knowledge-intensive IT services sector during the period of its rapid expansion between 1991 and 2010. Complementing the spectacular examples of entrepreneurs with no apparently relevant education and experience making fortunes in the early phase of IT services expansion, our results suggest that the expectations, requirements and valuations for skills of new entrants into the sector consolidated fairly early, in line with what could be found for most industries (Bruce Chelimsky Fallick 1996). Backgrounds of incoming workers had substantial impacts on compensation levels and propensity to stay, but did not differ much from what was traditionally observed for larger sets of industries with regards to importance of education (Oreopoulos and Petronijevic 2013) and relevant work experience (Parent 2000; Sullivan 2010). Taken together with the fact that the industries that we study have clear historical antecedents in the Swedish economy (see Johansson 2001), our results may call into question how 'new' even very dynamic sectors actually are in terms of the knowledge they employ.

In particular, our findings suggest that the evolution of the knowledge-intensive IT services sector was reflected not so much in *how it valued* skills of inflowing individuals, but in *which kind of skills* employers in the sector tended to attract over time. This could be illustrated by the idea of an 'entrance ticket' for labour into the sector, and how this changed as the sector was evolving.

While we focus on a particular sector, many of our findings may be relevant, in particular those sectors where production processes are heavily relying on knowledge and underlying technological base changes fast over time, such as technology-based KIBS (e.g. engineering services, cf. Miles et al. 1996) and other R&D-intensive industries. In such sectors, for instance, fast technological change ensures that technical skills, relevant to the sector, become obsolete very fast, which in its turn means that sectoral core competences are not strongly embedded in one dominating educational group at a particular point in time. Fast on-the-job training and high labour market turbulence leave more persistent effects from education as compared to experience in the sector *per se*, even if the latter provides workers with initial benefits at the moment of the hire. Also, formation of clusters of related industries in terms of labour market dynamics would be relevant for most sectors. Again, especially so for sectors which rely on inputs of knowledge embodied in workers as that creates particularly fruitful preconditions for forming linkages between industries. We believe, however, that further research need to investigate more thoroughly how those structures evolve over time, especially in rapidly changing industries.

While the Framtidsfabriken story in the beginning of this paper was seen by some as the manifestation of the growth dynamics of new industries, our aggregate numbers suggest that the IT services in general developed along a less spectacular, but much more powerful trajectory. Indeed, the herald industries of the 'new economy' seem to form, keep and value their labour force much like everyone else in the end, and have consistently developed towards a clearly distinguishable set of industries, forming a vital part of today's economy.

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Appendices

A1. Description of the variables

Variable name	Variable description	Values
Wage index	Entry wage relative to the median wage in the industry	Continuous
Stay	Probability of an individual to remain employed in the sector three years after entry	1 – an individual is employed in the sector at *t+3* 0 – otherwise
Wage growth	Probability of an individual to perform better than an industry average in terms of wage growth	1 – an individual enjoyed faster wage growth than an industry average 0 – otherwise
Sex	Sex of an individual	1 – male individual 0 – female individual
Age	Age of an individual	Continuous
Age squared	Squared age of an individual	Continuous
Edu_level	Highest achieved education level of an individual	1 – pre-gymnasial 2 – gymnasial 3 – after-gymnasial (<2 years) 4 – after-gymnasial (≥2 years) 5 – doctoral
Edu_track	Main specialisation of individual's education	1 – social sciences 2 – natural sciences, data and computing 3 – technology and engineering 9 – other
Entry mode	Entry mode of an individual to a job in one of the IT services industries	1 – fresh graduates 2 – non-participants 3 – related unemployment-to-job switches 4 – unrelated unemployment-to-job switches 5 – related job-to-job switches 6 – unrelated job-to-job switches
Reg. move	Indicator variable for regional move	1 – job switch associated with a regional move 0 - otherwise
Reg. family	Regional family of a region in which an individual becomes employed	1 – Stockholm 2 – Gothenburg 3 – Malmö 4 – Large regional centres 5 – Smaller regional centres 6 – Periphery
Firm size	Categorical variable for a size of a firm in which individual becomes employed	1 – 1 employee (individual consultancy) 2 – 2-10 employees 3 – more than 10 employees

A2. Descriptive statistics and correlation table. Entry conditions models

	N	Mean	Std. Dev.	1	2	3	4	5	6	7	8	9	10
Wage index	351982	0.8993	0.6566	1									
Sex	351982	0.7117	0.4530	0.1598	1								
Age	351982	35.0872	9.9179	0.3301	0.0033	1							
Age squared	351982	1329.4730	772.1719	0.2935	0.0051	0.9889	1						
Edu_level	351982	3.0288	0.9979	0.1607	0.0727	0.0128	-0.0128	1					
Edu_track	351982	3.8016	3.0058	-0.1571	-0.0916	-0.0621	-0.0407	-0.4182	1				
Entry mode	351982	5.2239	1.0970	0.3015	-0.0140	0.1773	0.1476	0.0215	-0.0438	1			
Reg. move	351982	0.1684	0.3742	-0.0808	0.0486	-0.1142	-0.1068	0.0492	-0.0198	-0.0512	1		
Reg. family	351982	2.1863	1.4379	-0.1711	0.0175	-0.0421	-0.0354	-0.0418	0.0158	-0.0571	0.1771	1	
Firm size	351982	2.6916	0.5988	0.2576	-0.0838	-0.0453	-0.0543	0.0413	-0.0709	0.1072	0.0170	-0.0495	1

A3. Descriptive statistics and correlation table. Probability to stay in the sector models

	N	Mean	Std. Dev.	1	2	3	4	5	6	7	8	9	10
Stay	294020	0.5642	0.4959	1									
Sex	294020	0.7071	0.4551	0.0919	1								
Age	294020	34.7854	9.6274	0.0545	0.0075	1							
Age squared	294020	1302.7120	738.0420	0.0434	0.0094	0.9898	1						
Edu_level	294020	3.0021	0.9933	0.1096	0.0770	0.0222	-0.0027	1					
Edu_track	294020	3.7687	2.9990	-0.0967	-0.0885	-0.0580	-0.0380	-0.4146	1				
Entry mode	294020	4.2282	1.0878	0.0044	-0.0104	0.1858	0.1584	0.0243	-0.0435	1			
Reg. move	294020	0.1670	0.3730	-0.0249	0.0494	-0.1173	-0.1104	0.0534	-0.0233	-0.0572	1		
Reg. family	294020	2.1977	1.4469	-0.0136	0.0147	-0.0463	-0.0396	-0.0432	0.0173	-0.0646	0.1760	1	
Firm size	294020	2.7103	0.5803	0.0402	-0.0812	-0.0341	-0.0397	0.0416	-0.0667	0.0988	0.0188	-0.0436	1

A4. Descriptive statistics and correlation table. Post-entry wage performance (output equations)

	N	Mean	Std. Dev.	1	2	3	4	5	6	7	8	9	10
Wage growth	165853	0.6217	0.4850	1									
Sex	165853	0.7439	0.4365	0.0133	1								
Age	165853	35.2475	9.4092	-0.2222	-0.0111	1							
Age squared	165853	1330.9170	727.0425	-0.2181	-0.0075	0.9907	1						
Edu_level	165853	3.0977	0.9656	0.0415	0.0648	-0.0285	-0.0454	1					
Edu_track	165853	3.5139	2.7831	-0.0282	-0.0554	-0.0144	-0.0014	-0.4041	1				
Entry mode	165853	4.2325	1.0460	-0.1209	-0.0113	0.1722	0.1464	0.0051	-0.0245	1			
Reg. move	165853	0.1588	0.3655	0.0653	0.0482	-0.1355	-0.1270	0.0636	-0.0305	-0.0619	1		
Reg. family	165853	2.1803	1.4139	0.0188	0.0189	-0.0502	-0.0444	-0.0152	-0.0017	-0.0664	0.1719	1	
Firm size	165853	2.7308	0.5674	0.1209	-0.1002	-0.0293	-0.0356	0.043	-0.0685	0.0946	0.0222	-0.0404	1

A5. Post-entry wage performance (selection equations)

Heckman probit	1991-2010	1991-1993	1994-1997	1998-2001	2002-2004	2005-2007
Edu_level (pre-gym)						
Gym	0.0474***	0.0173	-0.0081	0.0967***	0.0359	0.0654*
After-gym (<2 years)	0.1350***	0.1274**	0.0701**	0.1877***	0.1424***	0.0641*
After-gym (≥2 years)	0.1749***	0.1413***	0.0560*	0.2077***	0.2153***	0.2080***
Doctoral	0.0088	0.1061	-0.1026	0.0493	0.0120	0.0495
Edu_track (other)						
Social science	0.0418***	-0.0422	0.0525***	0.0613***	0.0159	0.0128
Natural science, data	0.3630***	0.4094***	0.3837***	0.3654***	0.2931***	0.3471***
Technology	0.1862***	0.1197***	0.1438***	0.1941***	0.1651***	0.2676***
Entry (unrelated JTJ)						
Fresh graduate	-0.0257	-0.1467	-0.0484	-0.0704*	0.0568	0.0010
Non-participant	-0.1501***	-0.2949**	-0.1587***	-0.2244***	-0.1010*	-0.0609
Unrelated UTJ	0.0715***	0.0107	0.0879***	0.0617***	0.0659***	0.0306
Related UTJ	-0.0435***	-0.0821***	-0.0467***	-0.0514***	-0.0710***	-0.0457**
Related JTJ	0.3675***	0.2465***	0.3019***	0.2970***	0.4101***	0.4229***
Regional move	-0.0304**	-0.0707	-0.0556**	0.0571***	-0.1400***	-0.1913***
Region (large reg. centres)						
Stockholm	0.0040	-0.0155	-0.1343***	0.1014***	-0.0731***	-0.0940***
Gothenburg	0.1325***	0.0547	0.0372	0.1613***	0.2169***	-0.0650**
Malmö	0.0542***	-0.1583***	-0.0631**	0.1963***	0.0559**	-0.1203***
Smaller reg. centres	0.0424***	0.0681	0.0349	0.2312***	-0.2229***	0.0511
Periphery	-0.1113***	-0.0257	-0.1015*	-0.0021	-0.0786	-0.4324***
Reg. move*Region (large reg. centres)						
Stockholm	-0.0378***	0.0183	0.0220	-0.1514***	0.0755*	0.1206***
Gothenburg	-0.0837***	-0.1952**	-0.0652	-0.1029***	-0.1004*	0.1182**
Malmö	-0.0738***	-0.1106	-0.0048	-0.2379***	0.0600	0.2240***
Smaller reg. centre	-0.0795***	-0.2105*	-0.1298**	-0.2144***	0.1271*	-0.0188
Periphery	-0.1350***	-0.5752***	-0.0546	-0.2215***	-0.0477	0.1570*
Firm size (2-10 emp)						
1 emp	0.0192*	0.0620	0.0459*	0.0794***	-0.0210	-0.0552**
> 10 emp	0.1303***	0.2109***	0.2275***	0.1033***	0.0583***	0.1471***
National sectoral growth	3.5428***	0.1537*	1.4777***	2.0964***	0.5968***	2.4760***

Note: Demographic controls (sex and age), industry and year dummies as well as a constant are included in the models but not reported. Standard errors are robust and clustered at the individual level. ***(**,*) indicate significance at 1% (5%, 10%) level

Article III

Specialised pervasiveness: Diffusion of IT competences in the Swedish economy

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Abstract: The paper investigates the diffusion of IT competences in the Swedish economy between 2001 and 2010 by looking at patterns of employment and reallocation of individuals in IT-related occupations. Particular emphasis is made on the expansion of IT employment outside of the IT sector. The results indicate that the labour market for IT workers was expanding rapidly during the period. At the same time, there were changes in its organisation with respect to emergence of clusters in the industry space as well as reinforcement of regional hierarchies. With regards to the IT as a general purpose technology, a concept of specialised pervasiveness – the ability of the IT to generate IT-related jobs in all sectors of the economy but with an increasing degree of specialisation and subsequent segmentation of the labour markets for IT workers – was proposed to capture this phenomenon.

Keywords: human capital, competences, diffusion, labour market, general purpose technology, IT

JEL codes: J24, J44, J61, J62

1. Introduction

This paper investigates the distribution and reallocation of workers in the information technology (IT) occupations across industries and regions in Sweden over 2001-2010 with the aim of exploring the patterns of diffusion of IT-related competences in the Swedish economy.

The introduction and spreading of the IT has left a deep structural impact on the modern society leading to, among other things, a vast reorganisation of economic systems, which allowed to characterise the IT as a general purpose technology (Bresnahan and Trajtenberg 1995; Bresnahan 2010). Multiple studies have demonstrated that the IT transformed modern production processes and generated significant productivity gains even in industries and sectors that do not produce with a high IT intensity (for literature reviews see Draca et al. 2007; Cardona et al. 2013).

More specifically, the access to the IT resources has been demonstrated to affect positively the performance of firms in terms of increasing product quality (Thatcher and Pingry 2004), improving workflow (Buhler and Vidal 2005), enhancing flexibility in responding to customer needs (Gunasekaran and Ngai 2004), improving communication with customers and suppliers (Fiala 2005) as well as increasing innovative capacity (Gordon and Tarafdar 2007). In that respect, the availability of the IT resources is an important factor for maintaining competitiveness and achieving sustained growth at a firm level.

At the same time, the diffusion of the IT in the economy generated the demand for new skills and led to the emergence of new (IT-related) occupations and new forms of workplace organisation (Bresnahan et al. 2002; López-Bassols 2002). Nevertheless, the theoretical and empirical discussion in the literature has so far largely focused on investments in the IT capital at the firm and industry levels, changes in and impact of the IT literacy of workers on firm productivity, as well as on the routinisation of certain tasks as an outcome of the IT diffusion and the subsequent substitution of relatively lower skilled workers by highly skilled ones – phenomena known as task-biased and skill-biased technological change (Autor et al. 2003; Adermon and Gustavsson 2015). Much less attention, however, has been devoted to the specialised IT human capital, that is, workers in IT occupations (Hagsten and Sabadash 2014).

This gap in the literature seems to be quite unmotivated though. IT workers play a fundamental role in the process of diffusion and adoption of the IT that fuels technological developments in IT producing sectors and enables the actual realisation of productivity gains in IT using industries (Peneder 2003). The specialised IT human capital allows making better use of the IT capital inputs, which means that a deficit in specialised IT skills not only restricts the IT adoption itself, but also limits potential benefits of adoption at a firm level (Forth and Mason 2004). It is, therefore, important to gain a better understanding of the extent and quality of IT-related labour resources available in the economy.

While some research efforts have been made to describe the patterns of employment and human capital formation in the IT sector (Lundmark 1995; Bienkowska 2007; Hawk et al. 2012; Martynovich and Henning 2016), it should be noted that the IT workforce is not equivalent to employees in the IT sector. A large share of the software development and other IT-related activities take place in many different sectors (Østergaard and Dalum 2007). Thus, focusing solely on employment in the IT sector would underestimate the availability and spread of IT competences in the economy.

The paper builds around three (sets of) research questions. The first question is formulated in the following way: *To what extent does the distribution of the IT workforce between the IT and non-IT sectors reflect the quality of IT workers' human capital?* This question aims at (1) estimating the degree to which the IT workforce is concentrated to the IT sector that is 'paradigmatic' to the IT diffusion, and (2) understanding whether there are differences in skill profiles of IT workers employed in the IT and non-IT sectors.

The second question concerns the regional patterns of IT employment: *In what way does the position of a region in the regional hierarchy affect the regional distribution of the IT workforce between the IT and non-IT sectors?* The motivation for this question is twofold. On the one hand, IT producing industries are characterised by highly uneven locational patterns. It has been demonstrated that the specialised IT activities tend to concentrate in dynamic regions at the top of the regional hierarchy (Lundmark 1995; Martynovich and Henning 2016). On the other hand, the IT adoption by user industries is also known to be spatially biased towards large urban centres (Forman et al. 2005). In that respect, the interaction of supply and demand factors may result in a very different distribution of IT labour between the IT and non-IT sectors at different layers of the regional hierarchy.

