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FEATURE: IT DIFFUSION AND INDUSTRY AND LABOUR-MARKET DYNAMICS*

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The emergence and rapid diffusion of information and communication technology is the most radical technological transformation of the last couple of decades and has had an enormous economic impact. This bundle of four articles contains research that discusses major economic implications of the diffusion of IT. They focus on two main implications of IT: (*i*) networks and industry dynamics, and (*ii*) IT and workplace organisation. The two sets of two articles contribute both original theoretical insights and new empirical results to these themes.

The adoption and rapid diffusion of the bundle of new information and communication technologies has been the most radical technological change of recent decades. Economists have been focussing on the economic consequences for education, wages, workplace organisation, markets and competition, and networks and innovation of this technological revolution for quite some time now. The four contributions cover core issues of networks and industry dynamics, and workplace organisation and the demand for labour in relation to the IT revolution.

The IT revolution has caused the costs of many kinds of interactions to drop by making a great many processes operate more efficiently and it has allowed the opportunity to engage in new interactions that have become cost effective. At first, revolutionary technologies are implemented in a rather mechanical way to make it less costly to produce the same level of output. The main reason for Charles Babbage to manufacture and use a 'computer' was to deal more accurately and efficiently with information (Babbage, 1832).[1] Such 'number crunchers' were the main appearance of computers until the late 1960s mainly used to carry out mathematical and statistical procedures, mass-integrated data processing and simulations of Bayesian decision-making.[2] Over time, a revolutionary technology changes and amends (in an endogenous or co-invention manner) to do entirely new things, such as to change the way in which markets

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[1] Babbage created an 'analytical engine' around 1845. Babbage's experiments with computing did not find continuation until in the 1930s electrical technology could provide an alternative for the exorbitantly expensive and difficult to handle mechanical systems he had to rely on.

[2] The first more or less useful results were obtained around the beginning of World War II, by Konrad Zuse in Germany and Howard H. Aiken in the US. These computers were referred to as electromechanical computing machines (e.g., Mark I (1939), Z3 (1943) and ENIAC (1945)). Advanced theoretical work on developing computer technology was done in the 1930s by the British mathematicians Church and Turing. See e.g., David (1989) for a more elaborate historical overview and comparison to the electric dynamo.

are functioning and structured, demand and supply are brought together, or restructure the way in which a firm is organised and influence the way in which innovation activities are pursued.[3] These more incremental changes or innovations are the result of the opportunities offered by the main breakthrough offered by 'general purpose technologies' (e.g., Bresnahan and Trajtenberg, 1995). These latter consequences of new technologies are often hard to predict at first appearance but lie at the heart of the study of the economic consequences of technological change.

An example of how difficult it appears to predict technological changes can be found in a study of Klahr and Leavitt (1967). They acknowledged that in the mid-1960s computer technology used in firms was being complemented by communication technology but they could not forecast the way in which computer technology would change decision making inside firms:[4]

> 'Presumably the organisational impact of this wave [of computer technology] may be broader and may move into somewhat higher levels of the organisational pyramid. One effect of this new thrust seems to be the binding together of several subparts of the total structure, often severely modifying some in the process. Another is to move the locus of large amounts of information to some central point; and, in some cases, to change the locus of certain decisions from one part of the structure to another. The still speculative part of real-time information systems forecasts the provision of instantaneous information to top executives at their will – though no one is quite sure what they should will, or how such innovations will affect present structures.' (p. 108).

This view on IT describes the developments until the mid-1980s relatively well, because mainframe computers were in heavy use and companies such as IBM and Computer Associates were big players in the market for hardware and software.

Sweeping changes took place in the early 1990s, when smaller, more mobile and networked computer technology became available. This client-server type of computing gave companies more flexibility in applying information technologies without losing computing power. In addition, the compatibility of different types of software and hardware increased substantially, making an impact on the way in which agents work together within organisations and 'meet' suppliers in consumer markets. Client-server computing puts the power of the mainframe computer into a server and networks permit a business system to run on less powerful and more mobile clients.[5] Bresnahan and Greenstein (1996) use Jonathan Swift's *Gulliver's*

[3] See for example Simon (1986) and David (1990) who draw analogies with other major invention such as the steam engine (Simon) and the electric dynamo (David).

[4] Another intriguing example of forecasting the way in which computer technology was likely to change the world is Leavitt and Whistler's (1958) essay on how firms would deal with computer technology in the 1980s. Their view was that most of the work would be automated and managers would control firms by pushing buttons.

[5] A more detailed overview of recent developments in computer technology can be found in the volume edited by Soete and ter Weel (2005). See Freeman and Soete (1990, Chapter 3) for a detailed description of the developments in computer technology until the late 1980s.

