

INSTITUTO POLITÉCNICO DE LISBOA
INSTITUTO SUPERIOR DE CONTABILIDADE E
ADMINISTRAÇÃO DE LISBOA



ISCAL

**OS IMPACTOS ECONÓMICOS DA AUTOMAÇÃO E DA ROBÓTICA:
UMA AVALIAÇÃO DA LITERATURA RECENTE**

Sónia Sofia Lopes Pereira

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Dissertação submetida ao Instituto Superior de Contabilidade e Administração de Lisboa para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Análise financeira, realizada sob a orientação científica prof. Doutor Orlando Manuel da Costa Gomes, Professor na área de Economia e Mercados Financeiros.

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DEDICATÓRIA

Dedico este trabalho á minha família, em especial aos meus pais Maria Lopes e José Brito pelo apoio e compreensão durante toda a minha jornada.

EPÍGRAFE

“[T]here’s never been a better time to be a worker with special skills or the right education, because these people can use technology to create and capture value.

However, there’s never been a worse time to be a worker with only ‘ordinary’ skills and abilities to offer, because computers, robots, and other digital technologies are acquiring these skills and abilities at an extraordinary rate.”

Brynjolfsson and McAfee (2015)

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A todos, muito obrigada.

RESUMO

Onde estamos hoje? A nova revolução robótica é mais do que um processo de substituição de pessoas por máquinas. As maravilhas das tecnologias digitais não devem ser desvalorizadas, embora os perigos que trazem para a economia, principalmente em termos da perda maciça de postos de trabalho, não devem ser negligenciados também.

É importante reforçar que a temática do desenvolvimento na automação industrial, mais especificamente, na robótica e desenvolvimentos mais avançados, está intimamente relacionada com a evolução da tecnologia da microeletrônica e das suas aplicações produtivas.

Tendo por base literatura recente sobre as consequências económicas da rápida automatização da atividade produtiva, dando especial ênfase nos assuntos relacionados com o emprego e crescimento económico, podemos encontrar uma mistura entre o ceticismo cauteloso e o otimismo moderado.

Assim, as perspectivas para o futuro apontam nitidamente no sentido de um desenvolvimento cada vez mais acelerado da inteligência artificial, disseminando e aprofundando neste sentido o estudo permite concluir que os trabalhadores, mesmo os altamente qualificados, são de facto substituídos por máquinas e os empregos estão a ser perdidos; no entanto, as políticas apropriadas e práticas empresariais podem permitir, e deve permitir, para tirar proveito da maior produtividade dos robôs, oferecer aos trabalhadores salários mais elevados e mais tempo de lazer.

Palavras-chave: Automação; Desemprego; Polarização do mercado de trabalho; Robótica na nuvem; Distribuição de tarefas e competências entre homem/máquina.

ABSTRACT

Where are we today? The new robotic revolution is more than a process of replacing people by machines. The wonders of digital technologies should not be undervalued, although the dangers they bring to the economy, especially in terms of the massive loss of jobs, should not be neglected as well.

It is important to emphasize that the development theme in industrial automation, more specifically in robotics and more advanced developments, is closely related to the evolution of microelectronics technology and its productive applications.

Based on recent literature on the economic consequences of the rapid automation of productive activity, with particular emphasis on issues related to employment and economic growth, we can find a mixture between cautious scepticism and moderate optimism.

Therefore, the prospects for the future clearly point to an increasingly accelerated development of artificial intelligence, disseminating and deepening in this sense the study allows to conclude that workers, even the highly skilled, are actually replaced by machines and jobs are to be lost; however, appropriate policies and business practices can allow, and should allow, to take advantage of increased productivity of robots, offer workers higher wages and more leisure time.

Keywords: Automation; Jobless economy; Labor market polarization; Cloud robotics; Distribution of tasks and skills.

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LISTA DE SIGLAS E ABREVIATURAS

BLS - Bureau of Labour Statistics

DVD - Digital Video Disc

EUA - Estados Unidos da América

IA - Inteligência Artificial

ISCAL - Instituto Superior de Contabilidade e Administração de Lisboa

OCDE - Organização para a Cooperação e Desenvolvimento Económico

PAICA - Programa para a Avaliação Internacional das Competências Adultas

PIB - Produto Interno Bruto

P&D - Pesquisa e Desenvolvimento

INTRODUÇÃO

Temática e interesse de investigação

A elaboração deste projeto de dissertação ***“Os impactos económicos da Automação e da Robótica: Uma Avaliação da Literatura Recente”*** visa fazer uma investigação sobre as consequências socioeconómicas da automação, e a sua rápida ascensão nos diversos sectores de atividade económica.

Numa época marcada pela evolução tecnológica este estudo torna se relevante e importante, na medida em que neste momento existe um interesse significativo sobre a estas questões atuais das consequências socioeconómicas que resultam da automatização e da robótica na atividade económica.

A pertinência do artigo ***“On the Economic Consequences of Automation and Robotics”*** que se segue relaciona – se com a avaliação das consequências que o crescimento da automação /robótica, tem no emprego, pois com a utilização destas tecnologias procura-se um maior ganho de eficácia e eficiência no desenvolvimento das tarefas que até ao momento têm vindo a ser realizadas pelo homem. O recurso a estas tecnologias pode conduzir a dissolução de vários postos de trabalho podendo desta forma conduzir a um aumento considerável do desemprego. O artigo referenciado sistematiza ideias sobre este processo e fornece um modelo conceptual para melhor entender a realidade que atravessamos.

De acordo com a revisão da literatura conclui-se que existe uma preocupação comum manifestada por especialistas na área da economia sobre o impacto que esta substituição (máquina/homem) terá ao nível de desemprego, distribuição de rendimentos, criação e exploração de novas áreas que permitam gerar novos postos de trabalho aos quais estão subjacentes novos conhecimentos e novas competências.

E verifica-se que existe uma tendência que se tem vindo a agravar por parte das organizações caracterizada por uma maior utilização de recursos tecnológicos em detrimento da mão-de-obra, consequentemente um aumento do desemprego em trabalhadores pouco qualificados.

A dissertação será composta por duas partes: uma primeira parte contendo o artigo escrito conjuntamente com o orientador ***“On the Economic Consequences of Automation and Robotics”*** e uma

segunda parte que faz uma análise ao artigo enfatizando a relevância da problemática e da potencial redução de postos de trabalho e das técnicas utilizadas.

Objetivo da dissertação

Dado a pertinência atual para a questão da robótica e automação, o objetivo desta dissertação será verificar quais são os impactos macroeconómicos dessas tecnologias emergentes na força de trabalho e se a sociedade precisa desses avanços tecnológicos, quão vulnerável estará a economia de trabalho?

Existem questões relativas sobre políticas públicas baseadas nas tecnologias emergentes, precisamos reconfigurar uma forma e descobrir como gerar benefícios sociais na nova economia que está se estendendo.

Processo de submissão do artigo “*On the Economic Consequences of Automation and Robotics*”

O artigo foi primeiramente submetido à revista *Studies in Economics and Finance*, tendo sido devolvido pelo editor, por considerar que o respetivo tema não ia ao encontro ao objeto fundamental da publicação, que é a ligação entre economia e finanças. Em função disso, o artigo foi resubmetido, em Abril de 2018, para o *Journal of Economic and Administrative Sciences*, onde foi bem acolhido, tendo sido já por duas vezes solicitadas revisões (junho e setembro de 2018). O artigo encontra-se publicado atualmente.

ON THE ECONOMIC CONSEQUENCES OF AUTOMATION AND ROBOTICS*

Orlando Gomes*

&

Sónia Pereira♦

- Version 3, September 2018 –

Structured Abstract

Purpose: The academic literature is currently placing significant attention on the study of the socio-economic consequences of the observable fast automation of all sectors of economic activity. Meaningful ideas on the economic impact of *the rise of the robots* are systematized in this paper.

Design / Methodology / Approach: With the goal of evaluating the channels through which the current wave of fast technological change affects the organization and performance of the economy and the behavior of agents, the paper is structured into two parts. The first part assesses the state of knowledge regarding the potential revolutionary role of robot use in production. The second part designs a model aimed at exposing the interplay between the most prominent features associated with the new economic reality.

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Research limitations / implications: The full macroeconomic impact of the fast, pervasive, and irreversible automation of production is far from being completely assimilated. At this level, no benchmark model should be interpreted as a definitive framework of analysis, and economic thought should evolve alongside with empirically observed evidence.

Findings: The current wave of innovation has implications that escape conventional economic thinking. The evaluation and prediction of what the new phenomena brings is fundamental to design policies that prevent income inequality to widen and growth to slow down.

Originality / value: We are facing an automation convulsion that replaces humans by machines at an unprecedented fast rate. This paper systematizes ideas about this process and offers a novel conceptual model to better understand what really is at stake.

Keywords: Automation; Jobless economy; Labor market polarization; Machine learning; Cloud robotics; Distribution of tasks and skills.

Article classification: Literature review / Research paper.

1. INTRODUCTION

At least since the seminal contributions of Joseph Schumpeter (1942) on creative destruction and Paul Romer (1986) on endogenous growth, economic theory has been teaching us that technological progress is the fundamental force behind the continuous and systematic increase in material prosperity experienced by humanity. Technological breakthroughs cause disruptions, leading to new products, new tools and new ways to produce, and although fast changes imply that some suffer transitory losses, the overall outcome is invariably favorable: innovation brings gains to societies and to the welfare of people.

Fears of technological unemployment have always been in the forefront of the potential threats perceived by economic actors concerning innovation. With machines that are increasingly more efficient in developing a wide array of tasks, people are likely to be discarded from the execution of such tasks, thus raising apprehensiveness about possible income concentration in the hands of few and about the eventual alienation of a significant part of the population that will no longer have the opportunity to contribute to society through their professional careers.

Related with the employment issue is the impact of technological progress over growth. Innovation is traditionally associated with the expansion of production possibilities, leading to the generation of new businesses and activities that require both more capital and more labor, given the complementary nature of these two inputs. Recent waves of innovation triggered a new reality concerning the structure of production; many of the new machines are now direct substitutes of labor rather than their complements and, therefore, in order to produce, a progressively smaller amount of the human input is required. Because this mechanism is susceptible of leading to strong income concentration, aggregate demand may be undermined, provoking a fall in the long-term potential of the economy to grow.

This paper surveys the recent literature about the economic consequences of the fast automation of the productive activity, placing the emphasis on the issues of employment and growth. A mix between cautious skepticism and moderate optimism can be found in the writings of the most prominent authors in the field. The systematization of the theoretical and empirical literature on the theme allow to unveil a series of patterns or stylized facts that will be used, subsequently, to assemble a theoretical model that might serve as a reference for a better understanding of the problem at hand.

The skillfulness of people and robots differs; robots are particularly suited to perform routine tasks that are located somewhere in the middle of a skills' scale, while low-ranked manual skills and high-ranked abstract skills are harder to mechanize. This evidence about job polarization is central to construct a framework addressing the impact of the new wave of technology and suggests that finding adequate distributions of skills is a first relevant step in assembling a coherent economic theory of robots.

The remainder of the text is organized as follows. Section 2 briefly reviews the distinctive features of the current phase of technological change. Section 3 discusses the impact of automation over employment, a discussion that is extended to section 4, where a more confined debate about the job polarization phenomenon is conducted. Section 5 focuses attention on how economists are relating automation with long-term growth. In sections 6 and 7, the analytical framework that allows to interpret the economic consequences of the recent wave of innovation is presented, discussed and operationalized. Finally, section 8 concludes.

2. THE WONDERFUL WORLD OF TECHNICAL WONDERS

The astonishing pace at which automation is progressing is changing every aspect of the economic and social environments. New machines and the software that makes them function, developed in the context of the digital revolution, have penetrated deeply in our lives, with meaningful widespread applications in industry and commerce, and also offering directly to households new and better ways to organize their daily routines.

This is the era of robots. Robots are distinguishable from other machines because they are entities that can be programmed to develop tasks that create value without need for any human intervention or control (Freeman, 2015; Graetz and Michaels, 2015); they can work for themselves, without direct help from the human workforce. Obviously, this implies a huge change in the current economic paradigm, with implications ranging from the organization of productive tasks and job opportunities, to the distribution of income and the dynamics of economic growth.

The new robot revolution is more than a process of substitution of people by physical machines. In fact, the physical part of the machines is becoming progressively less central as the possibilities to detach the software from the hardware become usual and trivial. This detachment signifies that machines may receive the information and knowledge they need to function from external, remote and diffuse sources, with data being communicated pervasively and at high speed through the internet and other electronic channels. The exchange of information and knowledge at a global scale creates unprecedented possibilities regarding the development of artificial intelligence and it also allows for the emergence of cloud robotics, a fundamental instrument for the future of production and distribution of goods and services.