While the first two questions have a rather static, or snapshot, perspective on the distribution of IT workers in industrial and geographic spaces, there is also an important dynamic issue. That is, *how are the dynamics of the IT workers reallocation conditioned by sectoral and regional factors?* In other words, are there any differences in how firms in different industries and different regions source IT workers? This is the third question to be addressed in the paper. Traditionally it was assumed that firms in the IT and non-IT sectors compete for the same pool of labour, even if some firms hire IT workers with certain niche skills, while others – with a broader skill portfolio (Hawk et al. 2012). The paper questions this assumption and aims at investigating whether the demand for IT workers is generic or sector-specific, and how this plays out in different regions.

The remainder of the paper is organised as follows. Section 2 provides a brief literature review on the issue of IT as a general purpose technology with a particular emphasis on the impact of IT on the labour markets. In Section 3, data and methodological considerations behind the empirical analysis are reviewed. Sections 4 and 5 present the empirical results with respect to the sectoral and regional patterns of IT workers distribution as well as reallocation of IT workers respectively. Section 6 synthesises the results through the prism of the literature on the general purpose technologies. Finally, Section 7 provides concluding remarks and suggestions for further research.

2. Diffusion of the IT and specialised human capital: A literature review

The diffusion of the IT initiated the processes of industrial restructuring – that is, changes in the production processes within industries – and structural change – that is, changes in the role of different industries in the development of the economy as a whole. It has been demonstrated that the IT possesses the characteristics of a general purpose technology, such as (Bresnahan and Trajtenberg 1995; Bresnahan 2010):

1. *pervasiveness* – having potential applications across a wide variety of products, processes and industries;

2. *technological dynamism* – providing a wide scope for technological improvement and elaboration;
3. *innovation spawning* – facilitating complementarities with existing technologies, fostering complementary innovation in user sectors, and bringing about sustained and pervasive productivity gains.

Indeed, the IT has been demonstrated to be adopted by a wide range of firms in different industries and to be a source of productivity growth at the firm, industry, and national levels (for reviews of the literature, see Draca et al. 2007; Stiroh 2010; Kretschmer 2012; Cardona et al. 2013; Stanley et al. 2015).

The IT diffusion has also left a deep impact on the functioning of the labour market as the latter is the mediator that ensures the adjustment to the new industrial systems (Aghion et al. 2006; Bachmann and Burda 2010). Not least, it led to the restructuring of regional labour markets and changing roles of different regions in the technology-induced economic transformation (Martynovich and Lundquist 2016).

To date, quite many studies focused on the general impact of the IT diffusion on the labour market. For instance, the research focused on the automation of routine tasks and resulting substitution of workers, involved in these tasks, by workers employed in occupations with more abstract task contents – the phenomenon known as the task-biased technological change (Spitz-Oener 2006; Goos and Manning 2007). As abstract tasks put demands on workers' human capital, this substitution resulted in higher relative demand for highly educated workers who possess a comparative advantage in executing these tasks (Böckerman et al. 2016). This, in its turn, boosted labour productivity and output growth in firms and industries (Belloc and Guerrieri 2015).

At the same time, productivity growth depends on the capacity of firms to learn from the new technology, also known as the absorptive capacity (Cohen and Levinthal 1990). Highly skilled labour is, indeed, an important component of this capacity (Liao et al. 2016). But it is not just skilled labour *per se*. Specialised IT labour is a crucial enabler of IT-induced change at the firm level (Forth and Mason 2004). IT workers – who are referred as 'paradigmatic' for the new, digital economy (Ensmenger 2003) – are positioned at the cutting edge of technological development, work with the IT itself, and are at the core of the transformation of production processes at the firm level (Adams and Demaiter 2008). In that respect, it comes as no surprise that the impact of employing IT workers on productivity gains is larger than that coming from generically skilled workers (Hagsten and Sabadash 2014).

One may claim that certain IT tasks may be outsourced to specialised providers of IT services. However, organisational learning has for a long time been seen as a by-product of activities performed at a firm level (Nelson and Winter 1982). For instance, firms learn the value of IT applications and further development opportunities by actually using them (Earl 1996). In that respect, the outsourcing of IT activities leads to the erosion of the IT-related knowledge in firms (McCray and Clark 1999; Willcocks et al. 1999). Therefore, discontinuing in-house IT functions may lead to losing the ability to benefit from future developments in the IT (King and Malhotra 2000).

In that respect, hiring IT workers is instrumental for firms to benefit from opportunities offered by the IT. While the diffusion of IT capital inputs is widely accepted as a showcase of pervasiveness feature of IT, it is the availability of IT workers which ensures realisation of its technological dynamism and innovation spawning features. Therefore, the availability of the IT labour is important for reaping full benefits of the IT-induced transformation.

3. Data and definitions

3.1. Data

Data employed in this paper comes from the linked employer-employee data set – the Longitudinal Integration Database for Health Insurance and Labour Market Studies (LISA) – provided by Statistics Sweden. For each individual registered in Sweden it contains a wide range of personal attributes including age, education, region of residence, etc. Individuals are linked to the establishments of their main employment for which location and industry affiliation, as well as occupations that they are employed at, are known. The occupation data is available from 2001 till 2010, while certain indicators can be traced back to 1990.

For each year between 2001 and 2010 a sample of individuals in the full working age (18-64) was derived. It was further restricted to individuals employed at the moment of data collection in each reference year, which corresponds to the official employment status *gainfully employed* in the data set.[1] The latter restriction was imposed to minimise the probability of including workers participating in short-term/project employment in the sample.

3.2. Defining IT occupations

According to the Swedish Standard Classification of Occupations (SCB 1998), there are five occupations that are directly related to performing IT tasks, namely: (1) computing services managers, (2) computer systems designers analysts and programmers, (3) computing professionals not elsewhere classified, (4) computer assistants, and (5) computer equipment operators. Of these, occupation (1) belongs to the category of Legislators, senior officials and managers, occupations (2) and (3) – Professionals, and occupations (4) and (5) – Technicians and associate professionals. Occupational codes, titles and main tasks descriptions for these are summarised in Appendix A1.

For the purposes of this paper, these five occupations were groups into three occupational categories, namely:

1. *IT managers* – occupation (1) above;
2. *IT professionals* – occupations (2) and (3); and,
3. *IT technicians* – occupations (4) and (5).

These occupational categories are employed in the remainder of the paper.

For each year between 2001 and 2010 a sample of individuals, who were employed in one of these occupations, was derive. The resulting data set included 238,272 unique individuals and 409,904 unique employer-employee matches.[2]

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1 Data in LISA is collected once a year (on December 31). The employment status of an individual reports whether she is employed at the moment of data collection, was employed at some point over the reference year but not at the moment of data collection, or was not at all employed over the reference year.

2 A match here is defined as an employment relation between a particular worker and a particular establishment. Employment lasting for several years is considered as one match.

3.3. The IT and non-IT sectors

In this paper, the IT sector is defined as a sector providing IT services to non-IT firms. According to the Swedish Standard Industrial Classification (SCB 2003), it comprises seven five-digit industries under the activity code 72 ‘computer and related activities’, that is: (1) hardware consultancy, (2) software consultancy, (3) software supply, (4) data processing, (5) database activities, (6) maintenance and repair of office, accounting and computing machinery, and (7) other computer related activities. Individuals are then classified as employed in the IT sector if an establishment, in which they are employed, operate in one of these industries.

Individuals in IT occupations, not employed in one of the IT service industries, are classified as employed in non-IT sectors. The latter are divided into seven industry groups based on the section they belong to in the Swedish Standard Industrial Classification, namely: (1) agriculture, forestry and fishing, (2) mining and quarrying, (3) manufacturing, (4) electricity, gas and water supply, (5) construction, (6) private services (excluding IT sector)[3], and (7) public services. These industry groups are used in the empirical analysis to investigate the employment patterns of IT workers outside the IT sector.

One reservation should be made here. There is, of course, the heterogeneity in employment patterns of IT workers in individual five-digit industries within these industry groups. However, the within-group variation in these patterns is much smaller than the between-group variation. Therefore, since the primary focus is on finding differences between the IT and non-IT sectors, it was decided to stick to the rather aggregated level of industry divisions.

3.4. Regional divisions

The division of individual regions into regional groups was performed in two steps. First, 290 Swedish municipalities were divided into the so-called local labour markets according to the methodology suggested by Statistics Sweden (SCB 2010). These are based on the statistics of commuting between

3 Individuals employed in firms belonging to five-digit industries coded 74501 (Labour placement agencies) and 74502 (Temporary employment agencies) were excluded from the sample. The reason is that being formally employed in one of these industries might be non-indicative: a person classified as employed there might, in reality, work for or be lent to a firm in another industry.

municipalities in the way that maximises homogeneity of commuting patterns within a region while sustaining cross-regional heterogeneity. This level of regional divisions is used to identify individuals for whom becoming employed in an IT occupation is associated with changing a region of employment.

Second, local labour markets are aggregated into the so-called regional families that are used to capture potential hierarchies in the labour market for IT workers. These are defined according to the methodology suggested by the Swedish Agency for Economic and Regional Growth that involves criteria, such as the population size and density, regional business dynamics, the share of individuals with higher education as well as the access to higher education institutions (NUTEK 2004). Six regional families are defined. The first three layers in the regional hierarchy are represented by three Swedish metropolitan areas – Stockholm, Gothenburg, and Malmö. Remaining local labour markets are divided into the large regional centres, smaller regional centres, and peripheral regions.

4. The labour market for IT workers in Sweden

4.1. Industrial segmentation

Over a decade between 2001 and 2010, the total employment in IT occupations in Sweden increased from 113,239 to 143,401 workers, equivalent to 26.64 per cent expansion (Figure 1). With the average annual employment growth rate of 2.66 per cent, this group of occupations expanded more than twice faster than the total employment in Sweden over the same time period (the average annual growth rate of 1.21 per cent). This resulted in the increase of its share in the national employment mix from 2.95 per cent in 2001 to 3.35 per cent in 2010.

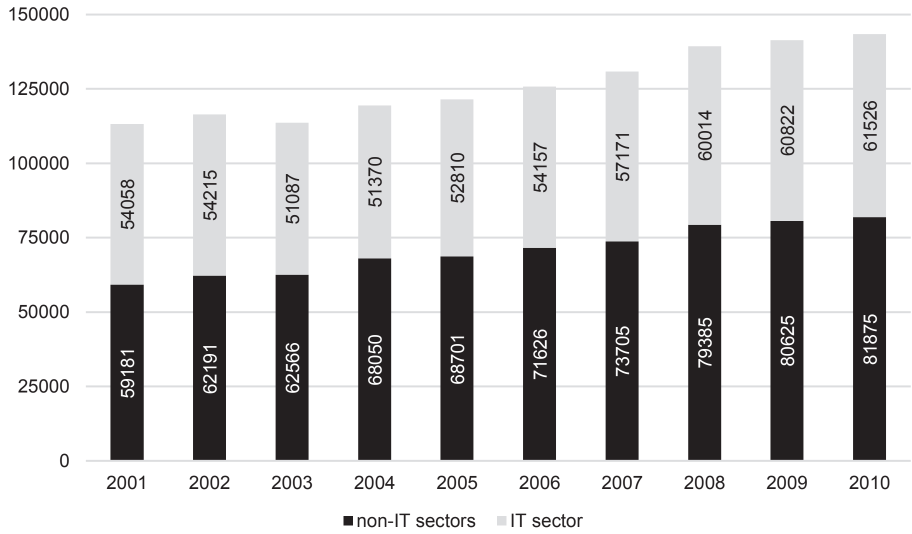


Figure 1. Workers in IT occupations, 2001-2010

The expansion of the labour market for IT workers was, however, unequally distributed between the IT and non-IT sectors: the IT employment growth in the latter was almost three times faster than in the former (the average annual growth rates of 3.67 per cent and 1.45 per cent respectively). Out of 30 thousand new IT jobs generated between 2001 and 2010[4], 75 per cent were created in non-IT sectors. This resulted in the increase of their share in the national IT employment mix from 52.26 per cent in 2001 to 57.10 per cent in 2010.

Within this period, the IT sector was quite severely affected by consequences of the 2001 dot-com crash. Between 2001 and 2003, the sector lost almost 6 per cent of IT employees as a result of the consolidation of the sectoral demand for workers (Martynovich and Henning 2016). At the same time, the IT employment in non-IT sectors continued to grow during this period, even though at a slower pace. In that respect, the collapse of the dot-com bubble was, to a great extent, driven by the financial factors, implying that its severe effects were confined to the IT sector itself. The demand for IT resources, and IT labour in particular, in the economy as a whole did not diminish even in the aftermath of the dot-com crash.

4 In terms of the net employment growth, not the gross job creation.

It should be noted here that these developments were, by no means, unique to Sweden. The similar tendencies have also been reported for, for example, the US (Currid and Stolarick 2010), the UK (IES 2002), Canada (ICTC 2015) and Denmark (Østergaard and Dalum 2006).

While non-IT sectors, in general, demonstrated an outpacing growth dynamics, there was a huge heterogeneity between various industry groups within, both when it comes to absolute numbers of IT workers and growth in IT employment (Figure 2).

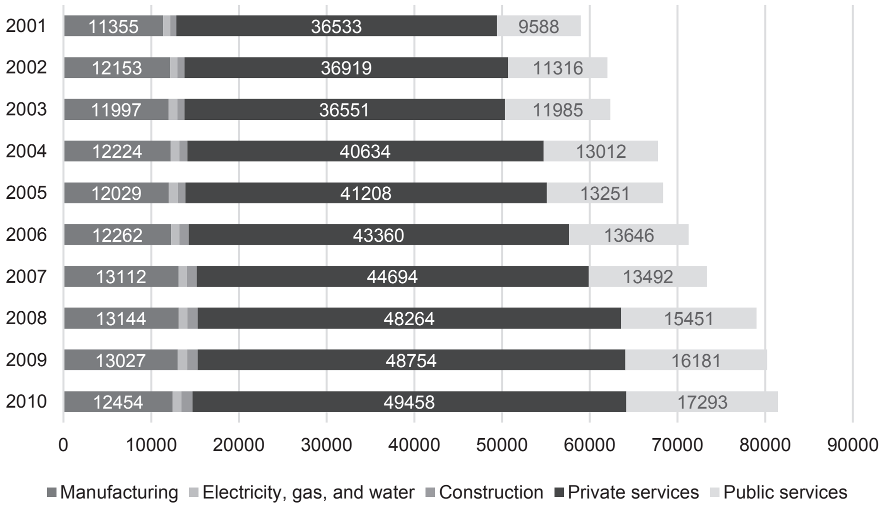


Figure 2. Major employers of IT workers outside the IT sector[5]

Firms in private services industries were, by far, the major IT workforce employers among non-IT sectors, concentrating around 60 per cent of workers throughout the considered time period. This industry group was followed, with a significant gap, by public services providers (21.12 per cent of IT employment in non-IT sectors in 2010) and firms in manufacturing industries (15.21 per cent respectively).

The IT employment in absolute terms increased in all industry groups between 2001 and 2010. This included manufacturing industries, where the

5 IT employment in two industry groups – namely, agriculture and forestry as well as mining and quarrying – is not reported in the figure as their contribution over the whole time period was negligible (between 183 workers, combined, in 2001 and 400 workers in 2010).

total employment shrank in the same period. When it comes to the relative growth, public services demonstrated the fastest expansion in IT employment among non-IT sectors with the average annual growth rate of 6.55 per cent and total growth of more than 80 per cent. To a great extent, this expansion was driven by the digitalisation of routines in public organisations and the increase in the number of public services accessible online. By 2009, 100 per cent of basic public services for business were fully provided online in Sweden; the corresponding value for public services for citizens was 92 per cent (European Commission 2010).

Even though the IT employment increased in all industry groups in absolute terms, it is interesting to check to what extent its expansion reflected the total employment growth in these groups. In other words, whether the number of IT workers increased to the same extent as the total employment. Figure 3 reports the changes in the IT intensity[6] of the employment mix in non-IT sectors.