Travels to describe the advantage of client-server computing compared to mainframe 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. IBM, having dominated large-scale business computing for decades, no longer found itself a leader. The MIS departments of large organisations were excited as well as threatened by the new opportunities. Both IBM and these departments began to appear as the inert Gulliver, roped and staked to the ground.' (pp. 3–4)

It is the economic aspects of this modern form of computer technology this Feature is concerned with. In particular, this Feature consists of a collection of articles intended to provide an overview of and new insights into the industry and labour-market effects of information and communication technology diffusion over the past two decades.

There are two major themes:

(*i*) networks and industry dynamics, and
(*ii*) IT and workplace organisation.

Both sets of articles have three things in common. On the empirical side it has been hard to identify network effects and changes in workplace organisation from existing data sources and the contribution of this Feature is to give new estimates by exploring network effects in the global market for workgroup servers and by investigating the consequences of computer technology adoption for workplace organisation and task assignment of different types of workers, using several large establishment/firm level data sets from the Netherlands and France. On the methodological side this Feature offers new insights into the role of IT in improving the matching between economic agents by reducing search frictions and in establishing a more efficient division of labour by looking at productivity increases and falling communication costs. These theoretical contributions add rigour to our understanding of the fundamental changes computer technologies have brought about. Finally, each of the contributions gives a perspective on useful and interesting future research into studying technological changes in networks from a theoretical and empirical point of view, and a research perspective on how to improve the understanding of the interplay between workplace organisation and the demand for labour in several ways. Together these four articles add to the substantial and increasing body of papers in this research area and yield a consistent understanding of how the IT revolution has had an impact and still affects market structures and the need for insight on how IT has generated market power for some parties, and how it has affected workplace organisation and the demand for labour.

1. Networks and Industry Dynamics

To maintain the analogy with *Gulliver's Travels* the first two contributions in this Feature are about the robes, nodes and strength of the 'network' with which Gulliver was tied by the people of Lilliput. From a theoretical point of view IT is able to have an influence on all three features of the network. First, it could establish new robes that were previously too expensive to explore, which extends the breath of the network; it could make the nodes denser in the sense that more information can come together in one node and in the sense that agents can meet more often; and, it has the potential to strengthen the network by reducing the number of weak links and by making markets more transparent. This could induce price decreases and quality improvements of the products and services traded in the network but it could also induce market power and lead to lower equilibrium quality and higher prices when one single player supplying a particular product becomes dominant.

Gerard van den Berg's theory article 'Revolutionary Effects of New Information Technologies' explores the market consequences of IT by focusing on the interaction between IT and differences in the composition of production technologies across agents or firms (van den Berg, 2006). The main aim of his contribution is to analyse the effects on the search process of agents of improvements in the information technology they have at their disposal. In his model the adoption of a novel technology improves the realisation of good matches for single agents, because improvements in IT increase the rate at which agents meet producers. This yields a better overview and a larger choice set on the side of agents. At the market level this may entail the removal of inefficient production technologies, because agents require less effort to find superior production technologies at lower prices. This gain in efficiency leads to upward jumps in the performance of networks. The key feature of the model is that due to information frictions an equilibrium exists in which inferior and superior production technologies coexist, but a decrease in the amount of information frictions results in firms using inferior production technologies disappearing from the market. The specific role of IT is to improve the technology of information processing and reduce the amount of frictions in the market. This in turn may result in the adoption of new production technologies and affect the composition of different technologies in use, which will be more efficient. This simple model of IT reducing search frictions is able to explain a number of recently observed phenomena, such as the success of Internet job search in improving the quality of matches between workers and firms.[6] Another key insight of the model is that the effects of improved information technologies spill over to other markets in which the

[6] Bontemps *et al.* (1999) develop a more complicated model building on similar assumptions with the presence of many different production technologies in which unemployment is falling when information frictions are reduced.

technology is not being used. The mechanism causing this effect is driven by agents' beliefs. At first the good equilibrium could be obtained but many markets are stuck in bad equilibria. After the revolution and the successful adoption of IT in some markets, the good equilibrium is attained in these markets. Now, if agents are trading simultaneously in different markets using different information technologies or if they are able to apprehend the changes in search behaviour in sectors in which the new technology is adopted, they start acting as if the new technology is implemented in all sectors of the economy. This induces a shift from the inefficient to the efficient equilibrium and drives out bad firms. Finally, the implications of the exit of bad firms and the flourishing of good firms are numerous. Some of the most important implications are the following. First, the growth rate of the economy increases and the agents' purchasing power rises because of falling prices, which is consistent with low inflation during the 1990s. Second, long-run growth levels remain similar because the long-run growth rate is determined by the arrival rate of new technologies, which is assumed constant. Finally, the exit of inferior technologies reduces the prices of commodities and price dispersion, which is consistent with findings suggesting that prices of commodities fall and converge if they become increasingly traded via the Internet.