Generalized wireless connections have broken the barrier of physical constraints raising tremendously the capabilities of robots. With the cloud technologies, capacity, memory and storage constraints are significantly reduced and, in some cases, possibly even eliminated (Koken, 2015). This enhances the potential of machines that are being used, increasingly, in every productive sector and also in everyday life. With cloud robotics we are above all entering a phase of machine intelligence. Machines are replacing more than manual force, they are replacing brains. Everything that can be done in an intelligible way (i.e., that can be codified) can be passed from humans to machines.

Empowering robots with cloud technologies has produced a revolution in the way productive activities are automatized. Regardless of distance, machines are able to access knowledge that can be easily adapted to the task they are supposed to perform. Moreover, machine learning

becomes possible because machines are intertwined, i.e., since they have a same central source of knowledge and information to resort to.

Recent innovations in the fields of automation and robotics are likely to continue and even to intensify. As new capabilities are developed, many other possibilities are unveiled. Autor (2015) and Pratt (2015) put into perspective some of the breakthroughs one can expect to emerge in the near future and that make automation to persist in its virtuous path. The metamorphosis will continue in the fields of machine learning and environmental control. Environmental control signifies regularizing the environment in order for machines to be able to perform tasks (as in an assembly line). Many productive tasks are adaptable to this amenity and the kinds of environment that might possibly be regularized are reaching a degree of high complexity and sophistication (e.g., road systems for driverless cars); as technology evolves, not only new robots enter the scene, but also new environments for them to thrive are conceived and developed.

Machine learning is progressing into what is becoming known as deep learning. Deep learning consists in robot learning from large datasets that are stored in the cloud. Deep learning algorithms will allow robots to make elaborate thinking and to use some of the senses that are today exclusive to living beings (as sight). The possibility to learn from accumulated codified knowledge is being potentiated by the easy and fast access to large banks of data from anywhere in the world. Growth in computing performance, improvements in the storage and use of energy, improved performance and larger scale of the internet, are all elements of a new context that will allow robots to thrive. Computers may learn much faster than humans and evolution may take us to a stage where processes like human imagination might be replicated by machines.

From an economic perspective, it is worth highlighting that cloud computing, machine learning, and other robot related innovations, introduce flexibility in the activity of firms. In a certain sense, as highlighted by Bayrak *et al.* (2011), the main economic consequence of the current wave of automation over the organization of economic activity concerns the possibility of converting fixed capital costs into variable costs. Firms and other economic players no longer need to invest large sums of financial capital to take advantage of the mechanization of activities. Most of their automation processes depend on software that can be hired or bought in modalities that allow automation to progress alongside with other variable inputs. The digital economy introduces flexibility allowing the cloud to be synonymous with cost reduction and efficiency gains.

The new economy, propelled by remotely managed machines, also stimulates entrepreneurship, by making it possible to access some of the potentialities of automation without bearing

overwhelming costs. Cloud computing is a way of taking advantage of large economies of scale, since the centralization of infrastructures allows for the spreading of costs over a large pool of users. The gains for the organization of productive activities could be enormous but, as for any other technological breakthrough, creativity is also needed to provide the best possible use for the tools of the human mind.

In the sections that follow, namely sections 3 to 5, a bridge is established between the current wave of technological change, with its main features as characterized above, and the respective consequences over the organization and performance of the economy. These consequences are deep and pervasive, as many recent contributions to the academic literature highlight. One of such contributions, Cowen (2013), is particularly illustrative and particularly incisive about the main mutations that are taking place and that we will explore in detail in what follows. Specifically, the mentioned author alerts for the extreme nature of the new economic landscape, where average jobs, average incomes, and average life conditions are disappearing fast. Growth is visible in top incomes and top wealth, but the average citizen seems unable to reap benefits from an economy of extraordinary productivity gains potentiated by the ever improving artificial intelligence resources and devices.

As Tyler Cowen emphasizes in his book, we are reaching an era where *average is over* and *hyper-meritocracy* is installed. This is an economy of winners and losers, an economy where cases of success coexist with vicious cycles that push many people, communities, and countries away from acceptable life conditions, leading to a clear two-hump shaped distribution of income and wealth. The winners are mostly those who position themselves in the labor market and in businesses as complements of machines; in opposition, those who possess skills similar to the ones of robots and automated processes are destined to be replaced by such machines and processes, because these are indeed becoming, at a fast pace, much more efficient and smarter.

3. ROBOTS AND THE FUTURE OF EMPLOYMENT

Economic transitions propelled by technological change have always led to mutations in the structure of employment and to surges of short-run unemployment. Ford (2015) underlines that this has occurred first with the mechanization of agriculture and then with the pervasive implementation of assembly lines in industry. In both cases, a painful transition process occurred with inevitable job losses. Nevertheless, the economy was able to accommodate these changes creating new jobs, often more enjoyable and, because associated with less standardized skills, also better rewarded in terms of wages.

Nonetheless, the most recent wave of automation appears to involve some distinctive features when compared with what was observed in the past. Since the beginning of the new century, although developed economies have continued to grow, practically no new net jobs were created in some of these economies, i.e., levels of employment remain at numbers similar to those in the year 2000. This implies a fundamental change in the distribution of income; business owners were able to retain most of the additional income, thus provoking a progressively wider gap between capital income and labor income.

The mentioned gap is the direct consequence of an undeniable fact: firms could raise productivity without attaching additional workers to production. While in the past, as taught by economic theory, machines were a complement to labor, i.e., instruments that helped raise labor productivity, there is now a substantial difference: machines entering the productive process in the last few years are meant to replace workers. New technologies are associated with the digital revolution, which has brought to economic organization a set of impressive new realities. The velocity and frequency with which technological novelties emerge and the ability of these technologies in penetrating areas of knowledge and action until recently exclusively reserved to humans are the most noteworthy facts.

The digital world is creating an economic reality where it is no longer just the jobs associated with low skills and poorly educated people that are under siege. There is a fast moving frontier that does not rest any more in routine or repetitive tasks but that is getting into every area where procedures are predictable and may be translated into some sort of algorithm. This includes sophisticated tasks such as driving a vehicle, teaching a class, or giving medical advice to a patient. Machines are invading every area of human intervention, including the ones requiring more advanced qualified knowledge. We are progressing towards a society where highly skilled activities might be partially or totally replaced by software algorithms (Ford, 2015, mentions as examples the professions of lawyer, journalist, scientist, and pharmacist).

Additionally, the extremely fast progress in the new technologies makes it extremely hard for people who are displaced to adapt to a progressively narrower set of possibilities, concerning alternative occupations that society considers useful beyond what machines (and dematerialized codes) do.

The mentioned process of dehumanization of work is not uniform. Some traditional sectors continue to employ large quantities of labor, while new firms in new sectors, as those associated with some online businesses and social media, are extremely profitable firms that employ relatively few people. As a result, the economic paradigm is changing; redistributive policies and

the architecture of the welfare state have to be thought out from scratch; the same is true regarding education and the skills required to thrive in a progressively more intensely automated economy.

In two influential books, Brynjolfsson and McAfee (2011, 2014), thoroughly discuss the implications of the uneven dispute between machines and men. They confirm that while some human skills are today more relevant than ever, others are losing the race against the machine. Machines are penetrating in fields never imagined in the past: advanced pattern recognition and complex communication. Creative ability, though, is still in the hands of humans.

Overall, it is a fact that the economy is becoming less labor intensive in a fast, large and widespread scale. Successful companies, in dynamic sectors of the economy, require indeed very small amounts of labor. Digital technologies are leaving behind millions of people: the low-skilled, those lacking a superstar quality and those who are not capital owners. The resulting inequalities may lead to economic and social unrest. To benefit from robot technologies, workers need to own part of the capital stock that replaces them. In the past two decades, in almost every country, income distribution has shifted from labor to capital. Unless workers earn income from capital, the observed inequalities will continue to rise. Employee ownership might be a vital path to avoid a new form of economic feudalism.

The social and economic mutations triggered by the current wave of innovation are by now a topic of intense academic research, both at the empirical and at the theoretical levels. In Acemoglu and Restrepo (2017), the effects of automation over employment and wages are thoroughly estimated. The measurement exercise performed by these authors indicates that job losses are significant. Their estimations are undertaken over a theoretical model in which two contradicting effects are highlighted: a displacement effect, as workers are replaced by robots, and a productivity effect, originating in the higher efficiency and its impact on the emergence of new tasks and job opportunities. Equating the displacement effect and the productivity effect, recent data reveals that the first is gaining supremacy. Pellegrino *et al.* (2017) make a parallel interpretation, emphasizing that the relationship between technology and employment is not straightforward and the fears of technological unemployment should be carefully weighted. Technological change is labor saving, but it also expands the production possibilities frontier making it possible to increase investment, consumption and businesses that will require new jobs.

In general, empirical studies avoid compromising with a straightforward relationship between innovation and employment. Evidence reveals that such relationship is contingent on a series

of factors, including the economic sector under evaluation. Typically, and despite the fears of job loss due to automation, the creation and perpetuation of stable jobs are more insistently found in innovative sectors and innovative firms; non-innovative sectors are the ones that apparently show more difficulties in creating and maintaining jobs (Evangelista and Vezzani, 2012; Ciriaci *et al.*, 2016; Piva and Vivarelli, 2018).

The list of studies addressing the linkages between robotics and the economics of the labor market is, by now, almost interminable. It ranges from books directed to wide and general audiences, as those by Hanson (2016), Pugliano (2017), Reese (2018), or Baldwin (2019), to academic studies that examine and put into perspective future scenarios about the evolution of employment and wages (e.g., Eichhorst *et al.*, 2016; Aghion *et al.*, 2017; Caines *et al.*, 2017; Cortes *et al.*, 2017; Dauth *et al.*, 2017; Eberhard *et al.*, 2017; Gibbs, 2017; Acemoglu and Restrepo, 2018; Cho and Kim, 2018; Dutz *et al.*, 2018; and Furman and Seamans, 2018; just to cite a few key recent works).

4. LABOR MARKET POLARIZATION

In a couple of influential contributions, Autor (2014, 2015) highlights that despite the increasingly pervasive range of activities that machines may perform, many areas of economic intervention remain where machines may assist workers but cannot replace them. Overall, substitution of labor by machines tends to be overstated, while complementarities between the two are often overlooked. Under this perspective, the tasks that follow routine codifiable procedures can indeed be automated; those which are flexible and require judgement and tacit knowledge are more resistant to automation. Humans have a comparative advantage in performing this second group of tasks.

In fact, the substitution of humans by computers in routine tasks amplifies the human comparative advantage in the tasks requiring creativity, adaptability and humanity. One cannot just look for what is lost when machines replace humans; as it happens, automation raises the value of the tasks that can only be performed by flesh and bone people.

The fundamental evidence, according to David Autor, is labor market polarization or job polarization: while machines may substitute for **routine tasks**, there are two types of non-routine activities in which people continue to be required. These are highly skilled tasks that demand knowledge, creativity and intuition (**abstract tasks**) and low skilled tasks that require human interaction (for instance attending in a store or giving health assistance); these are the

manual tasks. There is job polarization in the sense that manual tasks and abstract tasks, performed by workers in significantly different positions of the labor market skills' continuum, continue to need human intuition, creativity and judgment. The notion of job polarization is that routine jobs, in which people can be replaced, are middle-education middle-wage tasks. Those that cannot be mechanized can be found in both extremes of education and wage.

Although machines are progressively entering domains where one thought they could never enter, given the non-routine nature of the activities, there are still activities where human contribution is fundamental, and these are not likely to disappear from the occupational skill spectrum. Manual tasks, in particular, deserve attention in this discussion; they are tasks that do not require significant knowledge or effort but that are not possible to codify, i.e., to present under a set of rules leading to an algorithm. They respect to tacit knowledge.

Tacit knowledge is associated with what Autor calls the Polanyi's paradox, i.e., the evidence that we know more than we can in any way express, and therefore, to transmit to other people or to machines. This is also attached with what is known as Moravec's paradox, which consists in the idea that humans are able to learn in early ages some functions that are not replicable by machines, but take many years to acquire and master the competences that machines can be programmed to perform with extreme efficiency and quickness (the routine tasks).

From an empirical standpoint, several studies, including Autor and Dorn (2013), Goos *et al.* (2014), Michaels *et al.* (2014), Adermon and Gustavsson (2015), and Berger and Frey (2016), assess the role of robotics and machine learning in determining the future of labor in various parts of the globe, including the United States, Japan, and several European countries. They all find evidence, in a greater or lesser extent, pointing to job polarization. The *end of work* is not an expectable possibility, in these authors' view, but they recognize that job polarization exists, with non-routine skilled and non-skilled tasks continuing to require large amounts of labor, leading to the increase in the demand of skills demanding human interaction, situational adaptability and cognitive abilities.