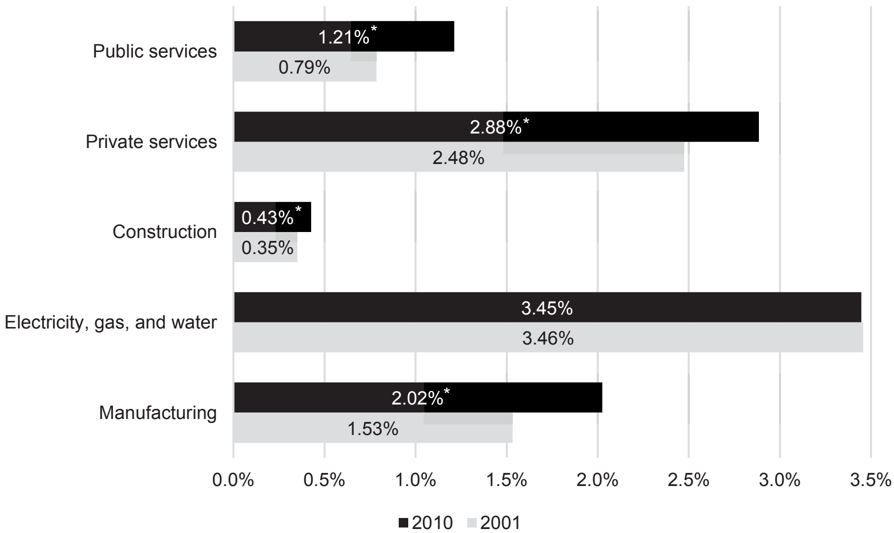


Figure 3. IT intensity of employment mix in non-IT sectors[7]

6 IT intensity is defined as the share of IT workers in the total employment mix in an industry group.

7 Here and further, a superscript * indicates a difference between 2010 and 2001 that is statistically significant at the 5 per cent level.

From this perspective, the picture becomes quite the opposite. Despite the fastest growth in the IT employment growth, public services providers remained one of the least IT-intensive industry groups with 1.21 per cent of workers being employed in IT occupations in 2010. Electricity, gas and water supply industries remained the leaders in the IT intensity of their employment mix, even though the share of IT workers in the sector remained more or less fixed between 3.4 and 3.5 per cent throughout the whole time period. All other industry groups demonstrated, to a varying degree, an increase in IT intensity.[8] Of course, the absolute numbers are not even closely comparable to the IT intensity of the IT sector that was around 60 per cent. Nevertheless, the tendency towards an increasing share of IT workers in the employment mix points towards the recognition of the importance of employing more IT workers in-house.

All in all, the labour market for IT workers expanded fast throughout the 2000s. Somewhat surprisingly, its expansion was particularly pronounced outside the IT sector. Not only industries in non-IT sectors demonstrated faster employment growth in absolute terms, but also almost all of them increased significantly the IT intensity of their employment mixes. These tendencies indicate that the ongoing IT adoption by firms manifested itself not only in investments in the IT capital but also in hiring IT workers. More generally, this points to the diffusion of IT competences in the Swedish economy beyond the core IT sector.

4.2. Human capital quality of the IT workforce

An important question is whether the quantitative expansion of IT labour market and the diffusion of IT competences beyond the IT sector was associated with changes in the quality of human capital of IT workers. Also, it is interesting to check whether there are any differences between the IT and non-IT sectors with respect to the latter. These questions are addressed in this section by looking at the education level and occupation structure of IT workers in different industries.

With regards to the education level (Figure 4), one can observe the increase in the share of highly educated workers in both IT and non-IT sectors. By

8 Including agriculture, fishing, and mining sectors which are not reported here.

2010, the share of IT workers with at least some post-gymnasial education[9] reached 72.23 per cent and 60.01 per cent in the IT and non-IT sectors respectively. While this tendency reflects a general trend towards an upgrade of the education level in the Swedish workforce – the corresponding share among all Swedish workers increased from 31.70 per cent in 2001 to 38.56 per cent in 2010 – the absolute numbers suggest that having at least some education at the post-gymnasial level is a particularly strong prerequisite for IT jobs, both within and outside the IT sector.

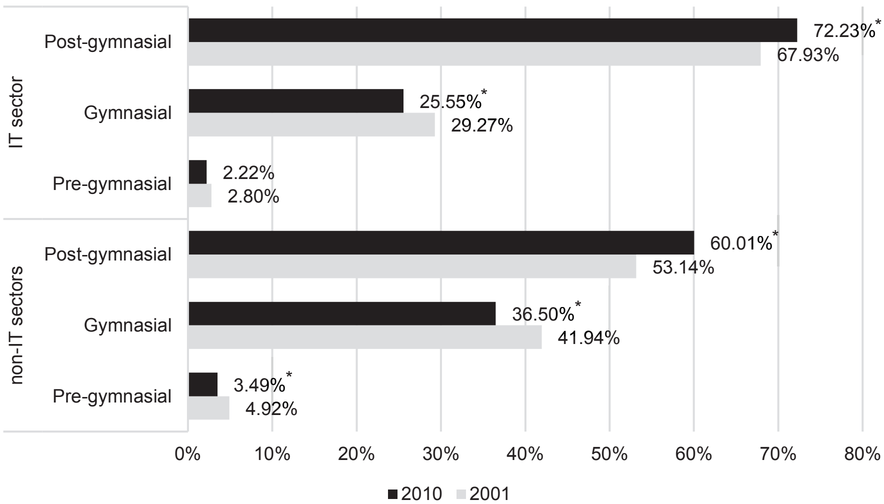


Figure 4. Education level of IT workers

In that respect, advanced education has increasingly become an important factor for becoming employed in an IT position (Warhurst et al. 2006). One possible explanation is that when it comes to IT occupations, the demand for knowledge and skills seem to be frequently shifting as the ongoing technological change renders today's knowledge obsolete tomorrow (Adams and Demaiter 2008). In this situation, the importance of higher levels of education is in signalling to employers that an individual has an ability to learn, and may adapt to changing knowledge requirements in the technologically dynamic field.

9 Gymnasium is the highest level of the secondary education in Sweden. The post-gymnasial education is predominantly the university education, but could also include other forms. Here, it includes having courses at the university level, having completed higher education, as well as obtaining a PhD degree.

When it comes to occupational divisions on the labour market for IT workers (Figure 5), it is IT professionals (highly skilled workers not involved in managerial tasks) that dominate the employment mix in both IT and non-IT sectors. While in absolute terms the labour market for this occupational group became of the equal size in the IT and non-IT sectors in 2010, the IT professionals represent a much higher share of IT workers in the IT sector (77.76 per cent against 58.46 per cent in non-IT sectors).

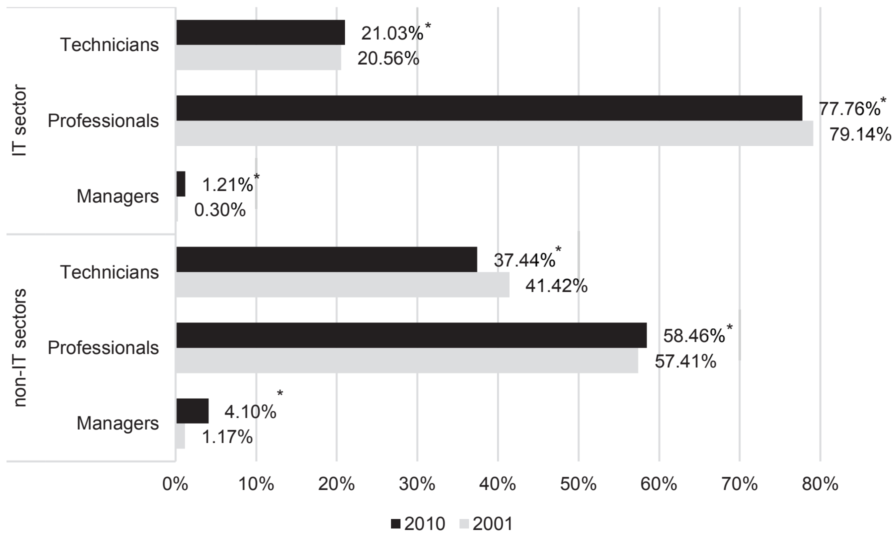


Figure 5. IT workers by occupation

What should be pointed, the relative demand for IT technicians – relatively lower skilled workers – decreased in non-IT sectors over the considered time period. Their share in the IT employment mix decreased by almost four percentage points. Coupled with almost the five-time expansion (in absolute terms) of the IT managers occupational group[10], this points to an increased complexity of tasks in which IT workers in non-IT sectors are involved.

Changing occupational structures reflect the evolution of IT activities in which IT workers are involved. Decentralisation of IT activities, driven by growing importance of networks in the 1990s, increased the demand for business and organisational skills in the IT workforce (Lee et al. 1995; Todd

10 The number of IT managers in non-IT sectors increased from 691 to 3354.

et al. 1995). Developments in the 2000s (most importantly, the explosion of the Internet use for business purposes) has further emphasised that IT workers should embody a mixture of technical, organisational, business, and management skills (Bassellier and Benbasat 2004; Byrd et al. 2006). This trend was reinforced by the rapid obsolescence of technical IT skills making it less strategically valuable to hire technical IT workers (Prabhakar et al. 2005).

All in all, there are two major points to be made with respect to the quality of human capital of IT workers. First, the increased level of education as well as the evolution of occupational structures imply that the quantitative expansion of the labour market for IT workers was complemented with the qualitative upgrade of the human capital in the IT workforce. Second, while non-IT sectors tend to lag behind somewhat with respect to both education level and share of workers in occupations requiring more advanced skills, some convergence is observed between the IT and non-IT sectors. In that respect, the skill requirements of IT prover and IT user sectors are becoming more alike than would be expected (Hawk et al. 2012). This provides another important qualification to the diffusion of IT competences in the Swedish economy.

4.3. Regional distribution of the IT employment

Figure 6 reports the regional distribution of the IT employment (irrespective of the sector) across different levels of the Swedish regional hierarchy. Not surprisingly, Stockholm remained, by far, the major regional labour market for IT workers throughout the whole time period. However, a slight trend towards decentralisation is observed, at least beyond the Stockholm region – from 49.97 per cent of the national IT employment in 2001 to just above 46 per cent in 2010. It was primarily driven by a fast expansion of the labour market for IT workers in Malmö that increased its share by almost 3 percentage points over the 2000s. This corresponds neatly to the period of transformation of Malmö into a ‘knowledge city’ that focuses on attracting technology- and knowledge-intensive activities, particularly in service sectors (Anderson 2014). Taken together though, three Swedish metropolitan areas concentrated around 70 per cent of IT workers throughout the whole time period, with only minor fluctuations over time.

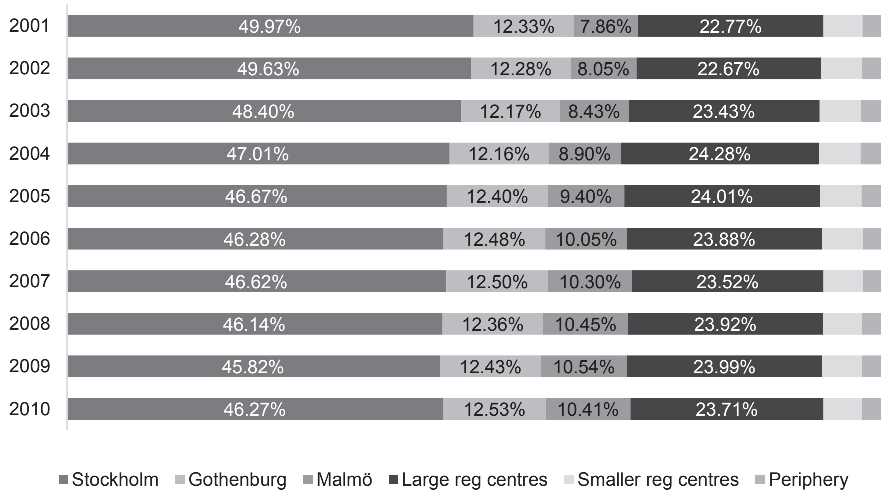


Figure 6. Regional distribution of the IT employment

It was demonstrated elsewhere that over the considered time period the employment in the IT sector was increasingly concentrating to Swedish metropolitan areas (Martynovich and Henning 2016). However, as their share in the total IT employment in these regions remained stable throughout the 2000s, this may indicate that the expansion of the IT employment in non-IT sectors proceeded at a faster pace in non-metropolitan regions. Figure 7 demonstrates that this is, indeed, the case.

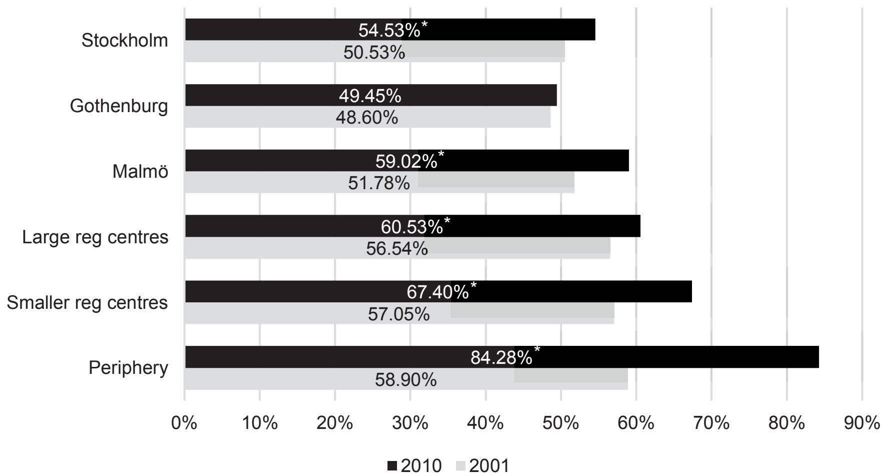


Figure 7. Share of non-IT sectors in the total IT employment

Two observations can be made here. First, the national trend an outpacing expansion of the IT employment in non-IT sectors is observed at all levels of the regional hierarchy. By 2010, in all regions but Gothenburg more than a half of IT workers were employed in non-IT sectors.

Second, there is a very strict hierarchy of regions with respect to the share of non-IT sectors in the regional IT employment. In fact, this hierarchy strengthened significantly over time. That is, the lower a region is located in the regional hierarchy, the higher is the share of non-IT sectors in the regional IT employment mix. In the most peripheral regions, this share reached more than 84 per cent in 2010.

This hierarchy may be driven by the tendency of knowledge-intensive activities to locate in the most dynamic regions at the top of the regional hierarchy, particularly metropolitan areas (Wood 2005; Chadwick et al. 2008). Apart from being regions with the highest potential demand, these regions offer advantages in terms of knowledge flows and knowledge spillovers by combining the localisation of clusters in specific industries with the industrial diversity (Karlsson et al. 2010). In that respect, firms in more peripheral regions may be prone to build up the IT capacity internally as the local supply of IT services is limited. This manifests itself in the higher shares of non-IT sectors in the regional IT employment mix.

Irrespective of sectoral divisions, there is also a rather strict hierarchy with respect to the IT intensity of regional labour markets (Figure 8).

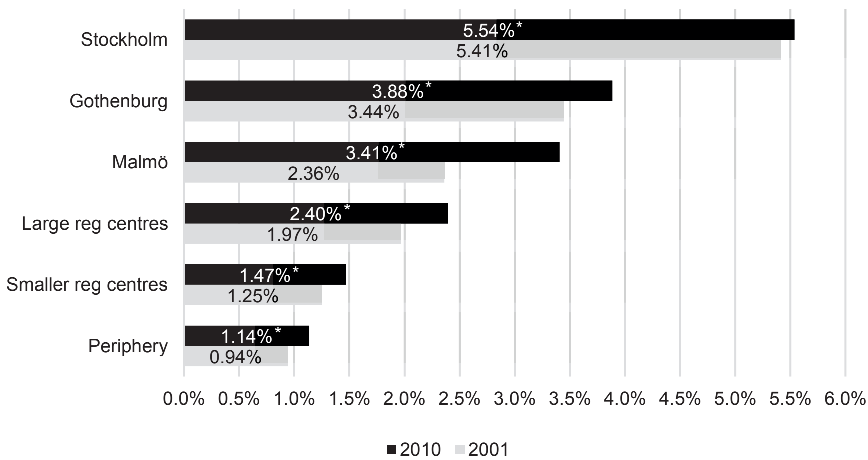


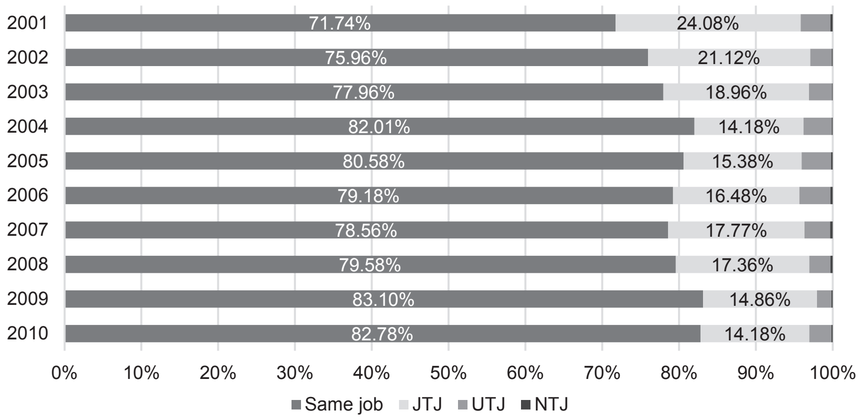
Figure 8. IT intensity of regional labour markets

All regions increased significantly the IT intensity of their employment mixes over the considered time period. However, there is a huge regional variation. For instance, the IT intensity of Stockholm's labour market reached 5.54 per cent by 2010. This number declines with each level of the regional hierarchy, being just 1.14 per cent in the most peripheral regions.