John Van Reenen analyses a specific example of changing markets as a result of IT and his focus in 'The Growth of Network Computing: Quality-adjusted Prices for Network Servers' is especially on quality-adjusted prices in the network server market (Van Reenen, 2006). Since the late 1980s computing architecture went through a paradigm shift, in which mainframe-orientated systems were replaced by PC client/server architecture as briefly summarised above. Instead of computer intelligence being centralised and users interacting via terminals, processing power was more decentralised, distributed between PCs with their own operating systems and servers linking these PCs together. This market for servers has become a major antitrust concern in Europe and the US in recent years.[7] The present analysis is mainly concerned with

(*i*) analysing the market for network servers and
(*ii*) estimating the quality-adjusted prices for network servers using hedonic price indices.

The server market is analysed from 1996 to 2001 and characterised by a number of large players on both the hardware and the software side. Servers are mainly used to share computer facilities among users. For example, servers are applied to handle security, share files, process large data files, carry out print jobs and send emails. The market for servers is relatively large with companies spending about one-third of their annual computer budget on servers. To estimate the prices of network servers over time for Europe and the US both the rapid decrease in observed prices and the increase in quality have to be taken into account. In addition, inferior technologies have exited the market, which leads to a selection

[7] Van Reenen (2004) analyses the market for work-group servers with a focus on antitrust concerns. The main finding of there is that demand is highly inelastic leading a monopolist to raise prices and reduce welfare.

bias in the estimated price if the prices of these technologies are not taken into account. Furthermore, a hedonic index does have estimation (as well as sampling) variance and hence can be imprecise compared to a matched model of measuring prices. These three reasons form the basis of selecting a 'hybrid model' comparable and in line with Pakes (2003), which includes variance reduction features and selection correction properties. Using data from a server tracker database combined with sales data from the major players in the market for all quarters between 1996/1 and 2001/4 the evolution of prices, revenues and number of servers sold can be investigated. The main finding of the article is that quality-adjusted prices for network servers have fallen dramatically by some 30% per year over the period 1996–2001. The estimates reveal that using the more precise hybrid model yields an estimate almost 15 percentage points higher than when using a matched model only, which does not take exit into account. These price falls have been similar in Europe and the US. The general interest in these results is that the improved quality and increasing presence of network servers has improved information flows between agents and driven out inferior models, which contributes to the switching to an equilibrium in which the average price and price dispersion is lower. This switch to an efficient equilibrium is likely to have contributed significantly to the dramatic fall in server prices since the mid-1990s, which is consistent with the theoretical predictions of reducing market frictions proposed by van den Berg (2006).

2. IT, Workplace Organisation and the Demand for Labour

The tying down of Gulliver required a huge coordination and team effort involving a great many citizens of Lilliput. In the first chapter, right after he landed and recovered his consciousness, Gulliver notes that '[t]hese people are most excellent mathematicians' to be able to get all different tasks fulfilled to tie him down. The division of labour into separate tasks or jobs is determined by the benefits of specialisation and the cost of communication. The IT revolution has improved communication possibilities as well as production opportunities and this has affected the division of labour and the demand for labour in fundamental ways. The two contributions by Lex Borghans and Bas ter Weel, and Patrick Aubert, Eve Caroli and Muriel Roger complement the two studies discussed above by investigating the interplay and complementarity between IT, workplace organisation and the demand for labour within the firm.