In the United States, in particular, the recovery from the great recession was characterized by weak employment growth, which affected primarily the middle-skill routine jobs. Routine jobs may have been permanently destroyed with the recession. Labor market polarization and a jobless recovery is apparently a clear feature of the US economy. In other developed countries, recoveries from recessions do not exhibit such a pronounced loss of jobs. The evidence shows that technology is not causing as dramatic jobless recoveries in other countries as in the US (Frey and Osborne, 2017; Graetz and Michaels, 2017).

The theoretical literature is also starting to offer some compelling views on the job - automation debate. Graetz and Feng (2015) build and explore a model that addresses job polarization. In particular, the question that is approached is which tasks firms choose to automate. Tasks are distinguished in terms of engineering complexity and training requirements. Some tasks are complex from an engineering point of view but simple for humans to learn, while others are easy to turn into a routine but difficult to learn (or at least imply time consuming learning). For two tasks with identical engineering complexity, the firm will choose to automate the one requiring more training, because it is in this that labor is more expensive. This leads in fact to job polarization: there are tasks that cannot be automated, but among those that can firms choose not to automate the simplest ones (cleaning services, cooking, haircutting ...).

There is by now a relatively widespread consensus among labor economists that labor market models need to be reviewed and adapted given the new reality and the new tendencies, namely the rapid diffusion of new technologies that replace labor, job polarization, and increases in wage inequality. One meaningful contribution that puts together this set of pieces is the study by Acemoglu and Autor (2011), who also explore a model where workers are assigned to tasks, with those tasks that are routinized leading to the displacement of workers. Tasks where problem-solving, creativity and judgement are required (being them skilled or non-skilled) tend to preserve jobs, in the mentioned framework.

5. AUTOMATION, ECONOMIC GROWTH AND INCOME DISTRIBUTION

If human labor is replaced by machines, the main economic problem should be distribution rather than scarcity, right? In an ideal world we all concur that the logical answer to this question is yes, but in the real world there is always perceived scarcity and people will always want to retain the largest amount of resources that they can get, and therefore straightforward and affirmative answers to the interrogation collide with a few caveats.

The persistent unemployment that the current surge of technological advancement is forming is likely to bring some hardship not just for particular groups but also for the performance of the economy as a whole. Because income concentrates in the hands of a few 'machine owners', the rising wages typically brought by in the past by productivity increases are no longer significant. This may imply a strong and sudden fall in consumer spending, diverting the economy from its potential growth path. As this new state of affairs sets in, the capacity of the economy to create wealth might ultimately be compromised.

Therefore, what should be interpreted as an important driver of increased efficiency and boosting productivity, the substitution of labor by machines, may end up by impairing growth, even under a long-term perspective. The fast pace of technological change may lead to a loss of jobs that will never be replaced. Solutions have to be found. Capital ownership has to be equated afresh in order to avoid increasing inequality and in order for humanity to benefit from the wonders of task developing machines.

If the economy could, at every instant, start afresh, it would be possible to conceive a setting where everyone owned a robot and where the robot would produce and create wealth for its owner. But reality is different: those with the ability and power to invest will concentrate the gains of automation and lead to significant concentration of income in the hands of few. For prosperity to continue, some fundamental changes must be implemented in the design and organization of the economic system. These changes must be carefully evaluated by governments as well as by intergovernmental institutions in the global arena.

Even if the income distribution issues are somehow mitigated, the wonders emanating from robot high efficiency will not be a panacea for all difficulties. Graetz and Michaels (2015) remark that advances in robotics will continue and that this will presumably benefit growth. Nevertheless, at the same time, robots, as humans, are subject to diminishing marginal returns; congestion effects are likely to set in, in various areas where automation is strong. In other words, automation will not necessarily make the essence of growth to depart from the well-known neoclassical prototypical framework. Innovation must be much more than a repetitive process of increasing robot productivity in the same tasks. Without new products, new ways of organizing production, and new forms of reaching consumers, robots, as other machines or as the labor force, will be subject to progressively lower marginal contributions to production.

To approach the relation between automation and economic growth, Prettnner (2016) investigates the dynamics of a modified neoclassical growth model. The difference relatively to the standard capital accumulation growth model is that automation capital instead of complementing labor is a perfect substitute for it. In the production function, the new input (automation capital) appears as a direct substitute for labor. In this case, and under a representative agent framework, it is straightforward to prove that there will be perpetual growth of per capita output even in the absence of technical progress.

Gasteiger and Prettnner (2017) resort to the same type of production function but apply it to an overlapping generations framework. Again, constant returns to capital hold in the absence of technological progress, however now the structure of the model does not lead to long-term

sustained growth. This occurs because wages are assumed as the source of investment, and automation implies an aggregate loss on wages. Such result contradicts the one in the representative agent growth model of Prettner (2016) because in this first model the agent could invest both out of the wage income and out of asset income. This new version of the growth model intends to illustrate the perverse effect over growth of the fall on wages that comes with the robotic invasion.

The production function assumed in the mentioned studies is of the type

$$Y(t) = K(t)^\alpha [L(t) + R(t)]^{1-\alpha} \quad (1)$$

where $Y(t)$ stands for output, $K(t)$ is conventional physical capital, $L(t)$ represents labor, and $R(t)$ is the stock of robotic capital, which directly substitutes for labor; $\alpha \in (0,1)$ represents the output-capital elasticity. In a competitive market, the wage rate has correspondence with the marginal product of labor, i.e.,

$$w(t) = (1 - \alpha) \left[\frac{K(t)}{L(t) + R(t)} \right]^\alpha \quad (2)$$

Equation (2) indicates that while an increase in physical capital raises the wage rate, the opposite occurs with automation capital. This is because more physical capital stimulates an increase in labor productivity, given their complementary nature. Instead, automation capital is a competitor relatively to labor, and therefore, as the stock of this type of capital is raised, workers become progressively more redundant and their marginal value falls.

Benzell *et al.* (2015) and Sachs *et al.* (2015) also resort to an overlapping generations framework in order to assess the economic implications of human replacement by machines. Their view on the effects of automation over growth and wellbeing is pessimistic. By itself, the model shows, technological progress has the potential to generate economic misery. Only well-designed education and redistribution policies may reverse this immiserating path.

In the above mentioned models, an increase in productivity due to the utilization of robots will raise output temporarily; however, by lowering the demand for labor, it also lowers wages and consumption in the long-run. Robots are an input that allows for production without labor; to

produce with robotic technology, firms only need to make capital investment. If those earning labor and capital income have different propensities to consume, then a change in the labor's share of income can have important effects on savings and investment. Automation involves two offsetting forces: more productivity and the elimination of jobs. The net effect depends on various factors, including policy choices.

6. A SIMPLE ANALYTICAL FRAMEWORK TO ORGANIZE IDEAS

From the above discussed literature, it emerges a series of regularities or stylized facts about the impact of automation over the economy. The substitution of manual and intellectual labor by machines opens a wide range of possibilities concerning the generation of new goods and the increase in the efficiency of production; however, there are risks and obstacles as well. Machines tend to substitute humans in a progressively wider array of tasks, beginning in the routine ones but spreading all over the skills' spectrum. Therefore, job tends to polarize, technological unemployment is likely to persist and increase, and overall welfare might decline.

In this section, in order to synthesize the above ideas, we propose an analytical illustration of the effects of increased automation over jobs, income and utility. A first step consists in recognizing that one has to look at the distribution of people and robots across tasks. Take, as the starting point, the following Weibull distribution,

$$f(x; \omega, \lambda, \theta) = \frac{\omega}{\lambda} \left(\frac{x + \theta}{\lambda} \right)^{\omega-1} \exp \left[- \left(\frac{x + \theta}{\lambda} \right)^{\omega} \right], \quad \omega, \lambda, \theta > 0 \quad (3)$$

Assume that in (3), $x \in (0,1)$ is an array of tasks, ranked from the most basic and intuitive for human beings to those involving a strong degree of sophistication. The outcome f will represent the ability to solve problems, i.e., the ability to perform tasks. The Weibull distribution is useful to approach the relation between tasks and the effectiveness of their completion because different values of parameters will allow describing distinct scenarios about the ability of men and machines in executing tasks. In particular, human labor will imply a relation between x and f that decreases with the complexity of tasks; machines, in turn, will fail in executing the most basic tasks, will perform well in terms of the medium-skilled routine tasks and, again, show an inability to tackle the most sophisticated activities. Therefore, the respective distribution must be hump-shaped.

From the Weibull distributions, we assemble task effectiveness functions for both humans and robots. These will be the following,

$$L(x) = Af(x; \omega_L, \lambda_L, \theta_L), \quad A > 0, \omega_L < 1 \quad (4)$$

$$R(x) = Bf(x; \omega_R, \lambda_R, \theta_R), \quad B > 0, \omega_R > 1 \quad (5)$$

The value of parameter ω determines the type of relation between tasks and their successful fulfillment. If $\omega < 1$, then this is an exponentially decaying relation; for $\omega > 1$, the hump-shaped form of the relation is likely to emerge (an outcome that depends on the value of the other parameters but that is certainly obtained for values of ω significantly higher than 1).

In aggregate terms, function $L(x)$ will represent as well the mass of individuals endowed with the ability to develop task x and that, therefore, specialize in this task. As it is obvious, there is a relatively large number of people capable of developing the simplest tasks but only a few individuals will be able to successfully undertake the most demanding activities, what again justifies the downward shape of function $L(x)$.

Assume that labor is defined in the unit interval. To assure that $0 \leq L(x) \leq 1$, we have to consider that the scaling parameter A is given by

$$A \equiv \frac{1}{\int_0^1 f(x; \omega_L, \lambda_L, \theta_L) dx} \quad (6)$$

Take the example displayed in Fig. 1, where $L(x) = Af(x; 0.5, 10, 0.05)$ and $R(x) = Bf(x; 3, 0.375, 0.05)$. In this case, $A \equiv \frac{1}{\int_0^1 f(x; 0.5, 10, 0.05) dx} \approx 4.7962$ and the value of B is chosen in order to allow for a stronger efficiency of robots over humans for some intermediate (routine) activities; in particular, assume $B=1.5$.

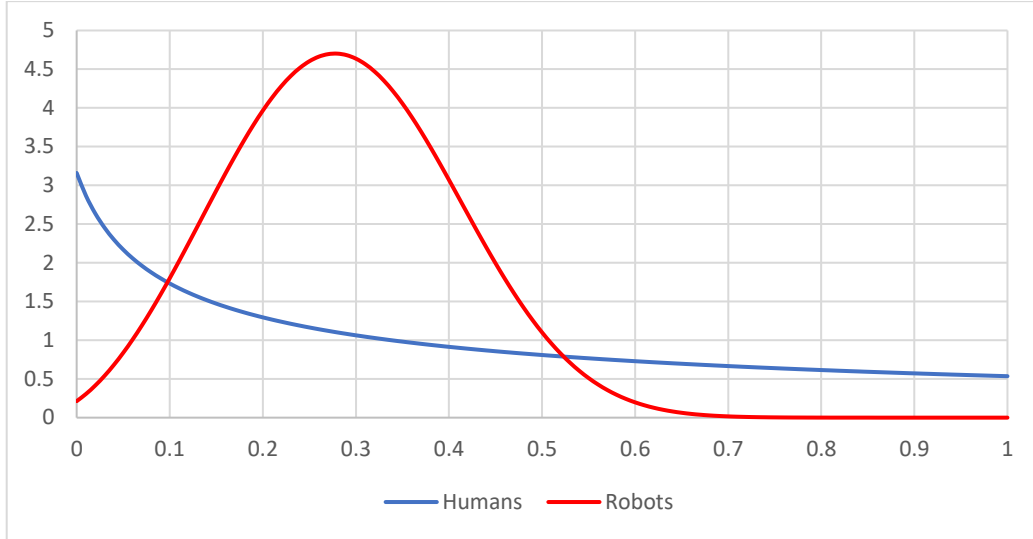


Figure 1 – Distribution of task performance across tasks.

Fig. 1 indicates that tasks within the range $x \in [0; 0.0976)$ should be performed by humans. Their ability to perform tasks is, then, overtaken by machines for the range of tasks $x \in (0.0976; 0.5232)$. Above the last threshold value, humans become again more skillful than machines, in activities that require strong human intuition and creativity.