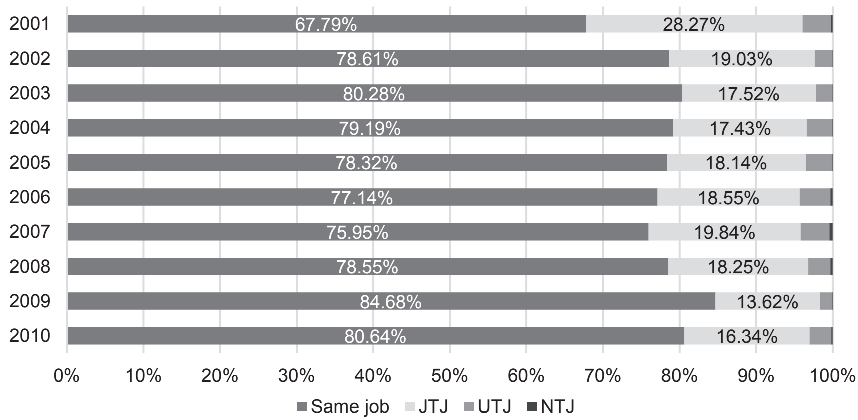
All in all, two conclusions emerge out of the discussion of regional divisions in the labour market for IT workers. First, even though metropolitan areas dominate the scene, the expansion of the IT employment proceeded at the same pace in regions at all level of the Swedish regional hierarchy. All regions increased both the absolute numbers of IT employment and the IT intensity of their employment mixes. Second, the underlying mechanisms of this expansion, however, were rather different. In more peripheral regions the growth in the number of IT workers was fuelled primarily by the expansion of IT employment in non-IT sectors, while it was more balanced in metropolitan areas. This points to strong sorting mechanisms involved in the regional distribution of the IT workforce and, consequently, the spatial diffusion of IT competences in the Swedish economy.

5. IT workers reallocation dynamics

This section focuses on the patterns of IT workforce sourcing across different industries and regions. Figure 9 reports the division of the IT worker stocks in the IT and non-IT sectors for each year between 2001 and 2010 with respect to their employment status in the previous year. In that respect, the distinction is made between workers who stay in the same job between years *t-1* and *t*, workers becoming employed directly from previous employment (JTJ), from unemployment (UTJ), and from non-participation (NTJ). Here, the differentiation between switches from unemployment and non-participation is performed in the following way: if a person was unemployed at *t-1* and was not connected by employment to any firm between *t-1* and *t-3*, she is considered a non-participant. The remaining workers, unemployed at *t-1*, are regarded as becoming employed from unemployment.



(a) non-IT sectors



(b) IT sector

Figure 9. IT workers by their previous employment status

It appears that the job matches of IT workers become increasingly stable as there is an increasing tendency for IT workers to remain employed in the same firm over time. This tendency is particularly pronounced in non-IT sectors. There is some cyclical variation also. Reallocation of workers across jobs has been repeatedly shown to demonstrate pro-cyclical patterns, that is, the number of job switchers increases during the upswing of the business cycle and decreases in the downswing (Bjelland et al. 2011; Hyatt and McEntarfer 2012). An increase on the share of workers remaining employed in the same job in the early 2000s and around 2008-2009 corresponds neatly to the periods of economic downturn in the Swedish economy (reinforced, in case of the IT sector, by the effects of the 2001 dot-com crash). In-between these two periods a slight decrease in the job stability is observed.

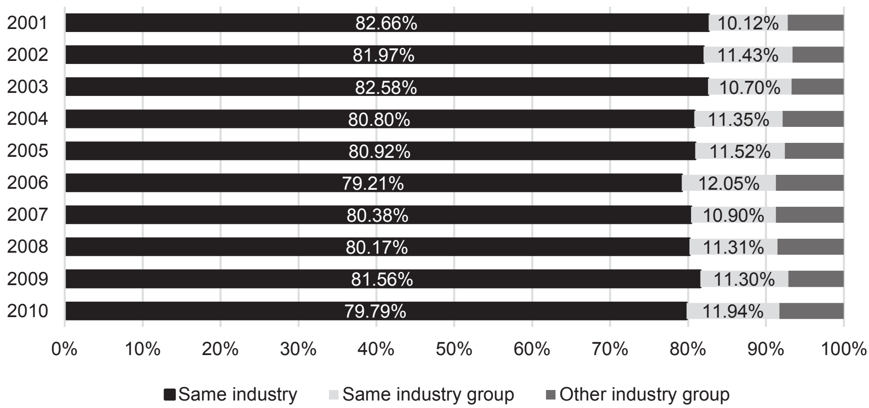
If workers do change jobs, however, they do so predominantly within the industry[11] of their previous employment (Figure 10).[12] The first striking feature here is that, in both the IT and non-IT sectors, most IT workers switch jobs within the industry of their previous employment. In particular, around 80 per cent of job switches happened with the same industry. Additionally, between 10 and 14 per cent of job switches (depending on a year) took place between firms belonging to the same industry group. This left less than 10 per cent of job switches across industry groups, and, thus, across unrelated employment.

This pattern of worker reallocation points to the rather rigid skill structures in the demand for IT workers. In other words, there is a strong component of the human capital specificity involved. Skilled workers possess highly specialised human capital which they acquire through education and on-the-job experience and which allows them to carry out certain tasks (Neffke et al. 2016). Empirical work has claimed that such human capital specificity is observed in the domains of a firm (Becker 1964), an industry of employment (Parent 2000; Sullivan 2010) or to an occupation (Poletaev and Robinson 2008; Kambourov and Manovskii 2009). The tendency workers to switch jobs within the same industry points to the fact, even though the evidence is indirect, that even within the same occupational category industry experience tends to be valuable for employers. One potential explanation to that lies in the nature of tasks that IT workers perform. As it was discussed above, there is an increased demand for IT workers to possess organisational, business,

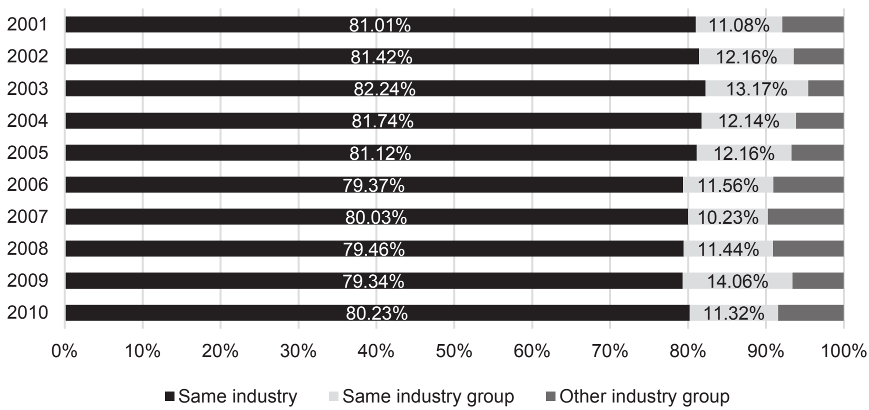
11 An industry here is meant as a five-digit industry in the Swedish Standard Industrial Classification.

12 Here, workers performing a direct switch from previous employment, as well as from unemployment are considered. For the latter, it is the industry of the last employment before becoming unemployed that is accounted for.

and management skills that are likely to be specific to an industry as compared to more technical IT skills which are rather generic.



(a) non-IT sectors



(b) IT sector

Figure 10. Job switchers by the source industry

There are however some notable regional differences in the reallocation of IT workers across industries (Figure 11). As in the case of other indicators discussed above there is a clearly observable hierarchy of regions. That is, the share of within-industry reallocations of IT workers decreases from the highest to the lowest levels of the regional hierarchy. In Stockholm, 89 per cent of IT workers switch jobs within the same industry. This share falls with each level of the regional hierarchy to 51.94 per cent in the most peripheral regions.

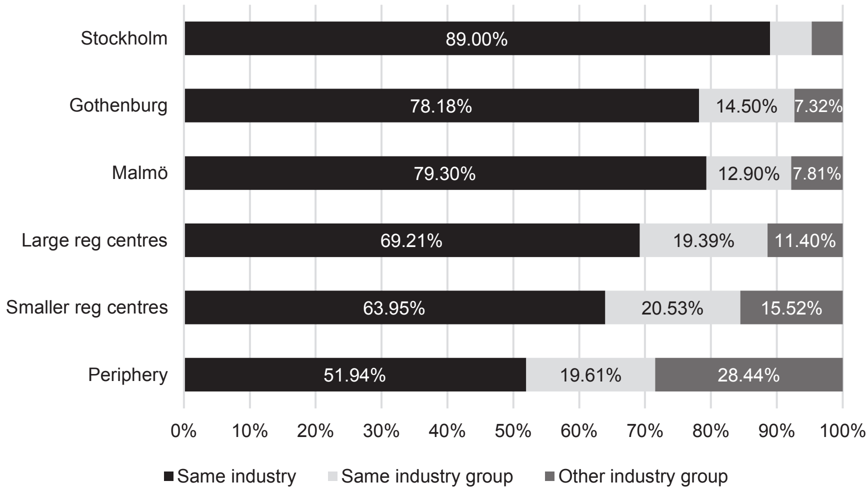


Figure 11. Job switchers by source industry and region (average, 2001-2010)[13]

There are three possible explanations for this tendency. First, Timmermans and Boschma (2013) find indications in the Danish case that firms in large regions need to be more specialised to sustain their competitiveness. In that respect, industry experience of workers would be of a higher value to employers in these regions. Second, and related, explanation is that firms in large regions differ in their IT adoption strategies from firms in smaller regions (Forman et al. 2005). For instance, the latter tend to implement less sophisticated IT applications into their production processes. In that respect, the tasks that IT workers perform may be more generic, which makes the importance of industry experience less. Finally, it is likely to be the issue of the availability of industry-specific skills at the regional level. As the labour market for IT workers is much larger in metropolitan areas, one may expect it to be much easier to find workers with narrowly defined skill profiles (e.g., with a particular industry experience) simply because the pools of available

13 As there are no significant differences across years as well as between the IT and non-IT sectors, the shares are reported as averages over the whole time period and across all industry groups.

workers is larger. In more peripheral regions, where the availability of IT workers is more limited, the demand for industry-specific skills might outpace the supply of these skills leading to regional skill shortages. This might force firms to employ workers who are (potentially) less suitable for jobs they are hired for, at least with respect to their industry experience.

Summing up the discussion, the industrial decomposition of IT workers job switches provides a strong evidence for existence of clusters of worker reallocation. That is, workers tend to switch jobs within the same industry that they have been employed before. With respect to the diffusion of IT competences, it implies that it is not just generic IT skills that are being spread, but rather the process of diffusion is conditional upon accumulation of industry-specific human capital. The regional decomposition, however, suggests that this process is dependent on the nature of IT activities performed in a region and the availability of workers at the regional level.

If it is the availability issue that explains the regional differences, one might expect that employers might search for workers outside of a region of they are not available locally. To check for this possibility, Figure 12 reports the share of workers for whom a job switch is associated with changing a region of employment.

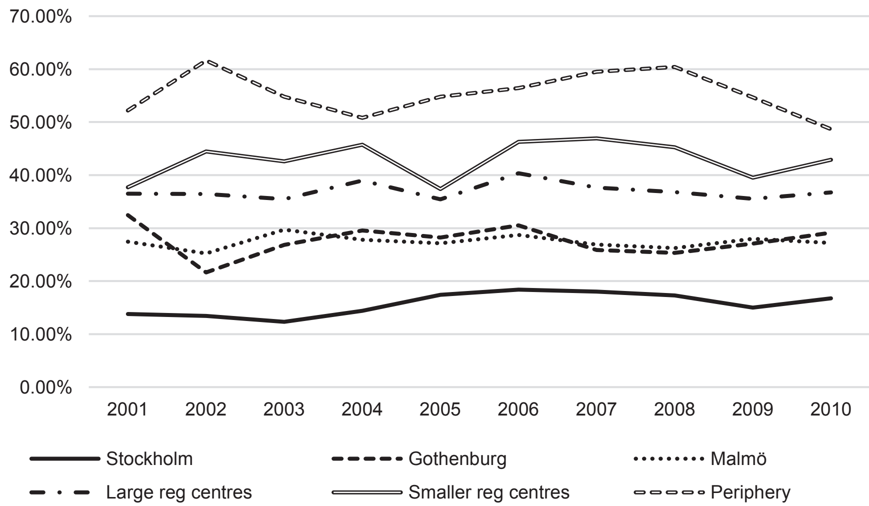


Figure 12. Share of regional movers among job switchers

Yet again, a clear hierarchy of regions is observed here. The more peripheral the region is, the higher is the share of inter-regional movers among job switchers. It varies between 12 and 20 per cent of IT workers becoming employed in Stockholm to more than a half – in the most peripheral regions. The distribution holds the same for both IT and non-IT sectors. This hierarchical distribution points, from another perspective, to the importance of regional availability of IT workers. It has been demonstrated that regional labour markets in more peripheral regions are smaller and have a lower tendency for job-to-job reallocations within the same sector. Here, one can also add that the local availability of IT workers plays an important role in making decisions regarding hiring IT workers.

That is, in dynamic labour markets at higher levels of the regional hierarchy, larger pools of IT workers allow employers to hire local workers who have relevant work experience that allows them to re-use significant portions of their accumulated human capital. When it comes to regions at lower levels of the regional hierarchy, there seems to be higher pressure to hire workers with less suitable backgrounds or from outside the immediate surrounding. With respect to the latter, it has been shown in the literature that worker reallocation across regions is a mechanism of knowledge dissemination across space (Fratesi and Senn 2009; Breschi et al. 2010). Therefore, for firms in more peripheral regions, where the supply of IT workers is rather small, hiring workers from outside the region may help bringing the relevant knowledge. Regional worker reallocation is then an important channel of diffusion of IT competences across regions.

6. Discussion

The results of the empirical investigation in this paper allow generating some interesting conclusions in the light of the literature on general purpose technologies. Scholars in this tradition predicted that the IT, being a pervasive technology, would increasingly penetrate production systems in a wide range of industries through investments in the IT capital, which would eventually lead to generalised productivity gains (David and Wright 1999; Bresnahan 2010). This paper demonstrated that the pervasiveness of the IT realises also through the increased employment of IT workers in both IT providing and IT user sectors.

Industrial decompositions of the labour market for IT workers in Sweden indicated that over the 2000s the IT employment grew rapidly in all sectors, both in absolute terms, but also in terms of the increased IT intensity of employment mixes of different sectors. In particular, 30 thousand new IT jobs were created during the considered time period. Of these, 75 per cent were generated in non-IT sectors, resulting in the decrease of a share of the IT sector in the total IT employment.

