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Studying general purpose technologies in a multi-sector framework: The case of ICT in Denmark

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ABSTRACT

General purpose technologies (GPTs) are technical breakthroughs that are able to spur and sustain growth via their pervasive use in the economy. This paper attempts to study the effects of these innovations for the economic system on a theoretical and empirical level. First, an input–output approach is combined with the replicator dynamics of evolutionary game theory, in order to give a rationale how the adoption of an innovation at the firm level leads to a changing production mode at the industry level. Subsequently, a structural decomposition analysis for Denmark from 1966 to 2007 tracks the impact of the current GPT, the information and communication technologies (ICT), on aggregate and sectoral labor productivity growth. Findings show that the broad diffusion of ICT affected growth significantly only after 2000, owing to technical change, substitution and capital deepening, and can be associated with skill-induced wage dispersion.

1. Introduction

History has witnessed a number of radical innovations that changed the mode of production and the structure of the economic system. Prominent examples are the steam engine, electricity, or more recently ICT. Given the pervasive use and potential for increasing the overall innovation rate, this type of major technological change can be captured by the notion of general purpose technologies (Bresnahan and Trajtenberg, 1995). The distinct evolution pattern of GPTs generates profound economic and social consequences: The arrival of ICT, for instance, has been associated with the productivity slowdown in advanced economies (especially in the U.S.) experienced in the 1980s; as the irreversibility of tailor-fit inputs for incumbent production processes and the obsolescence of capital, as well as the short supply of skilled labor hampered its efficient utilization right from the beginning (Helpman, 1998). Only after these barriers were overcome, could a phase of substantial growth be observed in the beginning of the 1990s. On an empirical level, a wide spectrum of studies have dealt with the immediate and long-term effects of ICT on productivity growth (see, e.g., Jorgenson and Timmer, 2011; Jorgenson et al., 2007; Basu and Fernald, 2007; Inklaar and Timmer, 2007). Most of these studies focus on Anglo-American countries, in particular the U.S., and identify IT as an important source for both capital deepening and total factor productivity growth in the late 1990s and after 2000.

Even though the ICT revolution took several decades to show up in the productivity accounts, the wages of skilled workers has risen significantly from the emergence of this GPT onward. The most common explanation is that the

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employment of ICT makes great demands on the qualification of the workforce: New skills are required that first need to be accomplished through investments in education and training. The relation between the emergence of a GPT and skill-biased technical change has been extensively discussed in the theoretical (Helpman and Trajtenberg, 1998a, 1998; Aghion and Howitt, 1998; Aghion et al., 2002; Jacobs and Nahuis, 2002) and empirical literature. Increasing computerization has not only led to higher levels of both skills and wages in the workforce (Majumdar, 2008; Allen, 2001; Autor and Krueger, 1998; Berman and Griliches, 1994; Krueger, 1993), but also to the substitution of low-skilled by higher-skilled workers (Levy and Murnane, 1996), and rising wage inequality both among and within different education groups (Murphy and Welch, 1992; Autor and Krueger, 1998). These works support other empirical findings that skill-biased technical change within the last 40 years was driven exogenously, by a technology push, rather than by a demand pull (Bogliacino and Lucchese, 2015).

Another strand of research investigated the effects of specific GPTs (without referring to this notion explicitly) within a dynamic input–output setting. Twenty years ago in their seminal work on the future effects of computerization on the labor force, Leontief and Duchin (1986) developed an input–output model to test four scenarios for how automation would impact the volume and composition of the workforce in the U.S. from 1980 until 2000. As evidenced by these empirical findings, rapid technical change due to advances in information and communication technologies has resulted in a differentiated qualification profile of the labor force. In a similar study for West Germany, Kalmbach and Kurz (1990) analyzed the direct and indirect effects of micro-electronics on size and structure of the labor force. In their model, strong emphasis is put on the role of private investment behavior for the diffusion process of this technological breakthrough. Pan (2006) suggests a dynamic input–output framework where R&D investments are endogenized and drive the evolving dominance of a new technology, embodied in fixed capital, in sectoral production. The approach is subsequently applied to the Chinese economy by projecting the impact of non-fossil energy on the electricity sector.

This paper aims at investigating in detail the role of GPTs for productivity growth and wage dispersion. An evolutionary, multisectoral approach is developed that explains the economic dynamics triggered by the emergence of a GPT on theoretical grounds. The Sraffian static model is augmented by the replicator-dynamics approach of evolutionary game theory to describe how the increasing population of carriers of the new technology at the firm level causes changes in the production method on the sectoral level. The theoretical framework lays the ground for a structural decomposition analysis, assessing the impact of ICT on aggregate and sectoral labor productivity for Denmark between 1966 and 2007. This economy was chosen for several reasons: Firstly, it belongs to the innovation leaders in the European Union, ranking second (behind Sweden) in the most recent Innovation Union Scoreboard [15]. Furthermore, it is a small open economy acting as a net importer of ICT products, which facilitates the investigation of ICT in its primary role as a factor of production.[1] Denmark also promoted the diffusion of this technology in its early state: In 1985, the government launched the ‘Technology Development Programme’, a four-year policy initiative directed towards ICT. Its top priority was to foster the broad application of internationally available information technology across all sectors, and in particular in small and medium-sized enterprises (Edquist and Lundvall, 1993, 283). In order to study the economic impact of ICT on production, we revert to labor productivity growth as an indicator of economic development, since ICT deeply affected the labor market: On the one hand, labor intensity of production decreased through automation owing to ICT capital, while on the other hand the IT boom has increased the demand for qualified workers. Annual changes in labor productivity are decomposed into technical change, (non-investment) final demand, shifts in the employment of low and high-skilled labor, factor substitution, and capital deepening. Furthermore, the effects of technical change *within* the ICT sector and capital deepening of ICT are studied on an intersectoral level. Finally, we also discuss transitional wage disparities between low and higher-skilled labor during the rise of the IT era.

The paper proceeds as follows: Section 2 introduces the multi-sectoral evolutionary framework. Section 3 describes the structural decomposition analysis and the underlying data, while a detailed presentation of the decomposition and the industry classification can be found in Appendices A and B, respectively. Section 4 displays the most important results with a special emphasis on the GPT at work, ICT. Concluding remarks are given in Section 5.

2. Methodology

The workhorse growth models on general purpose technologies (Helpman and Trajtenberg, 1998, 1998a; Aghion and Howitt, 1998) explain observed diffusion patterns of this type of radical innovations as a result of R&D activities. This section aims to provide a sound theoretical explanation of the micro-funded diffusion process by means of an evolutionary framework based on firm growth processes.

The model we propose centers around the vertical integration of sectors each of which produces a different commodity by a different production process. Since pervasive utilization throughout the economy is one of the major characteristics defining a GPT, analyzing the economic implications of GPTs in a multi-sector setting is inevitable. Therefore a classical input–output model developed by Sraffa (1960) serves as the basis of our investigation.

In an N-sector economy, let $a_{mn} \in (0, 1)$ be the amount of good m (produced in sector m) and l_n the amount of labor to produce one unit of output in sector n. Given this state of technology, the relationship between relative prices, a general rate of profit, and the implicit wage rate can be scrutinized in the following price equation:

[1] Economies such as the U.S., Japan or Finland—which are net exporters of ICT products—would cause a bias with regard to our research question:It is their extensive production and trade of ICT that affects economic development, more than the pervasive use of this GPT in production.