As long as machines are more skillful than humans in performing some intermediate tasks, as represented in the figure, people can then be separated into three groups:

- Group I: People associated with manual tasks, where humans have advantage in production over machines,

$$L(I) = \int_0^{\bar{z}} L(x) dx \quad (7)$$

- Group II: People associated with routine tasks, where humans are in disadvantage against machines,

$$L(II) = \int_{\bar{z}}^{\bar{z}} L(x) dx \quad (8)$$

- Group III: People associated with creative tasks, where again there is a human supremacy,

$$L(III) = \int_{\bar{z}}^1 L(x) dx \quad (9)$$

where \underline{z} and \bar{z} are, respectively, the first and the second intersection points between $L(x)$ and $R(x)$; in the example, these are the boundaries of x , $\underline{z} = 0.0976$ and $\bar{z} = 0.5232$. Under the assumed example, the obtained values for each share of the labor force are $L(I) = 0.2213$, $L(II) = 0.4725$, $L(III) = 0.3063$.

In our example, a little less than one quarter of the working population is associated with non-replaceable tasks respecting to the lower end of the skills' spectrum, while slightly more than 30% correspond to labor allocated to qualified creative activities that machines cannot develop given the current state of techniques. In this scenario, more than 47% of the labor force is attached to tasks that can be replaced by better performing machines, and therefore these are individuals who will be at risk of not finding a job opportunity consistent with the respective qualification and will probably be pulled back to manual work or will stay out of employment (yet another possibility exists, though it requires a possibly strong personal effort: they can acquire the qualifications that place them in the third segment of the assumed skills' scale).

The values employed in the above example were not selected in an arbitrary way. In order to somehow reflect real world conditions, the exercise was prepared taking into account relevant empirical evidence compiled in Goos *et al.* (2014, p. 2515, Table 2). In the referred table, occupations in the labor market have been separated into three categories: the lowest paying, the middling, and the highest-paying. Shares of labor in each of the three categories were computed, by the mentioned authors, for sixteen European countries, concerning the year 1993; additionally, the growth rate of each share for each country in the period 1993-2010 is also displayed in the table. The data relevant for the numerical example presented so far is the one concerning 1993 (the rate of change will be used later in the example to approach labor market dynamics).

The mentioned table reveals that, once excluded extreme values, the employment share in the lowest paying activities locates between 20% to 25%; the highest paying activities, in turn, represent, for most of the countries in the sample, around 27% to 36%. The remaining share, associated with the occupations found in the middle of the assumed scale, is a value larger than 40% but below 50%. The parameter values selected in our exercise are such that the computed labor shares fall in the intervals suggested by the analysis of the referred table. Therefore, for our study we implicitly assume a correspondence between the three categories in Goos *et al.* (2014) and those that were designated in section 4 as the ones involving, respectively, manual tasks, routine tasks, and abstract tasks. Obviously, this is an oversimplification because not all tasks classified as paying an intermediate remuneration are likely to be subject to replacement

of humans by machines (while some in the other two categories might effectively be subject to such replacement). Nevertheless, despite the possible caveats, the established correspondence allows to approximate our numerical exercise to observed evidence about the structure of the labor market.

Let us return to the specification of our model. It is reasonable to assume that more demanding tasks will deliver goods that have a higher market value and, therefore, allow input owners to earn higher income. Let the income associated with the successful performance of a task be given by

$$Y_L(x) = (1 + x)^a L(x), Y_R(x) = (1 + x)^a R(x), a \geq 1 \quad (10)$$

respectively for humans and machines. The specification of equation (10) indicates that better ranked tasks allow for obtaining progressively higher market rewards. Income by task and by type of producer (humans or robots) is represented in Fig. 2, for $a=7.5$.

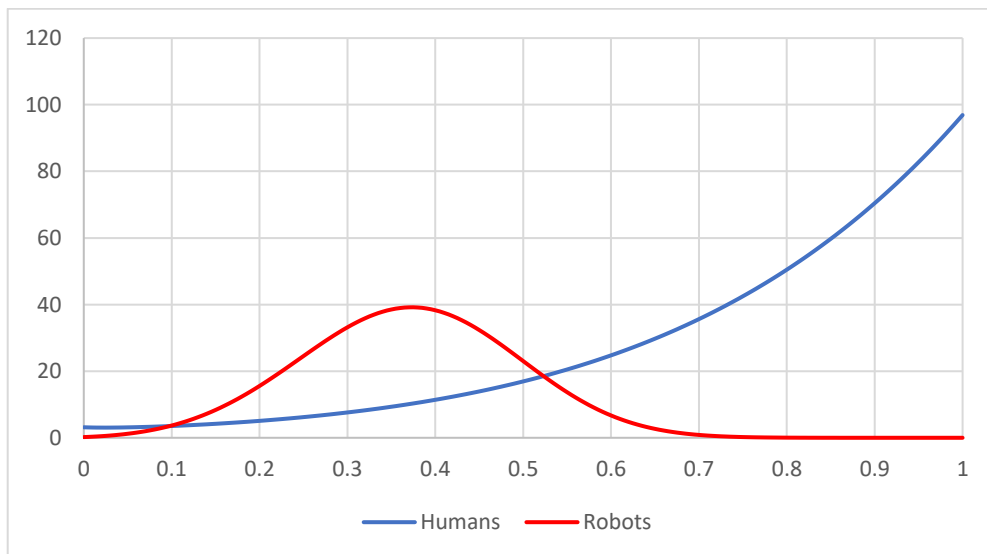


Figure 2 – Income by task.

Individuals in the first part of the scale have access to an aggregate income of

$$Y_L(I) = \int_0^{\bar{z}} (1+x)^a L(x) dx \quad (11)$$

while the highly skilled (people in the third group) get

$$Y_L(III) = \int_{\bar{z}}^1 (1+x)^a L(x) dx \quad (12)$$

Workers in the second group would receive the income given by the following expression, in the complete absence of machines,

$$Y_L(II) = \int_{\underline{z}}^{\bar{z}} (1+x)^a L(x) dx \quad (13)$$

For the values in the example, we have: $Y_L(I) = 0.3113$, $Y_L(II) = 3.8064$, $Y_L(III) = 23.2117$. As Fig. 2 anticipated, a large portion of the gains is reaped by the workers allocated to the abstract qualified tasks, since these are the ones to which the market assigns a higher value. On the contrary, workers in manual tasks capture a very small share of income.

The aggregate income of robot owners, if all activities possible of being automated effectively are passed on to robots, will be given by

$$Y_R = \int_{\underline{z}}^{\bar{z}} (1+x)^a R(x) dx \quad (14)$$

Under the numerical example, $Y_R = 10.7535$. Capital owners are capable of gaining much more when they have the possibility of replacing human labor by machines and artificial intelligence in routine tasks, given the much higher productivity of the latter, as it is evident from the two previously displayed figures.

To workers that eventually become jobless it might be attributed an unemployment benefit. Consider that this benefit equals the income of a worker in the less skillful task, i.e. $y_L(0) = (1 + 0)^a = 1$. Because the mass of workers in group *II* is $L(II) = 0.4725$, this will also be the total amount of the unemployment benefit. This group of workers loses an amount of income $Y_L(II) - L(II) = 3.3339$ due to the hypothetical loss of their jobs, when routine tasks completely migrate to the hands of machines.

Next, consider where the unemployment benefit comes from. Let us assume that a proportional tax is levied on workers with an income higher than a threshold value \underline{y} , i.e., with an income $(1 + x)^a > \underline{y}$. This implies that the tax is paid by workers who perform tasks such that $x > \underline{y}^{1/a} - 1$. For simplicity, assume that \underline{y} is large enough for only workers in group *III* to pay taxes; analytically, this implies $\underline{y} > (1 + \bar{z})^a$.

Therefore,

$$L(II) = \tau \times \int_{\underline{y}^{1/a}-1}^1 (1+x)^a L(x) dx \Rightarrow \tau = \frac{L(II)}{\int_{\underline{y}^{1/a}-1}^1 (1+x)^a L(x) dx} \quad (15)$$

Take $\underline{y} = 100$. In the assumed example, those who pay taxes are only the workers and, from these, the workers engaged in tasks $x > 100^{1/7.5} - 1 = 0.8478$. Workers in the interval $x \in (0.8478; 1)$ will be the taxpayers supporting the unemployment benefit of those whose tasks have been replaced by automated processes. The tax rate will be $\tau = \frac{0.4725}{11.6846} \approx 0.0404$. This result signifies that above the imposed threshold every income owner contributes with a percentage of 4.04% of their income to pay the compensation attributed to those whose skills have become obsolete given the capacity of machines to develop the same tasks.

Applying the mentioned tax rate, the disposable income of workers in group *III* becomes

$$Y_{L,D}(III) = \int_{\bar{z}}^{\underline{y}^{1/a}-1} (1+x)^a L(x) dx + \int_{\underline{y}^{1/a}-1}^1 (1-\tau)(1+x)^a L(x) dx \quad (16)$$

For the numerical illustration, $Y_{L_D}(III) = 11.5271 + 11.2121 = 22.7392$. Logically, the lost aggregate income of this class of workers corresponds to the transfer to workers who have lost their position to machines.

Each worker receives the compensation for her work or the unemployment benefit, depending on the skill she possesses [recall that there is an unspecified number of workers in the interval $(0,1)$]. The income of machine owners is modeled in a different way. Imagine a single firm that undertakes all the robot associated tasks. This firm earns the income given by expression (14). We assume that the firm is owned in equal parts by a share $\phi < 1$ of capitalists / entrepreneurs (by assuming that this value is lower than 1, we are saying that there are fewer capitalists than workers in the economy, which is a reasonable premise). The income of each robot owner will then be Y_R/ϕ .

We can now compute the aggregate utility of each group of agents in this economy, given their income levels. We assume that utility is logarithmic and that all households consume the totality of their income,

$$u(I) = \int_0^z \ln[(1+x)^a]L(x)dx \quad (17)$$

$$u(II) = \ln[(1+0)^a]L(II) = 0 \quad (18)$$

$$u(III) = \int_{\bar{z}}^{y^{1/a-1}} \ln[(1+x)^a]L(x)dx + \int_{\underline{y}^{1/a-1}}^1 \ln[(1-\tau)(1+x)^a]L(x)dx \quad (19)$$

$$u(R) = \ln(Y_R/\phi)\phi \quad (20)$$

Quantifying, for our numerical illustration, we get: $u(I) = 0.0710$, $u(II) = 0$, $u(III) = 1.2701$, $u(R) = 0.4678$ (we assume $\phi = 0.1$). Unemployed workers have utility zero (they all receive a compensation equal to 1); workers in group III have a much larger aggregate income than workers in group I, what implies that aggregate utility is also significantly higher than that

of the first group. The utility of machine owners is determined by the productivity of machines and also by the number of capitalists relatively to the mass of workers.

The global welfare of the society might be assessed by adding up the various utility outcomes, i.e., $U = u(I) + u(II) + u(III) + u(R) = 1.8089$. This value will be compared with the one that will be obtained in the next section, where a similar scenario is considered, but an increase in the productivity and pervasiveness of machines and automated processes is considered.

7. MODELLING THE RISE OF ROBOTS

Let us now consider a ‘rise of robots’ scenario, i.e., a technological breakthrough that elevates the skillfulness of the machines. This might translate into an increase of the value of parameter B . Let $B'=2$ be the new value of this parameter (recall that the original value was $B=1.5$). The new value of the parameter is chosen, as other values were previously selected, to conform with the empirical evidence; again, we refer to Table 2 in the paper by Goos *et al.* (2014), where, from 1993 to 2010, middling payed activities have lost around 8% to 11% of the existing jobs to the occupations in both ends of the skills distribution. The new value considered for parameter B will lead to an increase in the percentage of tasks where human labor might be discarded in favor of machines that falls inside the mentioned interval.

The impacts on task performance and task income are presented in Figs. 3 and 4.

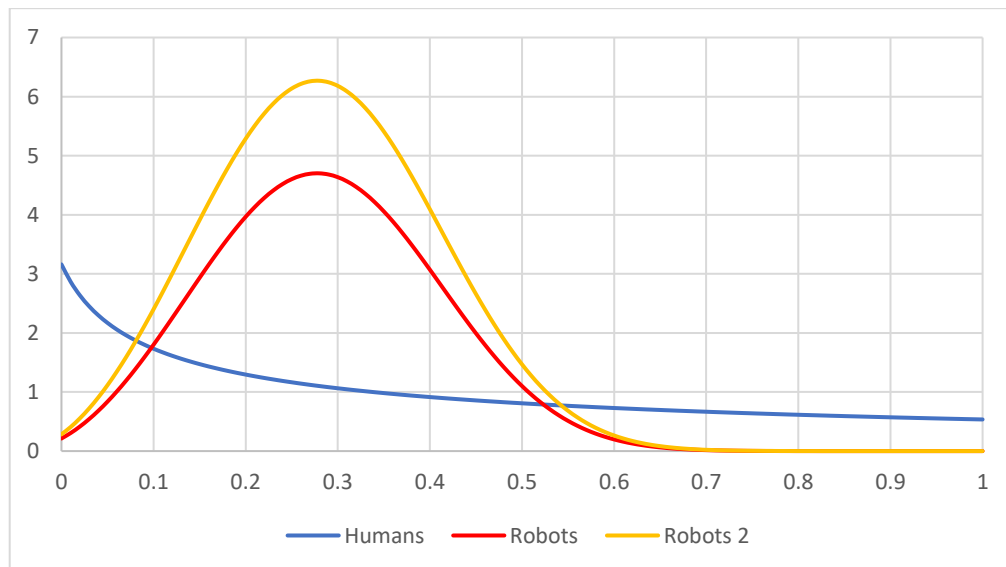


Figure 3 - Distribution of task performance across tasks, for an increase in robot skillfulness.