This rapid expansion was coupled by the qualitative upgrade of the IT workforce in both IT and non-IT sectors. On the one hand, the share of highly educated individuals was increasing over time at a faster pace than for the economy as a whole. On the other hand, particularly in non-IT sectors, the substitution of technical IT labour by relatively higher skilled IT workers (professionals and managers) was observed. In that respect, not only more IT workers were to be found outside the IT sector, but they became also increasingly skilled and involved in more advanced tasks. In that respect, the diffusion of the IT manifested itself in the ongoing diffusion of (increasingly advanced) IT competences in the Swedish economy beyond the core IT sector. In that respect, the IT demonstrated its pervasiveness also with respect to the labour market dynamics.

At the same time, there are signs of the labour market for IT workers to become increasingly stable over time. The share of individuals remaining employed in the same job between two consecutive years followed the downward trend over the 2000s, despite demonstrating some cyclical variation. However, if individuals did switch jobs, they did so predominantly within the same industry, both in IT and non-IT sectors. This points to the increasing importance of accumulating the industry specific human capital. In other words, the labour market of IT workers was characterised by clusters of worker reallocations in the industry space.

This suggests that the pervasiveness characteristic of the IT as a general purpose technology should be qualified further, at least with respect to the labour market dynamics it generates. Instead of talking of pervasiveness *per se*, one should talk about *specialised pervasiveness*. That is, the IT, indeed, possesses the capacity to generate IT-related jobs in all sectors of the economy (thus, pervasiveness). At the same time, the segmentation of the labour market for IT workers point to the increasing specialisation of IT workers that may limit employment opportunities for them in terms of finding an IT job in another industry (thus, specialised).

The development of the labour market for IT workers was also differentiated spatially as regions at different levels of the Swedish regional hierarchy demonstrated rather different patterns of organisation of the IT labour market. For instance, metropolitan areas played a major role as regional labour markets for IT workers as compared to more peripheral regions, which resembles the situation observed for the IT sector itself (Martynovich and Henning 2016). Nevertheless, despite the strict hierarchies, the expansion of IT employment took place in all regions, both in absolute terms and through increasing the IT intensity of their regional employment mixes. In that respect, the diffusion of IT competences realised not only across industries but also across regions.

Regional decompositions of the labour market for IT workers suggest that an important factor of development of regional IT labour markets is the local availability of the IT workforce. On the one hand, the share of non-IT sectors in regional IT employment mixes increased with each level of the regional hierarchy. It is known that firms involved in knowledge-intensive activities tend to locate in large regions (Wood 2005) due to the combination of the supply and demand factors. In that respect, the increased share of non-IT sectors in the regional IT employment in regions at lower level of the regional hierarchy may be explained by the fact that, in a situation of the limited supply of IT-related activities, firms in these regions are forced to develop IT competences internally. Therefore, mechanisms of expansion of IT competences in the Swedish economy were fuelled more by non-IT sectors in more peripheral regions, while the expansion was more balanced in metropolitan areas.

At the same time, firms located in more peripheral regions tend to employ individuals with less specific skill profile as compared to firms located in large regions. While this might be attributed to the specificity of IT activities in which IT workers are involved in different regions, it might also be the issue of smaller pools of IT workers in the periphery, and thus, availability. In this situation, firms located in smaller regions tend to hire workers from outside their immediate surroundings. This creates a mechanism for IT competences diffusion in space.

With respect to the IT as a general purpose technology, this implies that regional labour markets, with associated structures of supply of and demand for the GPT-related skills, may impose barriers to the successful diffusion of a new technology, particularly to more peripheral regions. Even under assumption that capital markets are absolutely fluid and that investments are made in cutting edge IT capital in peripheral regions, it is the specialised IT labour that is instrumental for making the best use of IT capital being rolled out (Forth and Mason 2004; Hagsten and Sabadash 2014). Limits in availability of specialised human capital may then constrain the possibilities for IT-enabled development. More generally, ensuring the diffusion of the general purpose technology requires not only investments in related capital assets but also corresponding accumulation of the specific human capital at the regional level.

7. Conclusion

This paper investigated the diffusion of IT competences in the Swedish economy by looking at the patterns of IT workers employment and reallocation between 2001 and 2010. The results of the study suggest that the rapid expansion of the labour market for IT workers was accompanied by changes in the organisation of the market with respect to emergence of clusters in the industry space as well as reinforcement of regional hierarchies. It is suggested that with regards to the labour market dynamics the pervasiveness of the IT as a general purpose technology is not universal, but rather specialised.

Analyses performed in this paper are associated with certain limitations which open up space for further research on the topic. First, data restrictions made it not possible to address earlier periods of the IT diffusion. There are indications that the expansion of the labour market for IT workers slowed down in the 2000s (Martynovich and Henning 2016). Therefore, considering the period before 2001 might add an important qualification to the tendencies observed in this paper. Second, more thorough analysis of importance of the industry-specific human capital may be performed. More research on income dynamics and employment prospects of IT workers possessing such human capital in different sectors is desirable. Finally, there is an emerging empirical evidence for firms to backsource IT activities, that is pulling back in-house activities that were previously outsourced (Kern et al. 2002). There are indications that backsourcing becomes one of the key strategies in improving the access to the IT resources at the firm level (for a review, see Dibbern et al. 2004). This makes it interesting to investigate to what extent the outpacing expansion of IT employment outside the IT sector is driven by the trend toward backsourcing, or whether it is a complementary development.

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Article IV

Local or not? Spatial biographies of Swedish IT entrepreneurs

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Abstract: The paper investigates whether spatial biographies of individuals have an impact of their probability to become entrepreneurs as well as post-entry success of firms they establish. In particular, the analysis aims at examining the extent of locational inertia of entrepreneurs, traditionally assumed in the literature, as well as a potential trade-off between individuals' local embeddedness and exposure to diverse knowledge accumulation opportunities across different geographical settings. It is claimed that locational inertia of entrepreneurs may be overestimated. The results of analysis suggest that employment histories of individuals have more information to offer for explaining entrepreneurial behavior than simply the contents and location of the most recent employment.

Keywords: entrepreneurship, mobility, locational behavior, spatial biographies, local embeddedness, external knowledge

JEL codes: J61, L26, L86, M13

1. Introduction

As it is often claimed in the literature, entrepreneurship is predominantly a local event. That is, individuals tend to start businesses in regions where they previously have lived and worked (Dahl and Sorenson 2009; Audretsch et al. 2012). This locational inertia of entrepreneurs has been explained as driven by personal factors (Lafuente et al. 2010; Curran et al. 2016) as well as by opportunities to leverage their social capital which is hardly transferrable to other locations (Varga and Schalk 2004; Kalnins and Chung 2006). Moreover, firms established by local founders tend to enjoy a better post-entry performance (Dahl and Sorenson 2012).

Yet, the locational inertia of entrepreneurs may be overemphasized. Studying the technology-based cluster in Ottawa, Harrison et al. (2004) demonstrated that while most individuals started new firms nearby their immediate past employer, many of them had relocated there to accumulate human and social capital prior to performing an entrepreneurial entry. Investigating an international in- and out-migration of individuals in the Silicon Valley, Saxenian (2006) went as far as characterizing entrepreneurs as the modern-day Argonauts roving the world in pursuit of their own golden fleeces. Frederiksen et al. (2016) demonstrated that the number of geographical relocations an individual performs prior to starting a business has an impact on its subsequent performance.

Indeed, knowledge-based theories of entrepreneurship suggest that individual mobility, being an important mechanism of knowledge transfer across firms, industries and locations, boosts generation, diffusion and exploitation of entrepreneurial opportunities in different markets (Agarwal et al. 2007; Wright 2011). Entrepreneurs draw on the experience and networks established at different firms and places during their entire career; and these condition the spatial organization of activities they initiate with their businesses (Stam 2010). In that respect, benefits of entrepreneur’s local embeddedness, while being supportive to a new firm, may be outweighed by benefits of acquiring diverse knowledge and building networks in different geographical settings. However, spatial biographies of individuals, i.e. histories of spatial relocation, and their impact on entrepreneurial activities have so far received an insufficient attention (Frederiksen et al. 2016). This paper is a step in this direction.

Two research questions are posited. The first question regards the probability of individuals to perform an entrepreneurial entry conditional upon their spatial biographies: *In what way does prior locational behavior of individuals influence their propensity to become entrepreneurs?* This question aims at revisiting the issue of locational inertia and investigating the extent of this phenomenon.

The second question addresses the relationship between spatial biographies of individuals and the performance of new firms they establish: *In what way is the post-entry performance of new firms affected by pre-entry locational behavior of their founders?* This question targets at investigating whether individuals' local embeddedness or their exposure to diverse knowledge accumulation opportunities across different geographical settings matters more for performance of their firms.

To address these questions, the paper focuses on spatial biographies of entrepreneurs in the Swedish knowledge-intensive IT services sector between 1991 and 2010. The sector is of an interest for several reasons. First, being a prominent example of the new entrepreneurial economy (Audretsch and Thurik 2001), the sector has experienced a remarkable growth in terms of new firm formation, employment and value added (Lasch et al. 2013). Second, knowledge-intensive services are increasingly identified as key nodes in knowledge networks fostering processes of knowledge creation and diffusion (Doloreux and Muller 2007). The sector, therefore, serves as a suitable research setting for analyzing the relationship between individual mobility (and associated knowledge flows), on the one hand, and entrepreneurial activity, on the other. Third, while IT services are often characterized as 'footloose' activities (Audretsch et al. 2011), the empirical evidence to date suggests that the spatial pattern of the sector remains city-dominated (Martynovich and Henning 2016). In that respect, it is interesting to investigate the locational behavior of entrepreneurs in the sector with supposedly limited spatial constraints.

Further, the analysis is restricted to entrepreneurial entries performed outside of the Swedish metropolitan areas for the following reasons. First, while many studies focus on entrepreneurship in urban contexts, less is known about entrepreneurial behavior in more peripheral regions (Bürcher et al. 2016). Second, since the knowledge-intensive IT services is a city-dominated sector, peripheral regions provide limited opportunities for acquiring sector-specific knowledge necessary to perform a successful entrepreneurial entry.

At the same time, smaller regions are characterized by more tightly woven social fabric leading to better local networking opportunities (Atterton 2007). Therefore, peripheral regions provide a great setting for analyzing a possible trade-off between local embeddedness and deploying external knowledge. In that respect, a particular emphasis is made on whether spatial biographies of entrepreneurs involved an employment experience in metropolitan areas which are the hotspots for knowledge accumulation in the sector.

Provided the setting discussed above then, the paper contributes empirically to the discussion on locational behavior of entrepreneurs by suggesting a methodology for constructing detailed spatial biographies of individuals and analyzing their impact on propensity of individuals for entrepreneurship and post-entry success of their businesses.

Conceptual contribution of the paper lies in demonstrating that the employment histories of individuals, not least their spatial biographies, have more to offer than the contents and location of the most recent employment. It is demonstrated that individuals with broad spatial biographies are, in certain cases, more likely to become entrepreneurs, and more successful ones for that matter, than local individuals. In that respect, locational inertia of entrepreneurs is, to a certain extent, overestimated.

The remainder of the paper is organized as follows. In Section 2, a brief review of the relevant literature is performed, while research questions formulated in the introduction are developed into a series of hypotheses to be tested. Section 3 provides a detailed discussion of the data, definitions, and methods employed. Section 4 presents a descriptive evidence on entrepreneurship in the Swedish knowledge-intensive IT services sector. Modeling results are presented in Section 5. Section 6 positions the major findings through the lens of current debates in the literature and provides concluding remarks.

2. Locational behavior of individuals and entrepreneurship

Process of entrepreneurship is spatially uneven (Stam 2010). Empirical evidence suggests that entrepreneurship is, to a great extent, a local event (Sorenson and Audia 2000; Audretsch et al. 2012). That is, new firms tend to be established and stay in regions where their founders have previously lived and worked (Pellenbarg et al. 2002; Michelacci and Silva 2007). In that respect, the question for an entrepreneur is often what kind of firm to start in a given location, rather than selecting a location for a given firm (Stam 2007).

This locational inertia of entrepreneurs might, on the one hand, be attached to their willingness to remain close to family and friends (Gimeno et al. 1997; Dahl and Sorenson 2012) and/or attain a certain quality of life (Marcketti et al. 2006; Lafuente et al. 2010). Such personal motivations often outweigh market-related locational factors (Curran et al. 2016).

On the other hand, entrepreneurs are economically and relationally embedded in places (Dahl and Sorenson 2009). This embeddedness stems from the location-specific social capital in the form of localized network externalities which are tangible assets with a limited transferability across space (Varga and Schalk 2004; Kalnins and Chung 2006). It improves the access to information and financial resources at a pre-entry stage (Shane and Stuart 2002; Nijkamp 2003) and plays an important role in continuing operations of new firms as their development is conditional upon establishing linkages to customers and suppliers as well as hiring employees. These are easier when an entrepreneur has an extended local network (Westlund and Bolton 2003). Local embeddedness may be particularly important in more peripheral regions as these are characterized by stronger informal networks (Atterton 2007; Dahl and Sorenson 2012).

In that respect, embeddedness in local social networks may be expected to lead to an increased quality of local knowledge exchange (Bürcher et al. 2016) as well as reduced risks associated with entrepreneurial entries (Westlund and Bolton 2003). This leads to the first two hypotheses to be tested in this paper:

> ***Hypothesis 1a:*** *Individuals are more likely to perform local entrepreneurial entries*
>
> ***Hypothesis 1b:*** *Local entrepreneurial entries enjoy better post-entry performance*

At the same time, entrepreneurial entries benefit from tapping into a variety of knowledge sources across space (Lorentzen 2008; Sacchetti 2009). It provides the access to new non-redundant knowledge (Maskell 2014) and allows avoiding risks of spatial lock-in and short-sightedness of learning (Liu et al. 2010). In that respect, an individual mobility across locations has been proposed as a channel of knowledge flows to newly founded firms (Saxenian 2006; Agarwal et al. 2007). These flows are related to entrepreneurial entries and their performance (Helfat and Lieberman 2002; Frederiksen et al. 2016).

Previous studies of locational behavior of entrepreneurs suggest that their locational inertia may be overestimated. It is possible that individuals are not so much rooted in place but rather have histories of spatial relocation in their pre-entry careers through which they accumulate knowledge necessary for establishing a new firm (Harrison et al. 2004; Reuschke 2014). Moreover, mobile individuals, acquiring knowledge in different geographical settings, may make the most promising entrepreneurs (Dahl and Sorenson 2012; Frederiksen et al. 2016).

Indeed, geographical mobility exposes individuals to new opportunities, which may be recognized and exploited, in different regional markets (Wright 2011). Besides, a broad spatial experience of entrepreneurs allows them to expand their social network with potential customers, suppliers, etc. In that respect, broad networks, and particularly their spatial configurations (Bahlmann 2015), provide individuals with a better position for discovering and exploiting entrepreneurial opportunities. Yet again, because of limited knowledge exchange opportunities, new firms in more peripheral regions are particularly dependent on external knowledge sources (Bürcher et al. 2016).

Therefore, systematic differences may be expected in individuals' propensity to become entrepreneurs as well as in performance of their firms between those with and without histories of spatial relocation. This provides the basis for the next two hypotheses.

> ***Hypothesis 2a:*** *Individuals' histories of spatial relocation affect their propensity for entrepreneurship*
>
> ***Hypothesis 2b:*** *Post-entry performance of new firms is conditional upon spatial biographies of their founders*

Provided that a history of spatial relocation matters for knowledge acquisition and building social networks, it may be important not only whether an individual relocated but also *where* she relocated. Prospects of learning depend on the combination of individuals' capacities and motivations, on the one hand, and an access to jobs offering opportunities for acquiring marketable assets, such as tacit knowledge and social networks, on the other (Gordon et al. 2015). In that respect, metropolitan areas may play a particularly pronounced role.

Metropolitan regions, characterized by high densities of human capital and knowledge spillovers, provide potential entrepreneurs with superior opportunities for learning and building social ties that may constitute the basis for a new firm (Acs et al. 2009; Gordon 2015). In that respect, these areas may act as attraction hotspots for individuals willing to work in the sector, acquire sector-specific knowledge, and more generally 'get on' in their careers (Glaeser and Saiz 2003). Relocation to metropolitan areas is then a precondition for if not a mechanism of a rapid achievement of their career oriented goals (Mulder and van Ham 2005). This allows characterizing such regions as 'escalator regions' (Fielding 1992).[1]

Having acquired relevant knowledge, individuals often relocate to more peripheral regions, where learning opportunities are fewer, but accumulated knowledge assets can be deployed in a more efficient way (Gordon et al. 2015). What is interesting, stepping off the 'metropolitan escalator' is often associated with performing an entrepreneurial entry in a destination region (Findlay et al. 2000; Reuschke 2015). Fielding (1989) referred to this as an export of the metropolitan 'entrepreneurial culture'.

