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The future of employment: How susceptible are jobs to computerisation?☆

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ABSTRACT

We examine how susceptible jobs are to computerisation. To assess this, we begin by implementing a novel methodology to estimate the probability of computerisation for 702 detailed occupations, using a Gaussian process classifier. Based on these estimates, we examine expected impacts of future computerisation on US labour market outcomes, with the primary objective of analysing the number of jobs at risk and the relationship between an occupations probability of computerisation, wages and educational attainment.

1. Introduction

In this paper, we address the question: how susceptible are jobs to computerisation? Doing so, we build on the existing literature in two ways. First, drawing upon recent advances in Machine Learning (ML) and Mobile Robotics (MR), we develop a novel methodology to categorise occupations according to their susceptibility to computerisation.[1] Second, we implement this methodology to estimate the probability of computerisation for 702 detailed occupations, and examine expected impacts of future computerisation on US labour market outcomes.

Our paper is motivated by John Maynard Keynes's frequently cited prediction of widespread technological unemployment "due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour" (Keynes, 1933, p. 3). Indeed, over the past decades, computers have substituted for a number of jobs, including the functions of bookkeepers, cashiers and telephone operators (Bresnahan, 1999; MGI, 2013). More recently, the poor performance of labour markets across advanced economies has intensified the debate about technological unemployment among economists. While there is ongoing disagreement about the driving forces behind the persistently high unemployment rates, a number of scholars have pointed at computer-controlled equipment as a possible explanation for recent jobless growth (see, for example, Brynjolfsson and McAfee, 2011).[2]

The impact of computerisation on labour market outcomes is well-established in the literature, documenting the decline of employment in routine intensive occupations – *i.e.* occupations

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[1] We refer to computerisation as job automation by means of computer-controlled equipment.

[2] This view finds support in a recent survey by the McKinsey Global Institute (MGI), showing that 44% of firms which reduced their headcount since the financial crisis of 2008 had done so by means of automation (MGI, 2011).

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mainly consisting of tasks following well-defined procedures that can easily be performed by sophisticated algorithms. For example, studies by Charles et al. (2013) and Jaimovich and Siu (2012) emphasise that the ongoing decline in manufacturing employment and the disappearance of other routine jobs is causing the current low rates of employment.[3] In addition to the computerisation of routine manufacturing tasks, Autor and Dorn (2013) document a structural shift in the labour market, with workers reallocating their labour supply from middle-income manufacturing to low-income service occupations. Arguably, this is because the manual tasks of service occupations are less susceptible to computerisation, as they require a higher degree of flexibility and physical adaptability (Autor et al., 2003; Goos and Manning, 2007; Autor and Dorn, 2013).

At the same time, with falling prices of computing, problem-solving skills are becoming relatively productive, explaining the substantial employment growth in occupations involving cognitive tasks where skilled labour has a comparative advantage, as well as the persistent increase in returns to education (Katz and Murphy, 1992; Acemoglu, 2002; Autor and Dorn, 2013). The title "Lousy and Lovely Jobs", of recent work by Goos and Manning (2007), thus captures the essence of the current trend towards labour market polarisation, with growing employment in high-income cognitive jobs and low-income manual occupations, accompanied by a hollowing-out of middle-income routine jobs.

According to Brynjolfsson and McAfee (2011), the pace of technological innovation is still increasing, with more sophisticated software technologies disrupting labour markets by making workers redundant. What is striking about the examples in their book is that computerisation is no longer confined to routine manufacturing tasks. The autonomous driverless cars, developed by Google, provide one example of how manual tasks in transport and logistics may soon be automated. In the section "In Domain After Domain, Computers Race Ahead", they emphasise how fast moving these developments have been. Less than ten years ago, in the chapter "Why People Still Matter", Levy and Murnane (2004) pointed at the difficulties of replicating human perception, asserting that driving in traffic is insusceptible to automation: "But executing a left turn against oncoming traffic involves so many factors that it is hard to imagine discovering the set of rules that can replicate a driver's behaviour […]". Six years later, in October 2010, Google announced that it had modified several Toyota Priuses to be fully autonomous (Brynjolfsson and McAfee, 2011).