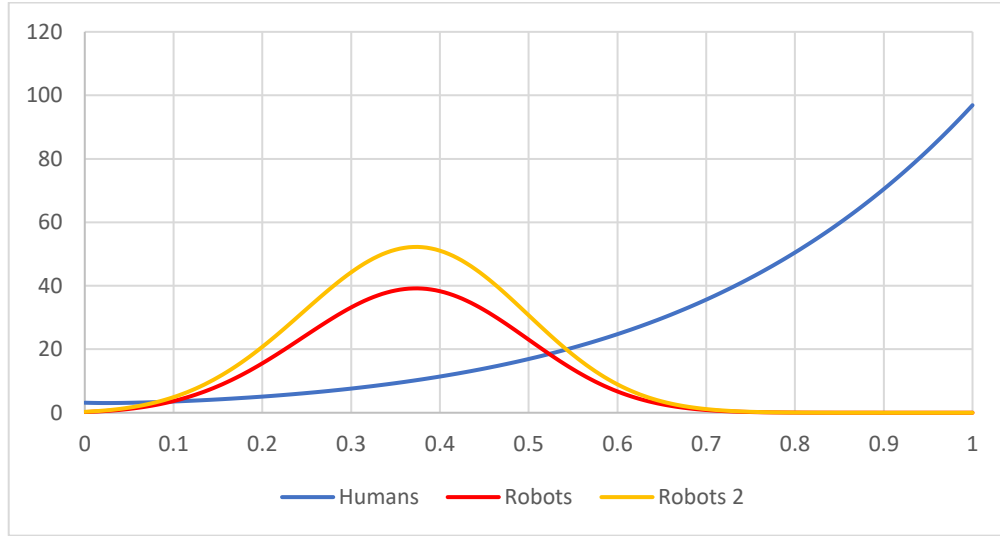


Figure 4 – Income by task, for an increase in robot skillfulness.

An overall increase in the robotic capacity of the economy implies, as indicated in the figures, a stronger efficiency associated with the activities already pursued, but also the replacement of human labor by machines on both sides of the task spectrum. There are some manual tasks that are hypothetically lost to robots, but there are also intellectually demanding activities that suffer the same fate.

For our example, we can quantify the effects. The relevant thresholds are now $\underline{z}' = 0.0809$ and $\bar{z}' = 0.5426$. The three shares of labor become $L'(I) = 0.1911$, $L'(II) = 0.5178$, $L'(III) = 0.2912$. Given the increase in machine productivity there is now a wider range of occupations for which labor might be replaced by machines; this amount has risen by almost 10%, which is a value within the range admitted by Goos *et al.* (2014) as representing the migration of people from routine jobs to other activities in the time frame 1993-2010.

Our ultimate goal is, again, to quantify utility levels for each group and for the overall economy and, thus, we follow the same steps as in the previous analysis. The gross income levels of workers in groups I and III are, respectively, $Y_L'(I) = 0.2540$, $Y_L'(III) = 22.8389$ (because less workers are now associated with each of these groups, their aggregate income is lower). The aggregate income generated by robots is, in the new setting, $Y_R' = 14.8369$, a value that is significantly higher than the previous one because not only the income generated by each already existing machine increases, but also because there are new machines penetrating tasks that were, in the previous period, within the domain of workers.

Total income is, in the initial period,

$$Y(t) = Y_L(I) + Y_L(III) + Y_R = 34.2765$$

and, after the robot new wave,

$$Y(t + 1) = Y_L'(I) + Y_L'(III) + Y_R' = 37.9298$$

Income increased approximately 10.66%. Is this increase in income reflected on the utility of the society? Let us do the math.

For the same set of parameter values and recovering equation (15), it is straightforward to compute the new tax rate, that workers in interval $x \in (0.8478; 1)$ will hypothetically pay in order to transfer a minimum income for unemployed workers; the rate is now $\tau = \frac{0.5178}{11.6846} \approx 0.0443$. The same individuals, those with the highest incomes, will now pay a relatively larger amount of taxes because the number of unemployed people has increased.

Finally, we compute utility levels,

$$u'(I) = \int_0^{\bar{z}'} \ln[(1+x)^a]L(x)dx = 0.0517$$

$$u'(II) = 0$$

$$\begin{aligned} u'(III) &= \int_{\bar{z}'}^{\frac{1}{y^{\frac{1}{a}-1}}} \ln[(1+x)^a]L(x)dx + \int_{\frac{1}{y^{\frac{1}{a}-1}}}^1 \ln[(1-\tau)(1+x)^a]L(x)dx \\ &= 0.8052 + 0.4161 = 1.2213 \end{aligned}$$

$$u'(R) = \ln\left(\frac{Y_R}{\phi}\right)\phi = 0.5$$

Overall, utility is now $U' = u'(I) + u'(II) + u'(III) + u'(R) = 1.7730$. Observe that $U' < U$ ($1.7730 < 1.8089$), what means that, despite the significant increase in the generated income (more than 10%), the sum of the utility of all agents in the economy falls. Basically, there is a winning group, the robot owners, and two losing groups: those who eventually become unemployed due to technological progress and those who have to pay taxes to compensate jobless workers. In an economy, as the one considered, where the number of machine owners is much smaller than the number of workers composing the labor force, this implies that few

gain a lot while many lose something. The joint effect is an eventual increase in aggregate income that occurs simultaneously with a loss in social welfare.

The proposed simple paradigm allows us to deepen the discussion on the economic consequences of automation. Three points in particular deserve a reflection and evaluation under this framework.

First, we have basically assumed a change in robots' performance, but one can also consider a change in human qualifications. Proper education policies and an individual effort stemming from the observation that education may be a way out of unemployment may lead to a change in the configuration of function $L(x)$. Maintaining $L=1$, the enhancement of skills would lead to a flatter frontier, and thus stolen jobs would be more of a manual nature, while workers would gain supremacy in a wider array of qualified tasks. The issue is whether the pace of increasing human skills is sufficient to overthrow the fast innovation in automation.

Second, the only assumed redistributive policy in the presented analytical framework is associated with the transfer of income from those in the right end of the labor distribution to those that lose their jobs to machines. Stronger redistributive policies may enhance welfare since, in fact, more is produced. Care is needed for redistribution not to constitute a disincentive to innovation.

Third, by concentrating income the described process might be contracting demand and, thus, implying an obstacle to long-term growth, as discussed in section 5. Measures must be taken for robotization not to be synonymous of exaggerated concentration of income and wealth. In our model, this signifies implementing policies that increase the value of parameter ϕ , i.e., policies that allow to expand the pool of robot owners.

Although the developed model is far from comprising all the relevant features that help in fully understanding the deep and pervasive impact of the replacement of people by machines in production, it is, nonetheless, a stylized framework capable of putting together some important pieces. Fundamentally, it illustrated how the replacement of people by robots potentially conducts to contradictory consequences: on one hand, overall productivity and income will surely rise; on the other hand, as the numerical example shows, it is likely that the consequent concentration of income leads to a fall in social welfare. The challenge, for public authorities, is to guarantee that the gains from automation are not reaped by a few capital owners at the expenses of those who *only* have to offer their more or less qualified working skills.

8. CONCLUSION

Where are we today? In three points, we surely all agree that (1) We are living in a time of astonishing progress with digital technologies; (2) The transformations brought about by digital technologies are profoundly beneficial; (3) Digitization brings some thorny challenges, namely in terms of employment and income distribution. In synthesis, the wonders of digital technologies must not be undervalued, although the perils they bring to the economy, namely in terms of the potential massive loss of jobs, should not be neglected as well.

There is, by now, in the context of the economic science, a large amount of literature assessing the impact of robots over jobs, wages, inequality and growth. This literature has been reviewed in this text. The resulting final message is ambiguous: workers, even high skilled ones, are in fact being replaced by machines and jobs are being lost; however, the appropriate policies and business practices may allow, and should allow, to take advantage of the robots' higher productivity, offering to workers higher wages and more leisure time.

Also, education and organizational innovation are fundamental to keep up with technological innovation and to transform the dangers of the digital economy into opportunities for all. Digital innovation is doing to our brains the same thing the steam engine did to our muscles: it allows to mechanize what previously seemed impossible to detach from human intervention. Artificial intelligence is leading us to places never before imagined.

Technological progress, given its nature, also tends to provoke anxieties. These anxieties are, according to Mokyr *et al.* (2015), of three types: 1. substitution of machines by labor; 2. moral implications and wellbeing issues brought about by the changes under progress; 3. the possibility of technological progress coming to an end. These worries are not new, and although the current evolution of techniques undisputedly possesses some peculiar features, the anxieties are, as in the past, exaggerated relatively to what should be the predictable future. Technophobia is understandable but exaggerated. Robots will not replace humans in every task and new activities will surely thrive; robots will not certainly conduct the economy and the society to inevitable pervasive misery.

This study has also sketched an analytical framework to address the economic impact of automation. By identifying the profile of effectiveness of task resolution by humans and machines, it became straightforward to exemplify how an economy that replaces labor by robots might grow in the short-run at the same time that aggregate welfare falls. This happens because capital owners are typically a smaller group than the one constituted by workers (labor, by its

nature, is necessarily dispersed because it cannot be detached from the households who provide it; capital, in turn, tends to concentrate in the hands of few).

The research in this paper suggests that, despite the voluminous amount of literature already produced on the theme of the economic consequences of the robot era, further work continues to be welcomed. It suggests that economic theory must continue to evolve in order to explain new challenging and fast changing phenomena. It also suggests that automation is impacting strongly the economy and the society: labor-leisure choices of households are changing, investment decisions of firms are evolving to new paradigms, and public authorities are being pressured to engineer the devices that are indispensable for a balanced and equitable social development.

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IMPACTO MACROECONÓMICO DA ROBÓTICA

1. INTRODUÇÃO

É sabido que no final do séc. XIX, com a Revolução Industrial, com a invenção da máquina a vapor que dispensou a utilização o uso das forças naturais e causou uma profunda transformação nos transportes, com as ferrovias, com a utilização da eletricidade, gerou o aparecimento da grande indústria e o surgimento do proletariado, assim como uma modificação radical nas estruturas económica, social e política das sociedades.

Ora, atualmente, vivemos uma nova revolução social com a automação, na qual o esforço físico do Homem é substituído por máquinas calculadoras, ordenadoras, corretoras e controladoras do seu próprio trabalho. Vivemos em tempos de progresso devido às tecnologias digitais, contribuindo para grandes benefícios, mas também grandes desafios.

Nesta secção da dissertação, usando como base o artigo escrito por Orlando Gomes e Sónia Pereira (2018), *“On the Economic Consequences of Automation and Robotics”*, o proposto é analisar e debater o impacto e consequências socioeconómicas do crescente desenvolvimento na automação e robótica nos sectores de atividade.

Logo, tal como no artigo que serve de base para esta reflexão, este capítulo também será constituído por duas partes principais: a primeira composta pelo estado de arte, considerando o papel da automação na produção e a sua rápida evolução tecnológica, e a segunda parte, analítica, com o desenho de um modelo que expõe a interligação entre as principais especificidades associadas à nova realidade económica que atravessamos.

Tendo por base literatura recente sobre as consequências económicas da rápida automatização da atividade produtiva, dando especial ênfase nos assuntos relacionados com o emprego e crescimento económico, podemos encontrar uma mistura entre o ceticismo cauteloso e o otimismo moderado nas obras dos autores.

A sistematização da literatura teórica e empírica sobre o tema permitirá desvendar uma série de padrões ou fatos estilizados que foram usados por Gomes e Pereira (2018), posteriormente, para montar um modelo teórico que possa servir de referência para compreender melhor a problemática.

2. EVOLUÇÃO TECNOLÓGICA

Estamos perante a era dos robôs. Os robôs distinguem-se das outras máquinas porque são entidades que podem ser programadas para desenvolver tarefas que criam valor sem a necessidade de intervenção humana (Freeman, 2015). De acordo com os autores Graetz e Michaels (2015), os robôs conseguem trabalhar sozinhos sem ajuda direta de algum ser humano. Obviamente que isto implica uma enorme alteração no paradigma económico, com implicações profundas desde a organização das tarefas produtivas e oportunidades de emprego até à distribuição de rendimentos e salários e a dinâmica do crescimento da economia (Gomes; Pereira, 2018).