In that respect, employment experience in a metropolitan area, and superior opportunities for learning and networking associated with that, may compensate for the absence of social capital in a region where entrepreneurial entry is performed. Provided that an individual has obtained advanced knowledge, she will be in a better position to identify and exploit entrepreneurial opportunities in a destination region. This suggests the third set of hypotheses to be tested.

> ***Hypothesis 3a:*** *Metropolitan employment experience increases the probability of an individual to perform an entrepreneurial entry in a peripheral region*
>
> ***Hypothesis 3b:*** *Post-entry performance of entrepreneurial entries is positively associated with employment experience of firm founders in metropolitan areas*

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[1] Originally, the idea of a 'metropolitan escalator' applied to global cities (e.g., London). More recent research suggests that escalator effects are observed also for second-order metropolitan areas (Champion et al. 2014).

3. Data and methodological considerations

3.1. Data and definitions

The data employed in this paper comes from the Longitudinal Integration Database for Health Insurance and Labor Market Studies provided by Statistics Sweden. For each individual registered in Sweden it contains a set of personal attributes as well as linkage to establishment of her main employment for which a type of employment, location and industry affiliation are known.

Location of individuals and firms is recorded at the municipality level. For purposes of the analysis, 290 Swedish municipalities are aggregated to 90 local labor markets (LLMs)[2]. This allows minimizing the risk of recording changing commuting patterns between municipalities as a spatial relocation. Metropolitan areas are then defined as LLMs of three largest Swedish cities, namely Stockholm, Gothenburg and Malmö. Remaining 87 local labor markets are considered as non-metropolitan regions.

The sampling frame of the database is the complete set of individuals and firms in the knowledge-intensive IT services sector. The latter includes five 5-digit industries under the activity code 72 'computer and related activities' according to the Swedish Standard Industrial Classification: (1) hardware consultancy; (2) software consultancy; (3) software supply; (4) data processing; (5) database activities.

Entrepreneurial entries are defined as new legal organizations (Frederiksen et al. 2016) and were identified in two steps. First, for each year between 1991 and 2010 the sample of all establishments and firms (establishments belonging to the same parent firm are linked through a shared firm identifier) operating in the knowledge-intensive IT services sector was derived. Second, for each year *t* new entries were identified according to the following rule: (1) an identifier for an establishment existed at year *t* but not year *t-1*, and (2) an identifier of a firm, to which an establishment was linked, existed for year *t* but not year *t-1*. The second condition ensured that establishments entering

2 LLMs are defined by the statistics on commuting between municipalities in the way that maximizes the self-containment of commuting flows.

through incumbent firms' expansion were excluded. As a result, 25457 entrepreneurial entries were identified over the considered time period.

Based on the income information distinguishing between incomes derived from wages and from business activities, founders behind each entry were identified. An entrepreneur is, therefore, defined as a person establishing a new firm. The sample was further restricted to entries with one founder. While new firms with multiple founders represent an interesting case from the perspective of the knowledge-based view of entrepreneurship – they might benefit from recombination of knowledge and social capital accumulated by all firm founders – considering them would require composing combined measures of their founders' backgrounds, bringing unnecessary complications into the analysis. 1586 entries were, thus, excluded from the sample. The resulting dataset included 23871 entries, of which 7492 (31.4 per cent) were performed in non-metropolitan regions.

3.2. Dependent variables and modelling issues

The first dependent variable, a propensity of an individual to become an entrepreneur, is defined as a binary variable indicating whether an individual becomes a founder of a new firm at year *t*, which did not exist at year *t-1*. In order to account for the possibility that individuals' spatial histories may be related to any type of job switches (entrepreneurial entry vs. getting a paid job), a reference group to individuals becoming entrepreneurs at time *t* consists of individuals getting a paid job in the sector at time *t* (Nanda and Sørensen 2010). Individuals, who perform a change in their job situation at certain time, may be characterized by different opportunity structures and risk attitudes as compared to individuals, who do not (Sørensen and Sharkey 2014). At the very least, the latter individuals are more likely to be satisfied with their current job situation, meaning that starting a business at a certain point in time is not in the list of their options. Besides, as the data at hand does not allow to define the motivation behind starting a business, it is at least possible to consider that as partly driven by a decision to change a current job situation. Given these considerations, it was job switchers, and not the whole working population, which was decided as a reference group.

Formally, the first dependent variable is operationalized in the following way:

$$\text{Entrepreneur} = \begin{cases} 1, \text{if an individual starts a new firm in IT services at time } t \\ 0, \text{if an individual gets a new job in IT services at time } t \end{cases}$$

The impact of spatial biographies of individuals on their propensity for entrepreneurship is then estimated as discrete-time event history models using logistic regression (Nanda and Sørensen 2010).

The second dependent variable, a post-entry performance of a new firm, is operationalized as its survival time and measured as the number of years the firm exists after entry. Firm survival rates are modelled using the semi-parametric Cox proportional hazard model (Cox 1972). The advantage of this widely used approach in survival analysis lies in its flexibility and robustness: neither does the model necessitate any assumptions about the distribution of survival rates, so that no restrictions are imposed on a shape of the hazard function, nor does it require estimating the baseline hazard.

Formally, the model is specified in the following way:

$$h(t) = h_o(t) * e^{X\beta}$$

where $h(t)$ – is a hazard function at time t after entry, $h_o(t)$ – a baseline hazard function (an unspecified hazard function reflecting the risk of failure provided that a firm survived until time t), X – a vector of covariates, and β – a vector of coefficients. Parameters in the vector β are estimated using the partial likelihood method, which focuses on the ordering of establishment exits and calculates the conditional probability of failure for firms that are observed to exit.

As the data is available until 2010, all firms that still exist at this year are right censored at that time point but are included to the analysis prior to this date.

3.3. Operationalizing spatial biographies of individuals

The spatial organization of entrepreneurial activities, initiated by individuals, are defined by their employment biographies (Stam 2010). It was, therefore, necessary to come up with an operationalization of individuals' experience prior to starting a new firm. This was performed by generating six-year employment histories for all individuals employed in the sector between 1991 and 2010[3]. These included an employment status, regions of employment and residence, an industry of employment, etc. Based on this, several

3 The annual data is available from 1985, which allows going back maximum six years from the first year in the considered time period (1991).

variables capturing biographies of individuals were specified. These included three variables describing their spatial biographies.

The first, *Entry location*, describes whether an individual switched regions immediately prior performing an entrepreneurial entry. It is formally defined in the following way:

$$\text{Entry location} = \begin{cases} 0, \text{if } region_t = region_{t-1} \\ 1, \text{if } region_t \neq region_{t-1} \text{ and } region_{t-1} \text{ is a metropolitan region} \\ 2, \text{if } region_t \neq region_{t-1} \text{ and } region_{t-1} \text{ is a non} - \text{metropolitan region} \end{cases}$$

where $region_t$ – local labor market region where an entry is performed at year *t*, $region_{t-1}$ – local labor market of employment (for employed individuals) or residence (for unemployed individuals) at year *t-1*. Three possible situations are described by the following qualitative categories: local entrants (if *Entry location*=0), movers from metropolitan regions (if *Entry location*=1), and movers from non-metropolitan regions (if *Entry location*=2).

The second spatial biography variable, *Prior relocation*, captures individuals' relocation patterns over six years of recorded employment history. Four relocation patterns are defined:

1. *stayers* – individuals who remained in the same region;
2. *one-time movers* – individuals who switched employment regions once;
3. *onward movers* – individuals who switched employment regions several times, without returning to the region of employment at the first year of recorded employment history;
4. *returners* – individuals who switched employment regions but returned to the region of employment at the first year of recorded employment history.

This variable is an extended measure of spatial biographies of individuals.

Finally, the third spatial biography variable, *Metropolitan employment tenure*, is simply the number of years (within six years of recorded employment history) that an individual spent being employed in a metropolitan area. Appendix A1 illustrates possible interactions between three spatial biography variables.

One important reservation should be made with regards to the spatial biographies of individuals and their impact on entrepreneurial behavior. The nature of the data does not allow distinguishing between joint motivations of individuals to relocate and to start a business. There are two possible situations. First, a decision to relocate might come first (e.g., for personal reasons). It is then possible that the decision to start a new firm may be driven by, for example, an absence of suitable employment opportunities in a destination region. In other words, starting a new business is an outcome of spatial relocation. On the other hand, an individual might have identified an entrepreneurial opportunity in a certain region prior to making a decision to relocate there. That is, an entrepreneurial opportunity is driving a relocation decision. Therefore, the association between spatial biographies of individuals and their entrepreneurial activities should be interpreted with caution.

3.4. Control variables

The extent to which mobility of individuals can induce entrepreneurial activities may vary with individuals' capacity to coordinate new knowledge and their knowledge acquisition efficiency (Qian and Acs 2013). Prior experiences expose individuals to different opportunity costs structures (Gimeno et al. 1997) and affect their potential to capitalize on knowledge flows (Cohen and Levinthal 1990). Thus, they influence the probability of recognizing and exploiting entrepreneurial opportunities (Shane 2000). Therefore, several control variables were included to account for effects previously demonstrated in the literature to have an impact on entrepreneurial behavior.

First, a dummy variable (*Higher education*) is added to control whether an individual has been involved in higher education. Second, as previous entrepreneurial experience has an impact on an ability to identify and exploit entrepreneurial opportunities (Audretsch et al. 2006), a dummy variable (*Entrepreneurial experience*) is introduced to capture whether an individual has established a firm within six year of recorded employment history (in other words, whether an individual possesses an entrepreneurial capital). Third, knowledge about technology, competitors, customer needs, etc. can often be learned only through industry participation (Klepper 2001). Besides, individuals with industry experience can make use of social networks from their prior settings (Colombo and Grilli 2005). To control for possible effects of prior employment in the sector, a variable measuring years of employment experience in the knowledge-intensive IT services (*Sector experience*) is included in the analysis[4]. Finally, length of unemployment (in years) prior to starting a firm or getting a job in the sector is recorded.

Besides, previous research highlighted the impact of demographic characteristics of individuals on their entrepreneurial decisions. Therefore, gender effects are captured with a dummy variable (Sørensen 2007). Also, potential linear and non-linear effects of age are captured by additional control variables (Dunn and Holtz-Eakin 2000).

In survival models controls for employment in a new firm at the year of entry as well as total employment in the IT services sector in a region of entry are included.

4. Entrepreneurial activity in the Swedish knowledge-intensive IT services sector

This section presents a descriptive evidence on the extent of entrepreneurship in the Swedish knowledge-intensive IT services sector between 1991 and 2010. To start with, Figure 1 illustrates the total amount of entrepreneurial entries in the sector projected against the sectoral employment.

There is a clear upward trend in both total employment and number of new entries. The latter increased from 196 in 1991 to 2389 in 2010. Quite pronounced is the rapid increase in the number of new entries between 2001 and 2004. Interestingly, this surge in entrepreneurial activity coincided with an overall contraction of the sector in the aftermath of the 2001 dotcom crash. Possible explanation to this may be that adverse labor market conditions forced individuals into entrepreneurship since other employment options were not readily available (Bergmann and Sternberg 2007; Hessels et al. 2008). For individuals, laid off their jobs as the dotcom crash hit the sector, starting a business could be the only opportunity to remain in the sector.

4 As this variable is available in the original dataset, it captures the total employment experience, not only employment experience over six years of recorded employment history.

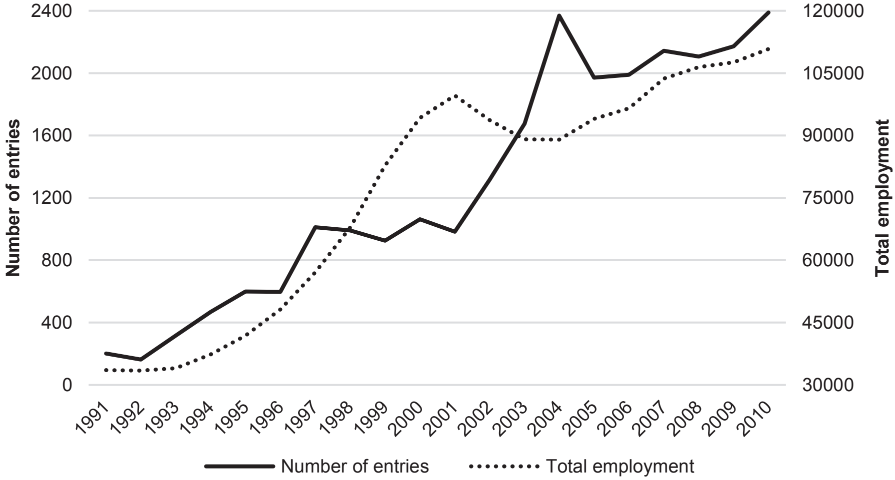

Figure 1. Entrepreneurial entries and employment in the Swedish knowledge-intensive IT services sector

Distribution of entrepreneurial entries across Swedish regions was, however, highly unequal as demonstrated in Figure 2.

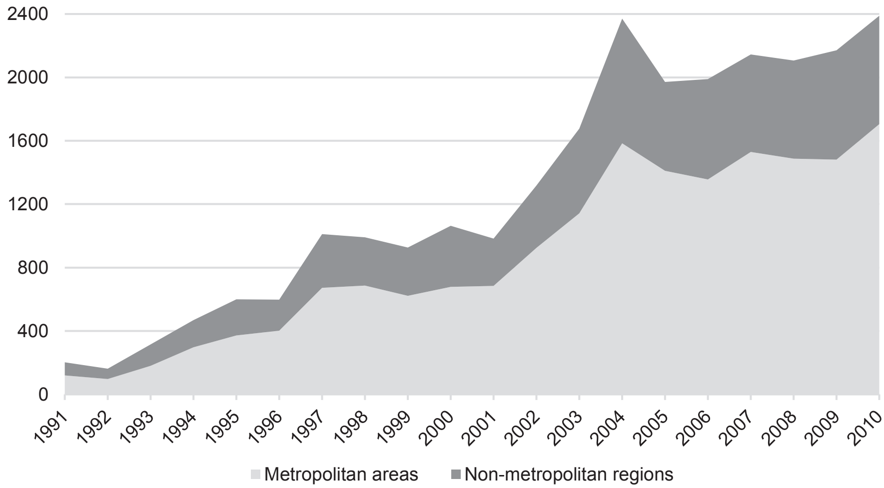

Figure 2. Entrepreneurial entries within and beyond metropolitan areas

Between 1991 and 2010, 68.5 per cent of new entries were performed in metropolitan areas. The share of such entries increased from 58.9 per cent in

1991 to 71.4 per cent in 2010. This corresponds to the previously documented pattern of an increased concentration of the knowledge-intensive IT services to metropolitan areas (Martynovich and Henning 2016). It should be noted, however, that the number of entrepreneurial entries in non-metropolitan regions was on the constant rise, increasing from 83 in 1991 to 684 in 2010.

With respect to entry location, a stark difference is observed between metropolitan and non-metropolitan regions (Figure 3).