To our knowledge, no study has yet quantified what recent technological progress is likely to mean for the future of employment. The present study intends to bridge this gap in the literature. Although there are indeed existing useful frameworks for examining the impact of computers on the occupational employment composition, they seem inadequate in explaining the impact of technological trends going beyond the computerisation of routine tasks. Seminal work by Autor et al. (2003), for example, distinguishes between cognitive and manual tasks on the one hand, and routine and non-routine tasks on the other. While the computer substitution for both cognitive and manual routine tasks is evident, non-routine tasks involve everything from legal writing, truck driving and medical diagnoses, to persuading and selling. In the present study, we will argue that legal writing and truck driving will soon be automated, while persuading, for instance, will not. Drawing upon recent developments in Engineering Sciences, and in particular advances in the fields of ML, including Data Mining, Machine Vision, Computational Statistics and other sub-fields of Artificial Intelligence, as well as MR, we derive additional dimensions required to understand the susceptibility of jobs to computerisation. Needless to say, a number of factors are driving decisions to automate and we cannot capture these in full. Rather we aim, from a technological capabilities point of view, to determine which problems engineers need to solve for specific occupations to be automated. By highlighting these problems, their difficulty and to which occupations they relate, we categorise jobs according to their susceptibility to computerisation. The characteristics of these problems were matched to different occupational characteristics, using O*NET data, allowing us to examine the future direction of technological change in terms of its impact on the occupational composition of the labour market, but also the number of jobs at risk should these technologies materialise.

The present study relates to two literatures. First, our analysis builds on the labour economics literature on the task content of employment (Autor et al., 2003; Goos and Manning, 2007; Autor and Dorn, 2013; Ingram and Neumann, 2006). Based on defined premises about what computers do, this literature examines the historical impact of computerisation on the occupational composition of the labour market. However, the scope of what computers do has recently expanded, and will inevitably continue to do so (Brynjolfsson and McAfee, 2011; MGI, 2013). Drawing upon recent progress in ML, we expand the premises about the tasks computers are and will be suited to accomplish. Doing so, we build on the task content literature in a forward-looking manner. Furthermore, whereas this literature has largely focused on task measures from the Dictionary of Occupational Titles (DOT), last revised in 1991, we rely on the 2010 version of the DOT successor O*NET – an online service developed for the US Department of Labor.[4] In particular, Ingram and Neumann (2006) use various DOT measurements to examine returns to different skills. Our analysis builds on their approach by classifying occupations according to their susceptibility to computerisation using O*NET data.

Second, our study relates to the literature examining the offshoring of information/based tasks to foreign worksites (Blinder, 2009; Blinder and Krueger, 2013; Jensen and Kletzer, 2005, 2010; Oldenski, 2012). This literature consists of different methodologies to rank and categorise occupations according to their susceptibility to offshoring. For example, using O*NET data on the nature of work done in different occupations, Blinder (2009) estimates that 22 to 29% of US jobs are or will be offshorable in the next decade or two. These estimates are based on two defining characteristics of jobs that cannot be offshored: (a) the job must be performed at a specific work location; and (b) the job requires face-to-face personal communication. Naturally, the characteristics of occupations that can be offshored are different from the characteristics of occupations that can be automated. For example, the work of cashiers, which has largely been substituted by self- service technology, must be performed at specific work location and requires face-to-face contact. The extent of computerisation is therefore likely to go beyond that of offshoring. Hence, while the implementation of our methodology is similar to that of Blinder (2009), we rely on different occupational characteristics.

The remainder of this paper is structured as follows. In Section 2, we review the literature on the historical relationship between technological progress and employment. Section 3 describes recent and expected future technological developments. In Section 4, we describe our methodology, and in Section 5, we examine the expected impact of these technological developments on labour market outcomes. Finally, in Section 6, we derive some conclusions.

2. A history of technological revolutions and employment

The concern over technological unemployment is hardly a recent phenomenon. Throughout history, the process of creative

[3] Because the core job tasks of manufacturing occupations follow well-defined repetitive procedures, they can easily be codified in computer software and thus performed by computers (Acemoglu and Autor, 2011).

[4] Goos et al. (2009) provides a notable exception.