É importante reforçar que a temática do desenvolvimento na automação industrial, mais especificamente, na robótica e desenvolvimentos mais avançados, está intimamente relacionada com a evolução da tecnologia da microeletrónica e das suas aplicações produtivas.

A nova revolução robótica é mais do que um processo de substituição de pessoas por máquinas. De facto, a parte física das máquinas é cada vez menos central, graças à possibilidade de separar o software do hardware, processo este, cada vez mais simples e comum. Esta separação significa que as máquinas podem receber a informação e conhecimento que precisam para funcionar, de fontes remotas, externas e difusas, com informação a ser comunicada continuamente e a alta velocidade através da internet e outros canais eletrónicos. A troca de informação e conhecimento numa escala global, cria possibilidades sem precedentes, tendo em consideração o desenvolvimento da inteligência artificial, e permite a emergência da robótica através da *Cloud*, uma ferramenta fundamental para o futuro da produção e distribuição de produtos e serviços (Gomes; Pereira, 2018).

Capacitar robôs com tecnologia de Nuvem, permitiu uma revolução na forma como as atividades produtivas são automatizadas. Independentemente da distância, as máquinas são capazes de aceder à informação, que pode ser facilmente adaptada à tarefa que é suposto exercerem. Além disso, a aprendizagem destas máquinas torna-se possível porque elas encontram-se interligadas, isto é, elas absorvem da mesma central de conhecimento e informação (Gomes; Pereira, 2018).

A forma destas máquinas de adquirir conhecimento está-se a tornar no que é designado por aprendizagem profunda. A aprendizagem profunda, *deep learning*, consiste no ato do robô obter conhecimento a partir de uma vasta base de dados que é armazenada na *Cloud*. Os algoritmos do conhecimento profundo permitirão aos robôs fazer pensamentos elaborados e usar alguns dos sentidos que hoje em dia são exclusivos dos seres humanos (Gomes; Pereira, 2018). A possibilidade de aprender a partir de conhecimento de dados codificado tem vindo a ser potenciado pelo fácil e rápido acesso a grandes bancos de bases de dados em qualquer parte do Mundo. O crescimento da performance dos computadores, melhorias no armazenamento e o uso de energia, são elementos de um novo contexto que permitirá aos robôs prosperar. Os computadores podem aprender muito mais rápido que os seres humanos e a evolução poderá levar-nos a um nível onde processos como a imaginação humana poderão ser replicados por máquinas (Gomes; Pereira, 2018).

As perspetivas para o futuro apontam nitidamente no sentido de um desenvolvimento cada vez mais acelerado da automação, disseminando e aprofundando, em consequência, o seu impacto sobre as estruturas económicas e sociais. Dum ponto de vista económico, é importante reforçar que a computação na Nuvem ou na *Cloud*, aprendizagem das máquinas, ou outros desenvolvimentos na área da robótica, introduzem flexibilidade nas atividades das organizações (Gomes; Pereira, 2018).

De acordo com os autores Bayrak et al. (2011), a principal consequência económica da onda corrente da automação sobre a organização da atividade económica concentra-se na possibilidade de converter custos fixos em custos variáveis. As empresas e organizações já não precisam de investir grandes somas de capital financeiro para tirar vantagens da mecanização das atividades. A maior parte dos processos automatizados depende de software que pode ser contratado ou adquirido em módulos, que permite que a automação progrida lado a lado com outros variáveis. A economia digital introduz flexibilidade, permitindo que a *Cloud* seja sinónimo de redução de custos e aumento da eficiência.

3. AUTOMAÇÃO E EMPREGABILIDADE

Transições económicas motivadas pela inovação tecnológica sempre levaram a mutações na estrutura da empregabilidade. Ford (2015) sublinha que a primeira vez que isto ocorreu foi com a mecanização da agricultura e depois com a implementação de linhas de montagem na indústria. Em ambos os casos, uma transição penosa ocorreu com a inevitável perda de empregos.

Contudo, a economia conseguiu adaptar-se a essas mudanças, criando novos postos de trabalho, alguns mais agradáveis, e por estarem relacionados com competências menos repetitivas, também mais bem remunerados (Felten et al., 2017).

No entanto, a vaga recente de automação parece possuir algumas características distintivas quando comparada com o que se passou no passado. Desde o início do século, as economias têm continuado a crescer, praticamente nenhum posto de trabalho foi criado em algumas dessas economias, o que implica alterações profundas na distribuição de rendimentos. Se no passado, as máquinas eram um complemento, atualmente, as máquinas substituem trabalhadores. As novas tecnologias, associadas à revolução digital, trouxeram novas realidades. A velocidade e a frequência com que as novas tecnologias emergem, além disso, a capacidade que têm de penetrar em áreas de conhecimento e ação que até recentemente eram exclusivamente de humanos são os fatos mais notáveis (Felten et al., 2017).

Nesta nova era já não são só os trabalhos associados a competências mais básicas que estão em risco, mas sim em todas as áreas onde os procedimentos são previsíveis e podem ser traduzidos em algoritmos tais como conduzir um veículo; ensinar uma aula, dar conselhos médicos a um paciente. As máquinas estão a invadir todas as áreas de intervenção humana, incluindo áreas que exigem conhecimentos mais avançados (Gomes; Pereira, 2018). Ford (2015) sugere profissões tais como advogados, jornalistas, cientistas e farmacêuticos. Adicionalmente, a rapidez extrema do progresso nas novas tecnologias faz com que seja extremamente difícil para pessoas que são substituídas, de encontrar uma alternativa. Contudo, a habilidade criativa ainda está na mão dos humanos.

Este processo de desumanização no trabalho não é uniforme. Alguns sectores tradicionais continuam a empregar grandes quantidades de pessoas, enquanto algumas empresas, em novos sectores, associados por exemplo a negócios online, empregam relativamente poucas pessoas. Como resultado o paradigma económico está a alterar, é essencial redistribuir políticas e redesenhar a arquitetura do Estado Social de raiz, assim como o sistema de ensino e aquisição de competências requeridas numa economia cada vez mais automatizada (Gomes; Pereira, 2018).

4. ESTUDOS EMPÍRICOS

Atualmente os estudiosos acreditam que a inovação leva ao crescimento económico. Seguindo esta linha de pensamento, a inteligência artificial (IA) traz grandes promessas no que toca ao crescimento económico. De acordo com Graetz e Michaels (2015), a robótica com tecnologia avançada somou uma percentagem média de 0,37 no crescimento anual do PIB (Produto Interno Bruto) entre 1993 e 2007 para os 17 países da amostra. Os autores notaram que estes efeitos podem ser comparados ao impacto dos motores de vapor no crescimento no Reino Unido.

Contudo, enquanto a robótica e a inteligência artificial crescem, o efeito no emprego é menos claro. Historicamente, há evidência empírica que comprova que a automação tanto pode complementar como substituir postos de trabalho. Os autores Autor e Salomons (2017) afirmam que, mesmo que o emprego decresça dentro de uma indústria com aumentos de produtividade específicos, o efeito negativo das quedas de empregabilidade é mais do que compensado por repercussões positivas para outros sectores. Da mesma forma, num estudo que examinou os efeitos do e-commerce em tijolo e argamassa em lojas de retail, Mandel (2017) mostrou que novos empregos criados em call centers e outros sectores, mais do que complementaram qualquer perda de emprego em lojas físicas, causada pela ascensão do comércio eletrónico. No caso específico de robôs, a pesquisa fornece resultados mistos, com alguns autores como Graetz e Michaels (2015) que não encontram qualquer efeito, e outros como Acemglou e Restrepo (2017) que encontraram evidências de que a adoção de robôs leva a perdas de emprego.

Frey e Osborne (2017) desenvolveram um estudo para tentar determinar como os empregos podem ser suscetíveis à automação por forma a dar uma ideia do impacto da automação sobre a empregabilidade nos EUA. Os autores focaram-se principalmente na aprendizagem da máquina e na sua aplicação em robótica móvel, e propuseram um modelo para prever a extensão do impacto da informatização em tarefas não rotineiras. Eles notaram potenciais obstáculos de engenharia em tarefas que envolviam altos níveis de perceção e manipulação, inteligência criativa e inteligência social (Felten et al., 2017).

Depois de categorizarem as tarefas através da sua suscetibilidade para automação, os autores mapearam essas tarefas para o motor de pesquisa de emprego O*NET que fornece descrições de competências e responsabilidades envolvidas numa ocupação ao longo do tempo. A integração deste conjunto de dados com o emprego e os salários da Secretaria de Estatística Trabalhista, trata se de uma unidade do departamento do trabalho dos EUA, a principal fornecedora de dados e fatos para o governo dos EUA quem no campo da economia quer na área da estatística do trabalho (Bureau of Labour Statistics – BLS), permitiu que os autores

conseguissem caracterizar certos subconjuntos do mercado de trabalho em alto, médio ou baixo risco de automação (Felten et al, 2017).

O estudo considera que 47% do emprego nos EUA está em alto risco de informatização. É de notar que este estudo está num nível agregado e não avalia como as organizações e empresas podem reagir, quais as medidas de salvação de postos de trabalho que possam surgir ou produtividade potencial e crescimento económico (Felten et al., 2017).

O trabalho de Frey e Osborne foi aplicado por outros investigadores noutros países – Brzeski e Burk (2015) sugerem que 59% dos postos de trabalho na Alemanha estão em alto risco de serem automatizados, enquanto, conduzindo a mesma análise na Finlândia, Pajarinen e Rouvinen (2014), sugerem que 35,7% dos empregos estão em alto risco de automação (Felten et al., 2017).

O relatório da OCDE também fez um estudo para avaliar a automatização de empregos em 21 países membro. A OCDE argumenta que haverá determinadas tarefas que serão deslocadas e que na medida em que há tarefas que diferem dentro das ocupações e mediante os países, pode haver certas funções menos propensas à automação do que Frey e Osborne previram (Felten et al., 2017).

Contando com a categorização de tarefas feita por Frey e Osborne, os autores mapeiam a suscetibilidade das tarefas à automação para os dados dos EUA a partir do Programa para a Avaliação Internacional das Competências Adultas (PAICA), uma fonte de dados que contem indicadores sobre características socioeconómicas, competências, informações relacionadas com o trabalho, tarefas e competências a nível individual. De seguida, construíram um modelo usando o PAICA para prever a suscetibilidade de automação para comparar com os dados de Frey e Osborne (Felten et al., 2017).

Ao realizar a análise a nível individual, a OCDE argumenta que é mais capaz de dar conta da variação da tarefa entre indivíduos dentro da mesma ocupação. Como resultado, o relatório sugere que Frey e Osborne sobrestimaram a medida em que as ocupações seriam suscetíveis à automação e o relatório da OCDE argumenta que apenas 9% dos postos de trabalho nos EUA e nos países da OCDE serão altamente suscetíveis à automação. O relatório sugere ainda que o percentual pode variar entre os países da OCDE, que variam de 6% (na Coreia) até 12% (na Áustria) (Felten et al., 2017).

Man e Puttman (2017) têm uma abordagem diferente para analisar os efeitos da automação no emprego. No seu estudo, os autores dependem de informações fornecidas a partir de patentes concedidas. Eles aplicam um algoritmo de aprendizagem de máquinas a todas as patentes

concedidas entre 1976 e 2014 para identificar patentes relacionadas com a automação (uma patente de automação é definida como um dispositivo que opera independentemente da intervenção humana e cumpre uma tarefa com razoável conclusão). Eles, então, ligam as patentes de automação às indústrias que são susceptíveis de serem utilizadas (Felten et al., 2017).

Ao examinar indicadores económicos em comparação com a densidade de patentes de automação utilizadas numa área, os autores concluíram que, embora a automação faça com que o emprego de produção caia, ao mesmo tempo, aumenta o emprego no sector de serviços, e no global tem um impacto positivo (Felten et al., 2017).

5. POLARIZAÇÃO DO MERCADO DE TRABALHO

Segundo David Autor (2014) sublinha que, embora a percentagem de ocupações em diversas áreas de atividade, estejam a ser “invadidas” por máquinas, sobram muitas funções onde a automação e os robôs podem assistir os trabalhadores, mas não os podem substituir. Sob esta perspetiva, se por um lado as tarefas que seguem rotinas com procedimentos codificáveis podem, efetivamente, ser automatizadas, por outro, aquelas que requerem julgamento e conhecimento tácito são mais resistentes. De facto, computadores podem substituir os homens em tarefas rotineiras, amplificando a vantagem do ser humano naquelas tarefas que exigem criatividade, adaptabilidade e humanidade.