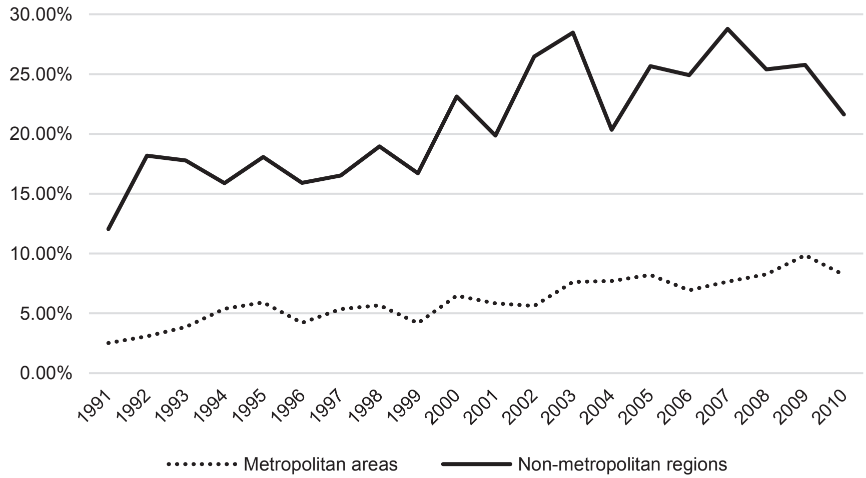

Figure 3. Entrepreneurial entries by non-local individuals

The share of entries by non-local individuals (that is, individuals who were not employed or residing in a region of entry at *t-1*) was significantly lower in metropolitan regions. In particular, between 1991 and 2010, around 7.2 per cent of entries in metropolitan areas were performed by individuals who relocated at the year of entry. In contrast to that, almost a quarter (22.9 per cent) of new firms in non-metropolitan regions were established by non-local individuals. The slight upward trend in the share of non-local founders may be observed over time. Nevertheless, it is clear that performing an entrepreneurial entry is predominantly a local event.

Finally, with respect to entrepreneurial entries in non-metropolitan areas, which are of the main interest in this paper, distribution of new firms according to the origin of their founders is presented in Figure 4.

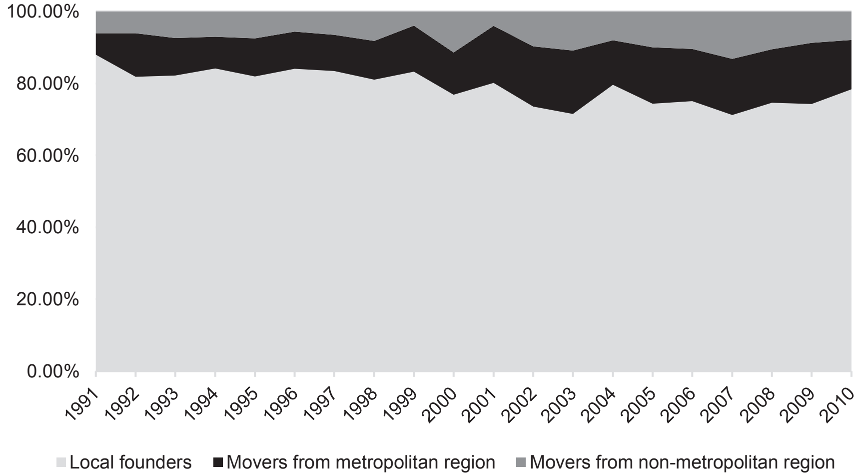

Figure 4. Entrepreneurial entries in non-metropolitan regions

Between 1991 and 2010, 14 per cent of entrepreneurial entries were performed by individuals relocating from metropolitan areas. Such entries were more common that those associated with a relocation between non-metropolitan regions (8.9 per cent of all entries). This difference has slightly increased over time in favor of entries from metropolitan areas.

In what follows, the descriptive evidence on relocation patterns of entrepreneurs in the knowledge-intensive IT sector is complemented by the analysis of the impact of individuals' spatial biographies on their propensity to become entrepreneurs as well as post-entry success of new firms.

5. Regression analysis

5.1. Transitions into entrepreneurship

Table 1 reports the results of estimating propensity of individuals for entrepreneurship conditional upon their spatial biographies. Appendix A2 provides a sample summary as well as a correlation table for variables included in the analysis.

Logistic regression	Model 1	Model 2
Entry location (Local entrant)		
Mover from metro	0.7273*** (0.0287)	0.5761*** (0.0366)
Mover from non-metro	0.4937*** (0.0209)	0.3209*** (0.0246)
Prior relocation (One-time mover)		
Stayer	0.8624*** (0.0272)	0.7885*** (0.0260)
Onward mover	1.0735 (0.0423)	0.9856 (0.0540)
Returner	1.3268*** (0.0500)	0.9757 (0.0497)
Entry location*Prior relocation (One-time mover)		
Onward mover from metro		1.2692* (0.1230)
Onward mover from non-metro		1.5135*** (0.1615)
Returner from metro		1.7881*** (0.1672)
Returner from non-metro		2.6428*** (0.2807)
Higher education (no)	0.8830*** (0.0225)	0.8831*** (0.0225)
Sector experience	0.9114*** (0.0061)	0.9104*** (0.0061)
Unemployment spell	1.0743*** (0.0072)	1.0719*** (0.0072)
Entrepreneur experience (no)	4.3958*** (0.1347)	4.3774*** (0.1343)
Individual controls (age, age^2, sex)	Yes	Yes
Industry dummies	Yes	Yes
Year dummies	Yes	Yes
Region dummies	Yes	Yes
Pseudo-R^2	0.1235	0.1252
N	101789	101789

Odds ratios are reported. Values above 1 indicate an increased probability of becoming an entrepreneur. Robust standard errors clustered at the individual level are reported in brackets. ***(**,*,$^{\perp}$) indicate significance at 0.1% (1%, 5%, 10%) level. Since odds ratios are reported, a significant value indicates a significant difference from 1. For categorical variables and dummies values in the brackets are reference values. (Fielding 1989)

Table 1. Transitions to entrepreneurship

Local individuals in non-metropolitan regions have the highest propensity to become entrepreneurs (*Entry location*). Probability to start a new firm as compared to obtaining a paid employment position is 27 per cent lower for individuals moving from metropolitan areas to a non-metropolitan region, and 51 per cent lower for movers between non-metropolitan regions (Model 1). In that respect, while individuals relocating from metropolitan areas are more likely to become entrepreneurs than other movers, they are still not as entrepreneurial as their local counterparts.

Considering more detailed spatial biographies of individuals (*Prior relocation*), however, adds an important qualification to this result. Individuals, remaining employed in the same region over six years of recorded employment history (stayers), tend to have the lowest probability to become entrepreneurs (14 per cent less likely than one-time movers). The most likely entrepreneurs are returners: they have 33 per cent higher probability to choose an entrepreneurship option for paid employment than one-time movers (and, 54 per cent higher than stayers). In that respect, while individuals tend to start new firms in regions where they were employed or resided at least a year prior to an entry, it is important to account for history of their previous relocations to be able to estimate more accurately the extent to which being local matters for probability of becoming an entrepreneur.

Moreover, an entry location tends to have significantly different effect on the propensity for entrepreneurship conditional upon individuals' prior relocations history (interaction term in Model 2). Returners from metropolitan areas have 79 per cent higher propensity to start a new firm than one-time movers from metropolitan areas, while it is 27 per cent higher for onward movers with a last relocation from a metropolitan area. Same order of effects is observed for movers between non-metropolitan regions. In that respect, when extended spatial biographies are taken into the consideration, a difference in the propensity for entrepreneurship between local and non-local individuals narrows down, and even disappears for certain groups of movers. For instance, returners from metropolitan areas are 3 per cent more likely to become entrepreneurs than local individuals.

When it comes to control variables, it appears that more educated (*Higher education*) and more experienced (*Sector experience*) individuals have lower propensity for entrepreneurship. In particular, having higher education tends to decrease the probability to become an entrepreneur by 12 per cent, while each additional year of work experience in the sector decreases it by around

9 per cent. This tendency might be driven by the sectoral specificity: low physical capital requirements as well as relative easiness of obtaining general skills in programming (Østergaard and Dalum 2011) might lead to an overrepresentation of young individuals among entrepreneurs in the sector[5], while more experienced workers would tend to go for more stable and secure employment positions. Another potential explanation is that individuals without official certification may have a hard time to get a paid employment position leaving them with the choice to start their own firms if they wish to work in the sector. Each year of unemployment (*Unemployment spell*) increases the propensity for entrepreneurship by 7 per cent. Finally, individuals with prior entrepreneurial experience are more than three times more likely to choose an entrepreneurship option for paid employment position than those without such experience.

Modelling the propensity for entrepreneurship with regards to spatial biographies of individuals sheds some new light on the locational inertia of entrepreneurs. On the one hand, it is, indeed, the case that local individuals in non-metropolitan regions have a higher tendency to become entrepreneurs compared to relocating individuals. This result provides support for Hypothesis 1a. On the other hand, it is not only a relocation immediately prior to the entry which is important to look at, but also an extended spatial biography of individuals. Different relocation patterns are associated with significantly different propensities for entrepreneurship, which provides an evidence in favor of Hypothesis 2a. Besides, it appears that a relocation direction – from a metropolitan area or from another non-metropolitan region – matters. Individuals moving from the former are more likely to prefer an entrepreneurship option to paid employment than those moving from the latter (but still not as likely as individuals performing a local entry). Moreover, when two measures of spatial biographies are combined, it appears that, for instance, returners from metropolitan areas are as, if not more, likely to start a business as local individuals. In that respect, a mixed evidence is also obtained for Hypothesis 3a. Indeed, metropolitan experience has a positive impact, but only with respect to particular relocation pattern.

All in all, the results of modelling propensity of individuals for entrepreneurship suggest that the locational inertia of individuals takes place, but is, to a certain extent, overestimated. If, however, the spatial biography of

5 This is also confirmed by the U-shaped relationship between age and propensity for entrepreneurship (not reported, but available upon request).

an individual matters for her decision to become an entrepreneur, the next question is whether it also matters for a post-entry success of her business. This issue is addressed further.

5.2. Post-entry survival

Table 3 reports the results of estimating Cox proportional hazards model for exit probabilities of new firms with regards to spatial biographies of their founders. Appendix A3 provides a sample summary as well as a correlation table for variables included in the analysis.

As in the case of propensity for entrepreneurship, entrepreneurs' pre-entry relocation patterns matter for survival of firms that they establish (*Prior relocation*). In particular, entries performed by individuals, staying in the same non-metropolitan region over six years of observed employment history, have the highest survival probability. The exit probability is higher for individuals with a history of spatial relocation: around 12-13 per cent higher chance of failure for one-time movers and returners, and almost 30 per cent higher – for onward movers (Model 1). In that respect, prolonged exposure to the regional environment (or, regional tenure), which provides an individual with opportunities for building local social capital, tends to improve survival chances of new entries. In that respect, the locational inertia of individuals is associated not only with their propensity for entrepreneurship, but also on the post-entry success of their businesses.

At the same time, the work experience in a metropolitan area tends to compensate for disadvantages associated with an absence of a regional tenure (*Metropolitan emp. tenure*). Each year of firm founder's employment in a metropolitan area is associated with a 2 per cent decrease in the exit probability (even though this effect is only significant at a 10 per cent level).

The importance of the latter is, however, conditional upon patterns of entrepreneurs' prior spatial relocation patterns (interaction term in Model 2). Returners tend to enjoy the biggest benefits from their metropolitan experience – 7 per cent decrease in the exit probability for each year of employment in a metropolitan area. For other movers, this effect becomes somewhat smaller. That returners are the main beneficiaries of the metropolitan employment experience is not really surprising, given that they have an opportunity to take the best of both worlds: having work experience in the most dynamic IT services clusters in metropolitan areas, providing them with superior learning opportunities, and being able to capitalize on the social capital they have accumulated in their pre-metropolitan lives.

Cox proportional hazards model	Model 1	Model 2
Prior relocation (Stayer)		
One-time mover	1.1234** (0.0436)	1.1109** (0.0444)
Onward mover	1.2996*** (0.0597)	1.3005*** (0.0691)
Returner	1.1284** (0.0481)	1.1735*** (0.0560)
Metropolitan emp. tenure	0.9809$^{\perp}$ (0.0111)	0.9344* (0.0274)
Prior relocation * Metropolitan emp. tenure (Returner)		
One-time mover		1.0617$^{\perp}$ (0.0341)
Onward mover		1.0496 (0.0379)
Higher education (no)	0.9658 (0.0287)	0.9640 (0.0287)
Sector experience	0.9512*** (0.0082)	0.9515*** (0.0082)
Unemployment spell	1.0185* (0.0081)	1.0182* (0.0081)
Entrepreneur experience (no)	0.8967$^{\perp}$ (0.0505)	0.8955* (0.0504)
Firm employment at entry	0.7669*** (0.0340)	0.7671*** (0.0340)
Regional IT employment at entry (log)	0.9962 (0.0191)	0.9964 (0.0191)
Individual controls (age, age^2, sex)	Yes	Yes
Industry dummies	Yes	Yes
Year dummies	Yes	Yes
Region dummies	Yes	Yes
N of subjects	6580	6580
N of failures	4820	4820
Log-likelihood	-38519.55	-38517.75

Hazard ratios are reported. Values above 1 indicate an increased probability of exit. Robust standard errors are reported in brackets. ***(**,*,$^{\perp}$) indicate significance at 0.1% (1%, 5%, 10%) level. Since hazard ratios are reported, a significant value indicates a significant difference from 1. For categorical variables and dummies values in the brackets are reference values. (Fielding 1989)

Table 2. Post-entry survival

Having work experience in the sector tends to decrease the exit probability by around 5 per cent for each year. This points to the increased importance of the specific human capital, which can only be obtained through learning-by-doing. Interestingly, this comes in contrast with results of Martynovich and Henning (2016), who demonstrated that a level of education (which is not significant here) has a more persistent effect on a wage performance of employees in the sector than industry experience. While it might be the outcome of using different measures of success for workers and entrepreneurs in the sector, this might also point to various mechanisms of learning and aspects of relevance of human capital between employees and entrepreneurs.

While longer spells of unemployment tend to increase the propensity of individuals for entrepreneurship, they tend to negatively affect survival chances of such entries. Having previous entrepreneurial experience helps an individual is associated with longer surviving entries, even though this effect is weakly significant.

Starting a firm with more employees tends to increase survival probability, which has two complementary aspects to it. On the one hand, number of employees at the moment of entry might be an indication for the seriousness of intentions behind the decision to start a firm. On the other hand, such effect qualifies the difference between firms which start with an intention to grow from firms which are established as individual IT consultancies.

Modelling survival of new entrepreneurial entries provides support to Hypotheses 2a-2c, even though to a different extent. On the one hand, new firms established by stayers tend to have the lowest exit probability compared to firms established by movers. On the other hand, different histories of entrepreneurs' prior relocations are associated with varying survival chances, which provides support for Hypothesis 2b. Firm founders' employment experience in metropolitan areas tends to have a positive impact on their businesses' survival in non-metropolitan regions. In that respect, the metropolitan employment tenure might be a substitute for employment tenure in a region where entrepreneurial entry is performed. The extent of substitution is, however, conditional upon entrepreneurs' prior relocation patterns: while returners enjoy the largest benefit from employment experience in metropolitan areas, it is less pronounced for one-time movers and, particularly, onward movers (who are, potentially, adventurers travelling the country in search of opportunities and ready for further relocation if their business is not living up to expectations). In that respect, only a limited support for Hypothesis 3b is obtained.

5.3. Dynamics over time

A surge in a number of entrepreneurial entries (Figures 1 and 2) as well as an increased mobility of entrepreneurs (Figure 3) after 2000 points to a potential shift in the dynamics of entrepreneurial activities in the knowledge-intensive IT services sector. Peculiarly, this shift coincided with the 2001 dotcom crash, which played an important role in the restructuring of employment opportunities in the sector (Warhurst et al. 2006; Martynovich and Henning 2016). This makes it interesting to check whether it was reflected also in the impact of spatial biographies of individuals on their entrepreneurial activities. Tables 3 and 4 present the results of re-estimating the models presented in Tables 1 and 2 for two sub-periods: 1991-2000 and 2001-2010[6].

When it comes to the propensity for entrepreneurship (panel (a) of Table 3), estimation results confirm the outcome for the whole time period: local entrants are most likely to become entrepreneurs in both sub-periods (*Entry location*). However, the difference between local entrants and movers, however, is mitigated over time. In the first sub-period movers from metropolitan areas were 45 per cent less likely to become entrepreneurs, while movers from non-metropolitan regions – 56 per cent less likely. In the second sub-period, the corresponding numbers are 21 per cent and 48 per cent respectively (Models 1 and 3). Notably, movers from metropolitan areas demonstrated a particularly fast catch-up to local entrants in the propensity for entrepreneurship. The negative impact of staying in the same region over six years of recorded employment history, as compared to individuals with a history of spatial relocation, becomes stronger in the second sub-period (*Prior relocation*). Besides, returners (particularly from metropolitan areas), which were the most likely entrepreneurs among movers over the whole time period, are become even more likely to choose an entrepreneurship option for paid employment over time (Models 2 and 4). For instance, individuals, returning from metropolitan areas, are 9 per cent more likely to become entrepreneurs compared to local entrants (3 per cent over the whole time

6 Only variables representing spatial biographies of individuals are reported. Other estimates are available upon request.

period, and negative in the first sub-period). All in all, it appears that individuals' spatial biographies have differential effect on their propensity for entrepreneurship at different times. That is, in the second sub-period the positive association between being local and starting a firm is reduced, while benefits from relocation (in particular, from metropolitan areas) become larger.

