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THE FUTURE OF EMPLOYMENT:

HOW SUSCEPTIBLE ARE JOBS TO COMPUTERISATION?

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I. 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). 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 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.

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 polarization, 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 behavior [. . .]". 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.

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II. A HISTORY OF TECHNOLOGICAL REVOLUTIONS AND EMPLOYMENT

The concern over technological unemployment is hardly a recent phenomenon. Throughout history, the process of creative destruction, following technological inventions, has created enormous wealth, but also undesired disruptions. As stressed by Schumpeter (1962), it was not the lack of inventive ideas that set the boundaries for economic development, but rather powerful social and economic interests promoting the technological status quo. This is nicely illustrated by the example of William Lee, inventing the stocking frame knitting machine in 1589, hoping that it would relieve workers of hand-knitting. Seeking patent protection for his invention, he travelled to London where he had rented a building for his machine to be viewed by Queen Elizabeth I. To his disappointment, the Queen was more concerned with the employment impact of his invention and refused to grant him a patent, claiming that: "Thou aimest high, Master Lee. Consider thou what the invention could do to my poor subjects. It would assuredly bring to them ruin by depriving them of employment, thus making them beggars" (cited in Acemoglu and Robinson, 2012, p. 182f). Most likely the Queen's concern was a manifestation of the hosiers' guilds fear that the invention would make the skills of its artisan members obsolete. The guilds' opposition was indeed so intense that William Lee had to leave Britain. That guilds systematically tried to weaken market forces as aggregators to maintain the technological status quo is persuasively argued by Kellenbenz (1974, p. 243), stating that "guilds defended the interests of their members against outsiders, and these included the inventors who, with their new equipment and techniques, threatened to disturb their members' economic status."

As pointed out by Mokyr (1998, p. 11): "Unless all individuals accept the "verdict" of the market outcome, the decision whether to adopt an innovation is likely to be resisted by losers through non-market mechanism and political activism." Workers can thus be expected to resist new technologies, insofar that they make their skills obsolete and irreversibly reduce their expected earnings. The balance between job conservation and technological progress therefore, to a large extent, reflects the balance of power in society, and how gains from technological progress are being distributed.

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How technological progress in the twenty-first century will impact on labour market outcomes remains to be seen. Throughout history, technological progress has vastly shifted the composition of employment, from agriculture and the artisan shop, to manufacturing and clerking, to service and management occupations. Yet the concern over technological unemployment has proven to be exaggerated. The obvious reason why this concern has not materialized relates to Ricardo's famous chapter on machinery, which suggests that labour-saving technology reduces the demand for undifferentiated labour, thus leading to technological unemployment (Ricardo, 1819). As economists have long understood, however, an invention that replaces workers by machines will have effects on all product and factor markets. An increase in the efficiency of production which reduces the price of one good, will increase real income and thus increase demand for other goods. Hence, in short, technological progress has two competing effects on employment (Aghion and Howitt, 1994). First, as technology substitutes for labour, there is a destruction effect, requiring workers to reallocate their labour supply; and second, there is the capitalisation effect, as more companies enter industries where productivity is relatively high, leading employment in those industries to expand.

Although the capitalisation effect has been predominant historically, our discovery of means of economising the use of labour can outrun the pace at which we can find new uses for labour, as Keynes (1933) pointed out. The reason why human labour has prevailed relates to its ability to adopt and acquire new skills by means of education (Goldin and Katz, 2009).

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Computerisation in non-routine manual tasks

Expanding technological capabilities and declining costs will make entirely new uses for robots possible. Robots will likely continue to take on an increasing set of manual tasks in manufacturing, packing, construction, maintenance, and agriculture. In addition, robots are already performing many simple service tasks such as vacuuming, mopping, lawn mowing, and gutter cleaning – the market for personal and household service robots is growing by about 20 percent annually (MGI, 2013). Meanwhile, commercial service robots are now

able to perform more complex tasks in food preparation, health care, commercial cleaning, and elderly care (Robotics-VO, 2013). As robot costs decline and technological capabilities expand, robots can thus be expected to gradually substitute for labour in a wide range of low-wage service occupations, where most US job growth has occurred over the past decades (Autor and Dorn, 2013). This means that many low-wage manual jobs that have been previously protected from computerisation could diminish over time.

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VI. CONCLUSIONS

While computerisation has been historically confined to routine tasks involving explicit rulebased activities (Autor, *et al.*, 2003; Goos, *et al.*, 2009; Autor and Dorn, 2013), algorithms for big data are now rapidly entering domains reliant upon pattern recognition and can readily substitute for labour in a wide range of non-routine cognitive tasks (Brynjolfsson and McAfee, 2011; MGI, 2013). In

addition, advanced robots are gaining enhanced senses and dexterity, allowing them to perform a broader scope of manual tasks (IFR, 2012b; Robotics-VO, 2013; MGI, 2013). This is likely to change the nature of work across industries and occupations.

In this paper, we ask the question: how susceptible are current jobs to these technological developments? To assess this, we implement a novel methodology to estimate the probability of computerisation for 702 detailed occupations. Based on these estimates, we examine expected impacts of future computerization on labour market outcomes, with the primary objective of analysing the number of jobs at risk and the relationship between an occupation's probability of computerisation, wages and educational attainment.

We distinguish between high, medium and low risk occupations, depending on their probability of computerisation. We make no attempt to estimate the number of jobs that will actually be automated, and focus on potential job automatability over some unspecified number of years. According to our estimates around 47 percent of total US employment is in the high risk category. We refer to these as jobs at risk – *i.e.* jobs we expect could be automated relatively soon, perhaps over the next decade or two.

Our model predicts that most workers in transportation and logistics occupations, together with the bulk of office and administrative support workers, and labour in production occupations, are at risk. These findings are consistent with recent technological developments documented in the literature. More surprisingly, we find that a substantial share of employment in service occupations, where most US job growth has occurred over the past decades (Autor and Dorn, 2013), are highly susceptible to computerisation. Additional support for this finding is provided by the recent growth in the market for service robots (MGI, 2013) and the gradually diminishment of the comparative advantage of human labour in tasks involving mobility and dexterity (Robotics-VO, 2013).

Finally, we provide evidence that wages and educational attainment exhibit a strong negative relationship with the probability of computerisation. We note that this finding implies a discontinuity between the nineteenth, twentieth and the twenty-first century, in the impact of capital deepening on the relative demand for skilled labour. While nineteenth century manufacturing technologies largely substituted for skilled labour through the simplification of tasks (Braverman, 1974; Hounshell, 1985; James and Skinner, 1985; Goldin and Katz, 1998), the Computer Revolution of the twentieth century caused a hollowing-out of middle-income jobs (Goos, *et al.*, 2009; Autor and Dorn, 2013). Our model predicts a truncation in the current trend towards labour market polarization with computerisation being principally confined to low-skill and low-wage occupations. Our findings thus imply that as technology races ahead, low-skill workers will reallocate to tasks that are non-susceptible to computerisation – *i.e.*, tasks requiring creative and social intelligence. For workers to win the race, however, they will have to acquire creative and social skills.

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