De acordo com o autor, o mercado está polarizado: enquanto as máquinas podem substituir os homens em tarefas rotineiras, há dois tipos de tarefas não rotineiras nas quais as pessoas ainda são requeridas (Gomes; Pereira, 2018):

- Tarefas abstratas – que requerem competências de alta performance, que exigem conhecimento, criatividade e intuição.
- Tarefas manuais – as competências exigidas são mais básicas, mas requerem a interação humana, como por exemplo, atender numa loja ou dar assistência médica. Estas tarefas podem não exigir tanto conhecimento, contudo, são impossíveis de codificar em algoritmos.

Os autores Graetz e Feng (2015) construíram e analisaram um modelo que situa a polarização dos empregos. A particularidade é, quais são as tarefas que as empresas e organizações optam por automatizar. Algumas tarefas são complexas dum ponto de vista construtivo e de desenvolvimento, mas simples para os humanos aprenderem, enquanto outras tarefas, são fáceis

de tornar rotineiras, porém difíceis de aprender por humanos (ou tomam mais tempo de aprendizagem ou formação). Para duas tarefas com complexidade em termos de desenvolvimento, a empresa opta por automatizar aquela que requer menos treino por parte de seres humanos, porque isso traz custos. Assim, conclui que há tarefas que não podem ser automatizadas e das que podem ser automatizadas, as empresas optam por não o fazer, tais como serviços de limpeza, cozinhar e cortar o cabelo (Gomes; Pereira, 2018).

6. ECONOMIA, DISTRIBUIÇÃO DE RENDIMENTOS E AUTOMAÇÃO

O desemprego persistente que o aumento atual do desenvolvimento tecnológico desenvolve é suscetível de trazer algumas dificuldades não só para grupos específicos, como também para a economia como um todo. Uma vez que os rendimentos se concentram nas mãos de alguns “donos das máquinas”, os aumentos de salários, tipicamente provenientes, no passado, do aumento de produtividade, atualmente já não são significativos. Isto poderá implicar uma quebra forte e súbita nas despesas do consumidor, desviando a economia do seu potencial caminho de crescimento (Gomes; Pereira, 2018). Estabelecido este estado das coisas, a capacidade da economia para criar riqueza pode ser comprometida.

Graetz e Michaels (2015) observam que os avanços na robótica continuarão e que provavelmente irão beneficiar o crescimento. No entanto, ao mesmo tempo, tanto robôs como seres humanos estão sujeitos a rendimentos marginais decrescentes e os efeitos do congestionamento são suscetíveis de se fazer sentir em várias áreas onde a automação é forte. A inovação deve ser muito mais do que um processo repetitivo de aumentar a produtividade dos robôs nas mesmas tarefas. Sem novos produtos, novas formas de gestão da produção e novas formas de alcançar os consumidores, tanto robôs, como outras máquinas, como trabalhadores serão sujeitos, progressivamente, a menores contribuições marginais provenientes da produção (Gomes; Pereira, 2018).

Prettner (2016) investigou a dinâmica de um modelo de crescimento neoclássico modificado. A diferença relativamente ao modelo padrão do crescimento da acumulação de capital é que o capital da automatização em vez de complementar o trabalho é um substituto perfeito para ele. Na função de produção, a nova entrada (capital de automação) aparece como um substituto direto para o trabalho. Neste caso, é direto provar que haverá um crescimento perpétuo da saída per capita mesmo na ausência do progresso tecnológico (Gomes; Pereira, 2018).

Gasteiger e Prettner (2017) recorreram ao mesmo tipo de função de produção, mas aplicaram-no a uma estrutura de gerações sobrepostas. Mais uma vez, os retornos constantes à prensão do capital na ausência do progresso tecnológico, contudo, a estrutura do modelo não conduz ao crescimento sustentado a longo prazo. Isto acontece porque os salários são assumidos como a fonte de investimento e a automação implica uma perda agregada em salários. Tal resultado contradiz o do modelo de crescimento do agente representativo de Prettner (2016), porque neste primeiro modelo o agente poderia investir tanto fora da renda salarial e de renda de ativos. Esta nova versão do modelo de crescimento pretende ilustrar o efeito perverso sobre o crescimento da queda dos salários que vem associado à invasão robótica (Gomes; Pereira, 2018).

7. MODELAÇÃO ANALÍTICA DA ASCENÇÃO DOS ROBÔS

De acordo com os autores Gomes e Pereira (2018) será considerada agora uma "ascensão do cenário dos robôs", isto é, um avanço tecnológico que eleva a habilidade das máquinas. Isso pode ser traduzido num aumento do valor do parâmetro B .

Considera-se então $B=2$ como o novo valor de B (até aqui estava a ser considerado $B=1.5$) e os outros valores foram selecionados previamente para se conformar com a evidência empírica da tabela 2 do artigo de Goos et al. (2014) (ver tabela 1) que conclui que entre 1993 e 2010, as atividades medianas perderam cerca de 8% a 11% dos postos de trabalho existentes para ocupações em ambas as extremidades da distribuição de competências. O novo valor para B levará a um aumento na percentagem de tarefas em que o trabalho humano pode ser descartado em favor das máquinas (Gomes; Pereira, 2018).

	Four lowest-paying occupations		Nine middling occupations		Eight highest-paying occupations	
	Employment share in 1993 (in percent)	Percentage point change 1993–2010	Employment share in 1993 (in percent)	Percentage point change 1993–2010	Employment share in 1993 (in percent)	Percentage point change 1993–2010
Austria	21.82	6.36	51.61	-10.44	26.57	4.08
Belgium	17.49	3.00	48.50	-12.07	34.01	9.08
Denmark	24.09	1.73	39.70	-10.30	36.21	8.56
Finland	20.24	-1.50	39.69	-10.60	40.06	12.10
France	19.92	4.19	46.69	-8.60	33.39	4.41
Germany	20.71	2.37	48.03	-6.74	31.26	4.37
Greece	21.66	4.81	47.81	-10.65	30.54	5.84
Ireland	21.13	3.68	48.21	-14.85	30.66	11.17
Italy	27.01	6.06	51.04	-10.59	21.94	4.53
Luxembourg	21.70	-2.38	49.91	-10.76	28.40	13.15
Netherlands	16.78	1.99	37.90	-7.56	45.33	5.57
Norway	22.85	4.73	38.82	-8.47	38.34	3.74
Portugal	25.75	0.73	47.46	-4.86	26.78	4.13
Spain	28.02	1.01	48.67	-11.95	23.30	10.93
Sweden	21.82	1.52	41.98	-9.55	36.20	8.03
United Kingdom	16.88	4.17	43.64	-10.94	39.49	6.77

Table 1 *Ações iniciais de horas trabalhadas e percentual de mudanças (por país)*

Fonte: Goos et al., 2014

De acordo com os autores, o simples paradigma proposto permitiu aprofundar a discussão sobre as consequências económicas da automação. Em particular, três pontos mereceram reflexão e uma avaliação no âmbito deste cenário (Gomes; Pereira, 2018):

- Basicamente foi assumida uma mudança no desempenho dos robôs, mas pode-se também considerar uma mudança nas qualificações humanas. Políticas de educação adequada e um esforço individual decorrente da observação de que a educação pode ser uma saída do desemprego pode levar a uma mudança na configuração da função $L(x)$. De acordo com os autores, “Mantendo $L = 1$, o aprimoramento das habilidades levaria a uma fronteira plana, e, assim, os empregos “roubados” seriam mais de natureza manual, enquanto os

trabalhadores ganham supremacia numa ampla gama de tarefas qualificadas. A questão é saber se o ritmo de aumentar as habilidades humanas é suficiente para derrubar a rápida inovação na automação” (Gomes; Pereira, 2018).

- A única política de redistribuição assumida no quadro analítico apresentado está associada à transferência de rendimentos daqueles que estão no lado direito da distribuição trabalhista para aqueles que perdem os seus empregos às máquinas. Políticas redistributivas mais fortes podem aumentar o bem-estar, pois, de fato, mais é produzido. Todo o cuidado é necessário para que a redistribuição não constitua um desincentivo à inovação.
- Concentrando os rendimentos, o processo descrito pode implicar um obstáculo ao crescimento a longo prazo. Medidas devem ser tomadas para que a robótica não seja sinónimo de concentração exagerada de rendimentos e riqueza. Neste modelo, significa implementar políticas que permitam expandir o número de proprietários de robôs.

8. IMPACTOS DA AUTOMAÇÃO – SOCIAL E ECONÓMICO

A inovação tecnológica causa alterações profundas na sociedade. Se olharmos para o exemplo da iniciação da agricultura, o que aconteceu foi que o homem deixou de ser nómade e passou a ser sedentário, fixando a sua residência onde o cultivo era mais produtivo. Se tomarmos o fenómeno da agricultura como exemplo, com certeza “sociólogos” da época afirmariam que esta nova “tecnologia” traria impactos negativos, como por exemplo, fixa-lo num só local onde ele iria nascer e morrer, impedindo que lhe trouxesse o conhecimento adquirido pela movimentação para outros locais de saber se haveria um local melhor para caçar. Este argumento, analisado nos dias de hoje, parece absurdo pois temos bom conhecimento que as vantagens superaram as desvantagens, contudo, isto é dito nos dias de hoje (Leal, 2005).

Da mesma forma podemos analisar o efeito que as novas tecnologias causam, assim como a sua polémica, onde existem grupos que argumentam e debatem se os pontos positivos superam ou não os pontos negativos.

Já foi referido que com a Revolução Industrial, a polémica sobre estas questões causou inúmeros debates. Se por um lado a produção em massa gerou a descida dos preços dos bens de consumo,

permitindo que as pessoas tivessem acesso a eles, por outro lado, a linha de produção encaminhou alterações profundas no regime de trabalho.

Se analisarmos o fenómeno da linha de montagem inventado por Ford, podemos constatar o seguinte (Leal, 2005):

- Em 1914 a sua fábrica tinha 7882 tarefas distintas, onde menos de metade requeriam operários em condição física dita normal, enquanto as restantes não requeriam uma plena capacidade física;
- Das tarefas de precisão, 670 podiam ser executadas por operários sem ambas as pernas; 2637 por operários com uma única perna; 2 por operários sem ambos os braços, 715 por operários com um só braço e ainda 10 tarefas podiam ser executadas por cegos.

Se analisarmos este aspeto positivo da divisão de trabalho não implica necessariamente que pessoas com necessidades especiais tenham conquistado o seu espaço de trabalho, contudo, esse espaço existe, algo que no período anterior não acontecia.

Por outro lado, a alteração no ambiente de trabalho também trouxe dificuldades.

9. INOVAÇÃO NO PRODUTO E NO PROCESSO

Quando se analisa o impacto e consequências de uma inovação tecnológica, é possível classificá-la quanto ao tipo de inovação em foco. Bastos (1998) faz a distinção entre a inovação do processo e a inovação do produto onde defende que a inovação do processo tem como objetivo o aumento da produtividade sem modificações no produto final, já a inovação do produto tem como objetivo a alteração e melhoria do produto ou, até mesmo, o desenvolvimento de um novo produto.

Assim, se por um lado a inovação de processos racionaliza o trabalho, aumentando a produtividade e com isso o esperado é a diminuição dos postos de trabalho; por outro lado a inovação do produto, uma vez que tem tendência para criar novos mercados, também tende para aumentar o volume de empregabilidade. Contudo, a inovação do produto também pode causar a substituição de produtos, observando-se uma transferência de mercados como por exemplo o caso do DVD que substituiu a videocassete (Acemoglu et al, 2017).

É fundamental considerar o processo híbrido da automação, onde a inovação do produto como um robô ou uma máquina CNC representam para outra indústria uma inovação no processo, no caso da indústria que compra um robô para substituir mão-de-obra. Assim, é de ressaltar que a forma como uma inovação de processo afeta a sociedade também está relacionada com o tipo de demanda do produto produzido. A longo prazo o impacto de inovações tecnológicas acabam por se refletir tanto na qualidade como na expectativa de vida das pessoas que têm acesso aos bens de consumo, principalmente em países desenvolvidos onde a tecnologia trouxe uma melhoria substancial na qualidade de vida. Se formos a ver, o tempo médio de vida de um Neanderthal passou de 30 anos, para 35 anos no período pré-industrial e hoje em dia nos países desenvolvidos é de 75 anos (Demasi, 2003).