Logistic regression	1991-2000		2001-2010	
	Model 1	Model 2	Model 3	Model 4
Entry location (Local entrant)				
Mover from metro	0.5531*** (0.0445)	0.3843*** (0.0539)	0.7929*** (0.0363)	0.6509*** (0.0471)
Mover from non-metro	0.4349*** (0.0341)	0.2145*** (0.0332)	0.5212*** (0.0264)	0.3751*** (0.0334)
Prior relocation (One-time mover)				
Stayer	0.9433 (0.0545)	0.8357** (0.0495)	0.8191*** (0.0310)	0.7591*** (0.0302)
Onward mover	1.0726 (0.0811)	0.9587 (0.0960)	1.0672 (0.0496)	0.9930 (0.0655)
Returner	1.5989*** (0.1099)	1.0740 (0.0969)	1.2201*** (0.0550)	0.9360 (0.0578)
Entry location*Prior relocation (One-time mover)				
Onward mover from metro		1.5067* (0.3083)		1.2075 (0.1350)
Onward mover from non-metro		1.9080** (0.4030)		1.3857** (0.1730)
Returner from metro		2.2091*** (0.4238)		1.6714*** (0.1815)
Returner from non-metro		4.4199*** (0.8849)		2.1278*** (0.2694)
Pseudo-R^2	0.0957	0.0993	0.1172	0.1184
N	45830	45830	55959	55959

Odds ratios are reported. Robust standard errors clustered at the individual level are reported in brackets. ***(**,*) indicate significance at 0.1% (1%, 5%) level. Since odds ratios are reported, a significant value indicates a significant difference from 1. For categorical variables and dummies values in the brackets are reference values. (Fielding 1989)

Table 3. Propensity for entrepreneurship. Dynamics over time

What my lay behind this dynamics is technological advances, such as cloud computing, high-speed broadband internet and Wi-Fi, which enabled greater worker and entrepreneur mobility (Lafuente et al. 2010). Increasingly over time, where there was a signal, there was a potential business opportunity (Rigby 2008). In that respect, an increased opportunity for mobility would also lead to discovery of new entrepreneurial opportunities beyond immediate location of individuals, which would, in its turn, lead to an increased propensity of mobile individuals for entrepreneurship. Besides, the diffusion of IT as a platform for development of business activities in all regions would generate an increased demand for IT services beyond metropolitan areas, implying more potential business opportunities and more firms established to serve that demand. In that situation of an increased demand, on the one hand, an increased competition, individuals from metropolitan areas would be more likely to identify entrepreneurial opportunities as they were used to working in a highly competitive environment.

An impact of spatial biographies of individuals on survival of their businesses also changes over time (Table 4). For instance, the benefits of staying in a region over six years of recorded employment history, documented for the whole time period, become more pronounced as time goes by (*Prior relocation*). Indeed, in the 1990s there is no significant difference between stayers and one-time movers and only a weakly significant difference between returners and stayers, while these effects become stronger in the 2000s. The overall hierarchy of effects, however, remains more or less the same: onward movers appear to be the most disadvantaged ones.

Cox proportional hazards model	1991-2000		2001-2010	
	Model 1	Model 2	Model 3	Model 4
Prior relocation (Stayer)				
One-time mover	1.0917 (0.0725)	1.0747 (0.0735)	1.1359** (0.0552)	1.1266* (0.0563)
Onward mover	1.3576*** (0.1112)	1.3026** (0.1223)	1.2801*** (0.0719)	1.3003*** (0.0842)
Returner	1.1268$^{\perp}$ (0.0778)	1.2238** (0.0930)	1.1357** (0.0603)	1.1496* (0.0706)
Metropolitan emp. tenure	0.9590* (0.0208)	0.8678** (0.0412)	0.9891 (0.0130)	0.9741 (0.0355)
Prior relocation*Metropolitan emp. tenure (Returner)				
One-time mover		1.1293* (0.0617)		1.0226 (0.0403)
Onward mover		1.1483* (0.0715)		1.0046 (0.0443)
N of subjects	1999	1999	4581	4581
N of failures	1778	1778	3042	3042
Log-likelihood	-12093.39	-12090.29	-23445.96	-23445.69

Hazard ratios are reported. Robust standard errors are reported in brackets. ***(**,*,$^{\perp}$) indicate significance at 0.1% (1%, 5%, 10%) level. Since hazard ratios are reported, a significant value indicates a significant difference from 1. For categorical variables and dummies values in the brackets are reference values. (Fielding 1989)

Table 4. Post-entry survival. Dynamics over time

With regards to the metropolitan employment tenure (*Metropolitan emp. tenure*), its effect is only observable in the 1990s (and quite strongly; for instance, returners enjoy a 13 per cent decrease in failure probability for each year of employment in a metropolitan region). It disappears in the 2000s.

This might be the other side of the story of an increased penetration of IT service firms to non-metropolitan regions. Indeed, the development of the IT services sector beyond metropolitan areas boundaries (not least, due to an increased mobility of entrepreneurs) might have improved the opportunities for learning and obtaining relevant knowledge outside the latter. This, coupled with the adaptation of educational systems to the digital paradigm (Vona and Consoli 2015), could lead to a decreased importance of metropolitan areas as learning hotspots, even if they still concentrated most of firms and IT employment opportunities. In its turn, this would decrease the advantage of employment experience in these regions for obtaining knowledge necessary to start a longer-surviving firm.

All in all, considering, how the relationship between spatial biographies of individuals and their entrepreneurial activities changes over time, suggests that this relationship develops as the sector matures and the environment around it changes.

6. Discussion and conclusion

The paper aimed at investigating the extent to which spatial biographies of individuals, that is their histories of prior relocation, have an impact on their propensity to become entrepreneurs and post-entry performance of firms they establish. The departing point was the notion of locational inertia of entrepreneurs (Audretsch et al. 2012; Dahl and Sorenson 2012), implying that most individuals start new firms in regions where they have previously lived and worked. It was hypothesized that the locational inertia, driven by the local embeddedness of entrepreneurs (Dahl and Sorenson 2009), may be offset by deployment of diverse knowledge from different geographical settings accumulated by mobile individuals (Agarwal et al. 2007; Frederiksen et al. 2016), particularly those with employment experience in metropolitan areas. Empirically the paper was set around entrepreneurial entries in the knowledge-intensive IT services sector in Swedish non-metropolitan regions between 1991 and 2010.

The results of analysis demonstrate that the locational inertia of entrepreneurs, indeed, takes place. Between 1991 and 2010, more than three quarters of entrepreneurial entries in non-metropolitan regions were performed locally. Besides, these individuals were demonstrated to have higher propensity to choose entrepreneurship option for paid employment. Firms established by such individuals may also be expected to survive longer.

At the same time, empirical investigation suggests that there is more complexity beyond the local/non-local dichotomy of entrepreneurs' spatial origin. It was demonstrated that it is not just the location of individuals immediately prior to performing entrepreneurial entry, but also their extended spatial biographies that matter for their entrepreneurial activities. Distinguishing between several patterns of relocation (stayers, one-time movers, onward movers, and returners) as well as directions of relocation (from a metropolitan area or a non-metropolitan region), it was shown that in certain cases individuals with broad spatial careers may be more likely to start a successful business than local entrants.

The analysis suggests that while the traditional role of metropolitan areas is in providing the most fertile ground for knowledge-intensive sectors (Simmie and Strambach 2006; Karlsson et al. 2010), their importance goes beyond that. Having work experience in metropolitan areas was demonstrated to increase the probability of an individual to start a new firm, and a successful one. This might be attributes to the role of metropolitan areas as learning hotspots for individuals willing to obtain sector-specific knowledge in a dynamic urban context. This is particularly emphasized for individuals relocating to metropolitan areas for a while, but returning to their home regions to start a business. In this case, they become both embedded locally in a region of entrepreneurial entry, but also embedded in broader knowledge networks at the sectoral level. This allows drawing parallels between such individuals and Saxenian's (2006) New Argonauts: just as the latter travel to the Silicon Valley to work in the dynamic learning context and started successful businesses upon return to their home countries, the former tended to become the most promising entrepreneurs upon their return to their home regions.

The relationship between spatial biographies of individuals and entrepreneurial activity was shown to be changing over time, which points to the fact that the latter is related to the sectoral evolution (Audretsch and Thurik 2003). Indeed, as the industry matures and develops, so do the constraints and opportunity structures for potential entrepreneurs (Aldrich and Baker 2001). In that respect, it is important to account for how the evolution of the sector as well as the development of the environment, in which it operates, is reflected in the entrepreneurial behavior, not least in its locational aspect.

All in all, the results of analysis indicate that spatial biographies of individuals are related to the probability of entrepreneurial entry and its subsequent performance. In that respect, employment histories of individuals offer more information than simply the contents and location of the most recent employment, which should be incorporated in future analyses of entrepreneurial activities.

6.1. Limitations and further research

The study comes with limitations which provide the space for further investigation. First, while it was demonstrated that sectoral context matters for the changing relationship between spatial biographies of individuals and their entrepreneurial behavior, it is quite possible that the observed dynamics may be unique to the IT services sector. Therefore, other sectors should be considered in future analyses (particularly, other knowledge-intensive industries, where mobility of entrepreneurs may be an important channel of knowledge diffusion).

Second, the analysis of post-entry performance of new firms should be extended to incorporate not only survival of new entries but also their employment and/or sales growth. This is important since previous research suggests the existence of underperforming firms which manage to survive despite the low performance (Gimeno et al. 1997). Accounting for other performance indicators would allow connecting the entrepreneurial performance to development of regions, particularly in terms of upgrading their knowledge base (Neffke et al. 2014), as well as the role of entrepreneurs in the spatial diffusion of industries.

Finally, the data employed in this paper did not allow saying much about individuals' motivations, neither with regards the decision to start a firm, nor the decision to relocate. In that respect, deeper qualitative studies of the relationship between spatial biographies of individuals and their entrepreneurial behavior might offer a more detailed perspective on the issue.

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Appendices

A1. Spatial biographies of individuals. Hypothetical examples

Person	t-6	t-5	t-4	t-3	t-2	t-1	t (entry)
A	Växjö	Växjö	Växjö	Växjö	Växjö	Växjö	Växjö
B	Linköping	Linköping	Linköping	Linköping	Linköping	Linköping	Växjö
C	Stockholm	Stockholm	Stockholm	Stockholm	Stockholm	Stockholm	Växjö
D	Linköping	Linköping	Linköping	Linköping	Linköping	Växjö	Växjö
E	Stockholm	Stockholm	Stockholm	Stockholm	Stockholm	Växjö	Växjö
F	Linköping	Linköping	Stockholm	Stockholm	Stockholm	Växjö	Växjö
G	Linköping	Linköping	Stockholm	Stockholm	Stockholm	Stockholm	Växjö
H	Växjö	Stockholm	Stockholm	Stockholm	Stockholm	Växjö	Växjö

The table presents (some) possible combinations of spatial relocations of individuals. For demonstration purposes, it is assumed that individuals A-H perform an entrepreneurial entry at year *t* in a local labor market of Växjö. Then, provided their recorded employment histories, the following categorical values with respect to spatial biography variables are assigned to these individuals.

Person	Entry location	Prior relocation	Metropolitan emp. tenure
A	Local	Stayer	0
B	Mover from non-metro	One-time mover	0
C	Mover from metro	One-time mover	6
D	Local	One-time mover	0
E	Local	One-time mover	5
F	Local	Onward mover	3
G	Mover from metro	Onward mover	4
H	Local	Returner	4

Note, for example, that the difference between individuals B and D is that the former moved to Växjö at the year of entry, while the latter moved to Växjö a year before entry. That is why individual B is classified as a mover from a non-metropolitan region and individual D – as a local founder, while both of them are one-time movers according to their extended spatial biography. Besides, none of them has any employment tenure in a metropolitan region. In that respect, even being classified within the same category according to one of the spatial biography variables, doesn't mean that they will be classified together with respect to another spatial biography variable.

A2. Transitions to entrepreneurship. Sample summary

	N	Mean	Std. dev.	1	2	3	4	5	6	7	8	9	10
1. Entrepreneur	101789	0.0825	0.2751	1									
2. Sex	101789	0.7363	0.4407	0.0894	1								
3. Age	101789	34.6147	9.9740	0.0713	0.0040	1							
4. Age squared	101789	1297.6570	765.3007	0.0794	0.0054	0.9884	1						
5. Higher education	101789	0.6028	0.4893	-0.0141	0.1025	0.0397	0.0094	1					
6. Sector experience	101789	1.3570	2.3340	-0.0291	0.0626	0.3190	0.2975	0.0958	1				
7. Unemployment spell	101789	1.0127	2.0006	0.0254	-0.0022	-0.3399	-0.2948	-0.0682	-0.2660	1			
8. Entrepreneurial experience	101789	0.0800	0.2713	0.2029	0.0638	0.1341	0.1314	-0.0060	0.0648	-0.0879	1		
9. Entry location	101789	0.4796	0.7613	-0.0515	0.0584	-0.0133	-0.0156	0.0627	0.0262	-0.0982	-0.0296	1	
10. Prior relocation	101789	2.0543	1.0664	0.0099	0.0557	-0.0980	-0.0987	0.0683	-0.0320	0.0050	0.0054	0.4887	1

A3. Post-entry survival. Sample summary

	N	Mean	Std. dev.	1	2	3	4	5	6	7	8	9	10	11
1. Age	6580	37.2737	11.6481	1										
2. Age squared	6580	1524.9870	938.5607	0.9882	1									
3. Sex	6580	0.8748	0.3310	-0.078	-0.0641	1								
4. Higher education	6580	0.5757	0.4943	0.0478	0.0334	0.0514	1							
5. Sector experience	6580	1.0164	1.8953	0.2344	0.2146	0.0483	0.0874	1						
6. Unemployment spell	6580	1.2202	2.0545	-0.2482	-0.2102	-0.0453	-0.0362	-0.2345	1					
7. Entrepreneurial experience	6580	0.0853	0.2793	0.1313	0.1297	-0.0177	0.0000	0.0944	-0.0854	1				
8. Entry location	6580	0.7030	1.4991	0.0679	0.0484	0.0188	0.0344	0.1437	-0.2039	-0.0277	1			
9. Metropolitan employment tenure	6580	2.1279	1.1078	-0.1214	-0.1194	0.0636	0.0062	-0.0289	0.0043	-0.0947	0.2539	1		
10. Firm employment at entry	6580	1.1103	0.7127	0.0168	0.0095	-0.0001	-0.0125	0.0699	-0.0542	0.1184	-0.0133	-0.0371	1	
11. Regional IT employment at entry (log)	6580	6.0821	1.4094	-0.0676	-0.0634	0.0251	0.1070	0.0367	-0.0028	-0.0088	-0.0429	-0.048	0.0218	1

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The diffusion of the information technology has led to the profound transformation of economies all over the world. Among other things, it has left a deep impact on the functioning of the labour market and people's relationship to the world of work. This dissertation aims at qualifying the role of the labour market in the process of economic transformation induced by the introduction and diffusion of the information technology.

The dissertation integrates the theoretical perspectives on the long-term economic development with the insights from the labour market studies into the evolutionary model of economic change that links the behaviour of economic agents at the micro-level of the economy with the macro-level outcomes and determinants of this behaviour. Empirically, the dissertation investigates the co-evolutionary dynamics of industrial restructuring and worker reallocation across and within regional labour markets in Sweden in the period between 1985 and 2010.

The findings of this dissertation indicate that the dynamics of technological change and its implications for functioning of the regional labour markets should be approached through the prism of technology diffusion process which unfolds *in time and space.*

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