In 'The Division of Labour, Worker Organisation, and Technological Change' Borghans and ter Weel (2006) investigate the relationship between the adoption of computer technology and workplace organisation both from a theoretical and empirical point of view. The main aim of the article is to present a simple model of the costs and benefits of specialisation to examine how far one can go toward explaining changes in the division of labour resulting from the adoption of IT. A second aim is to estimate the key predictions of the model using a panel of Dutch establishments surveyed in the 1990s. The model is based on a density function of a continuum of tasks, representing the work that has to be carried out in a firm. The way a firm assigns these tasks to workers describes the organisational structure of a firm.[8] Such an organisational structure is determined by the trade-off between the benefits of specialisation and communication costs where the firm decides upon assigning particular (sets of) tasks to individual workers. The adoption of IT might affect both the time needed for each task (production effect) and the costs of communication with fellow workers (communication effect) in production. The impact on the organisational structure and the division of labour might go two ways, however. The productivity effect will decrease the benefits of specialisation because the time devoted to a task falls and one worker is able to carry out more tasks during working time. This leads to smaller team sizes and to educational segregation within firms. The communication effect, on the other hand, will induce more cooperation among workers and hence increase the level of specialisation within the firm. Assigning workers with different skill levels will become more beneficial because for each task the right person, in terms of skill levels, can be hired. Borghans and ter Weel show that both effects resulting from IT adoption increase the demand for higher educated workers and hence induce a skill bias in the demand for labour. Empirically the article's aim is to distinguish between firms that adopt IT because of production or communication reasons. When the latter is relevant they argue that firms adopt IT at once for the entire (or a large share of the) workforce to reap the fruits from improved communication possibilities, whereas if the former is more relevant individual (or team) decisions with regard to adoption are more relevant. Based on a panel of more than 2,000 Dutch establishments their empirical results suggest that the productivity effect dominates the communication effect with respect to the overall pattern of organisational change in the 1990s, associated with the adoption and diffusion of IT within firms. This result suggests that improvements in productivity associated with the 'stand-alone' character of IT have been more important than the increased possibilities of communication. The empirical evidence also suggests that there exists heterogeneity in the way IT improves productivity. Especially for larger firms, firms competing in the high-quality segment and exporting firms, improved communication possibilities seem to be the dominant factor of IT adoption, while in firms in which the productivity effect dominates a tendency towards generalisation of work is observed.

In 'New Technologies, Workplace Organisation and Age: Firm-level Evidence' Aubert *et al.* (2006) investigate the impact of IT and workplace organisation on the age structure of the workforce, using French firm-level data. There are two views on the effects of new technologies and innovative workplace organisations on the demand for older workers.[9] First, the new technologies and forms of firm

[8] This way of modelling jobs is consistent with and extends the approaches of Autor *et al.* (2003) and Borghans and ter Weel (2004; 2005). These approaches do not explicitly take the division of labour within firms into account and neglect the gains from specialisation, which is the core focus of the present contribution. Borghans and ter Weel (2004, 2005) develop a number of examples and speculate how the division of labour is likely to change, but do not formally model the division of labour as in the present contribution.

[9] See also Weinberg (2005) for an empirical analysis of the relationship between experience and technology adoption. His findings, using US data, suggest that IT has complemented the skills of high-school educated workers and substituted for college graduates' skills. Hence, skills complementarity seems to hold for lower educated workers, whereas skills obsolescence plays a more important role for relatively more educated workers when adopting IT.

organisation complement existing skills, so there will be a positive relationship between more experienced and older workers and the adoption of these innovative modes of production. Second, the argument that skills become obsolete over time implies that older workers' skills are less adaptable to new technologies compared to younger workers, so their labour-market fortunes worsen when a new technology or organisational innovation arrives. The empirical strategy in Aubert *et al.* is to estimate wage-bill shares to capture the effects of innovations on the demand for older workers, but also to account for the inflow and outflow of workers. Particularly the latter is important (and by and large neglected in previous studies) in determining the possibility of an age bias of technological change because the observed composition of a firm's workforce might be the result of labour-turnover policies that are not necessarily age neutral. The database used consists of a sample of almost 4,000 French manufacturing firms in the late 1990s and results from combination of three separate data sources that include information about the firms' workplace organisations, the demographics of the workforces and the firms' financial situation. The estimation results offer at least three novel insights. First, there is a negative and significant correlation between wage-bill shares by age (measured in four ten-year categories from 20 to 59) and the use of computer technology, the Internet and the presence of innovative workplace practices. When these results are decomposed by gender it turns out that the negative relationship between the wage-bill shares by age and IT are stronger for women and that younger men seem to be benefiting relatively more from innovative workplace practices.[10] Decomposing the data into three major occupational categories suggests that, besides a skill bias in labour demand, the negative age bias is present across all occupations. The second contribution of the article is the analysis of labour turnover by explicitly investigating the hiring and firing policies of firms. The estimates suggest that more innovative firms hire relatively younger workers. The results with respect to firing decisions are less clear and seem to point towards a need for more experienced workers to ensure coordination of work. Finally, this contribution extends the work of Bresnahan *et al.* (2002) and the earlier contribution of Caroli and Van Reenen (2001) on the interplay between organisational change, IT adoption and the demand for labour by explicitly focusing on the age composition of the workforce within a large sample of firms. The evidence in favour of skills obsolescence suggests that innovations in terms of technology adoption and workplace organisation do not only yield a skill bias in the demand for labour but also a sizeable age bias.

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[10] This result is consistent with the findings of Weinberg (2000). In a study using the US CPS data he finds that particularly women have benefited from computer technology adoption because computers have de-emphasised physical strength and stamina. Given the focus on manufacturing firms in Aubert *et al.* (2006) this seems to be a particularly relevant observation in light of their estimates.

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