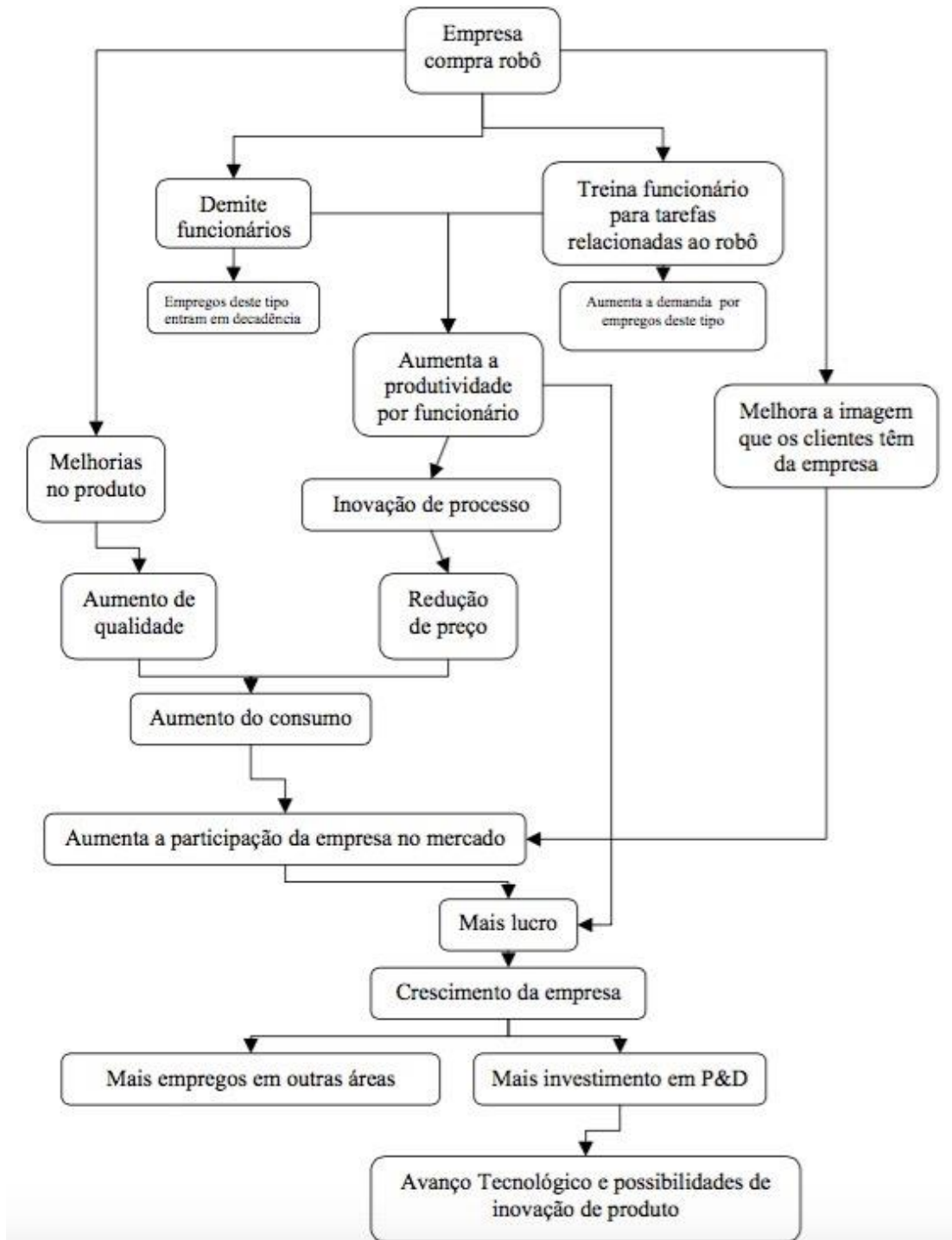
O autor Mori (1989) cita a tese de Ayres e Funk que classifica as vantagens da automatização em cinco categorias:

1. Redução da força de trabalho
2. Aumento da capacidade de produção
3. Distribuição de capital
4. Aumento da qualidade dos produtos
5. Aceleração da melhoria do desempenho dos produtos

O mesmo autor defende que a curto prazo as três primeiras categorias só beneficiam os lucros dos empresários, contudo, a longo prazo, a população tem melhores produtos a menor preço (Mori, 1989).

Outros autores como McCurdy (1989) defendem que é muito difícil encontrar exemplos históricos sustentáveis de desemprego causado pela inovação da tecnologia. De acordo com o autor, a História demonstra o contrário pois os países desenvolvidos com uma rápida inovação tecnológica tiveram baixas taxas de desemprego, ou seja, o desenvolvimento e uso da tecnologia facultam o aumento de produtividade, de lucros e de crescimento económico. Quando os trabalhadores são dispensados por substituição das suas funções por máquinas, esse desemprego é temporário pois a dinâmica de mercado leva a novas oportunidades de emprego e as taxas de desemprego voltariam ao normal (Acemoglu et. al, 2017).

De qualquer das formas, quer seja por diminuição do preço dos bens ou retendo o lucro, o dinheiro voltará ao circuito económico, sendo que em ambos os casos, há um aumento no consumo (Endler, Ribakova, 1994).



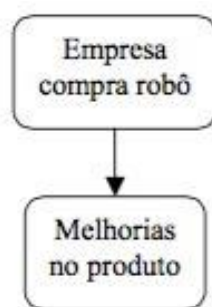
Fluxograma 1- Empresa investe em automação

Fonte: Leal, 2005

Quando uma empresa compra um robô é com o objetivo de que o investimento seja mais vantajoso que manter o processo manual. Por norma, como se trata de um investimento grande, pressupõe-se que um dos funcionários, engenheiro ou técnico, e que aos olhos da empresa, tenha uma boa capacidade de aprendizagem e perspectivas de continuação e até mesmo progressão, assuma a responsabilidade sobre a operação do robô. Este funcionário receberá uma formação que até pode ser dada pela empresa fornecedora da máquina, os demais, ou são recolocados ou dispensados. Em muitos casos, estes tipos de investimentos são feitos em épocas que as empresas estão em expansão e/ou financeiramente estáveis, o que significa que não haverá grandes necessidades de despedimento, sendo mais fácil a realocação de pessoal. Noutras circunstâncias, este investimento em automação é feito como uma contingência para aumento de produção sendo que os funcionários que tiveram as suas atividades substituídas pelo robô tendem a ser dispensados, e com essa dinâmica a empresa evita maiores resistências, principalmente no período de implementação da nova tecnologia (Leal, 2005).

Como resultado final após um expectável período de oscilações, a empresa atinge o equilíbrio com aumento de produtividade por funcionário ou de forma equivalente, um produto que custe menos.

Outra possível consequência da automatização de processos é a melhoria do produto.



Fluxograma 2 – Melhorias no produto associadas à automação

Fonte: Leal, 2005

Neste caso podemos ter dois cenários (Leal, 2005):

No cenário 1, o produto final não é alterado, isto é, as suas características base, contudo, sofre melhorias relativas à qualidade. Surge também um padrão de qualidade, que pode não ser necessariamente superior ao manual, mas é assegurado com a automatização. Assim, a empresa elimina oscilações no padrão de qualidade, dependendo da habilidade do(s) operário(s).

No cenário 2, dão-se melhorias que alteram o produto em si, transformando-o ou até criando um produto novo que pode ser, ou não, um substituto do anterior. Neste cenário temos a possibilidade de inovação do produto, que pode levar a um novo mercado consumidor. Se considerarmos que o novo produto é um substituto do anterior, também existe uma vantagem competitiva em relação ao antecessor.

Associado a utilização de novas tecnologias está o marketing, pois com a sua utilização, a automatização fica associada a melhoria de qualidade e uniformidade, de tal maneira que até a relação cliente – fornecedor altera. A empresa que se automatiza tem a sua imagem melhorada a priori junto ao cliente (Leal, 2005).



Fluxograma 3– Aumento do lucro associado à automação

Fonte: Leal, 2005

É fundamental ressaltar que os empregos criados pelo crescimento de uma empresa são noutras áreas, como as vendas, marketing, desenvolvimento do produto, manutenção, etc. Conforme já foi referido, a tendência é que não sejam criados novos postos no sector que sofreu a automatização, levando a que certas profissões vão perdendo a sua importância e para que haja uma procura maior de profissionais noutras áreas (Leal, 2005).

Realçar o fato de que quanto mais lucro a empresa tiver, mais poderá investir em P&D. Esse investimento adicional abre portas para inovações de produto, formação em pesquisa aplicada, exploração de novos nichos de mercado, etc. Em suma, a possibilidade de inovação do produto que abra novos mercados e crie empregos é maior (Leal, 2005).

Se analisarmos, por outro lado, o impacto sob o ponto de vista da empresa que fabrica robôs ou soluções de automação, este também é positivo.

Como há um aumento de vendas, é esperado que se dê por consequência um aumento da empresa, gerando mais contratações nos sectores da produção, manutenção e instalação. É importante também notar que neste tipo de ramo, a venda de um produto desta gama vem acoplada com um contrato de manutenção, resultando em mais receitas para a empresa fornecedora do equipamento (Leal, 2005).

CONCLUSÕES

A nova economia, impulsionada por máquinas geridas remotamente, estimula o empreendedorismo, possibilitando o acesso a algumas das potencialidades da automação sem suportar custos avassaladores. A computação na *Cloud* é uma forma de tirar proveito das grandes economias de escala, uma vez que a centralização das infraestruturas permite a propagação de custos sobre um grande número de utilizadores. Os ganhos para a organização de atividades produtivas podem ser enormes, mas, como para qualquer outro avanço tecnológico, a criatividade também é necessária para fornecer o melhor uso possível para as ferramentas que a mente humana é capaz de gerar.

As competências de pessoas e robôs diferem; os robôs são particularmente adequados para executar tarefas rotineiras que estão localizados em algum lugar no meio de uma escala de habilidades, enquanto as competências manuais de baixo escalão e competências abstratas de alto escalão são mais difíceis de mecanizar. Esta evidência sobre a polarização do trabalho é fundamental para a construção de um quadro que aborda o impacto da nova onda de tecnologia e sugere que encontrar distribuições adequadas de competências é um primeiro passo relevante na montagem de uma teoria económica coerente.

O progresso tecnológico, dada a sua natureza, também tende a provocar algumas ansiedades. Estas ansiedades são, de acordo com Mokyr et al. (2015), de três tipos:

- Substituição por máquinas no trabalho;

- Implicações morais e questões de bem-estar relacionadas com as alterações em andamento;
- A possibilidade de um progresso tecnológico chegar ao fim.

O estudo desenvolvido por Orlando Gomes e Sónia Pereira (2018) não só colocou em perspetiva os diferentes pontos de vista sobre o impacto económico da automação como também esboçou um quadro analítico para abordar essa questão. A mensagem final resultante é ambígua: os trabalhadores, mesmo os altamente qualificados, são de facto substituídos por máquinas e os empregos estão a ser perdidos; no entanto, as políticas apropriadas e práticas empresariais podem permitir, e deve permitir, para tirar proveito da maior produtividade dos robôs, oferecer aos trabalhadores salários mais elevados e mais tempo de lazer.

Qual será o impacto associado a estas tecnologias? Se por um lado a vantagem económica associada é amplamente aceite, por outro o impacto sobre o emprego é um debate que ainda cria muitas discussões. Enquanto muitas tecnologias estão associadas com corte de custos através da eliminação da mão-de-obra, existem por outro lado vários efeitos compensatórios, empregos gerados por estas novas tendências. Há respostas para todos os gostos na literatura especializada, desde as que vêm a tecnologia como grande responsável pelo desemprego e desigualdade de rendimentos até as que a consideram como a grande saída para se criar novos postos de trabalho e melhorar o bem-estar humano.

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ANEXO

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13 de junho

Dear Dr. Gomes:

Manuscript ID JEAS-04-2018-0049 entitled "On the Economic Consequences of Automation and Robotics: an Appraisal of the Recent Literature" which you submitted to the Journal of Economic and Administrative Sciences, has been reviewed. The comments of the reviewer(s) are included at the bottom of this letter.

The reviewer(s) have recommended publication, but also suggest some revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript.

To revise your manuscript, log into <https://mc.manuscriptcentral.com/jeas> and enter your Author Centre, where you will find your manuscript title listed under "Manuscripts with Decisions." Under "Actions," click on "Create a Revision." Your manuscript number has been appended to denote a revision.

You will be unable to make your revisions on the originally submitted version of the manuscript. Instead, revise your manuscript using a word processing program and save it on your computer. Please also highlight the changes to your manuscript within the document by using the track changes mode in MS Word or by using bold or coloured text.

Once the revised manuscript is prepared, you can upload it and submit it through your Author Centre.

When submitting your revised manuscript, you will be able to respond to the comments made by the reviewer(s) in the space provided. You can use this space to document any changes you make to the original manuscript. In order to expedite the processing of the revised manuscript, please be as specific as possible in your response to the reviewer(s).

Emerald has partnered with Peerwith to provide authors with expert editorial support, including language editing and translation, visuals, and consulting. If your article was rejected, or had major revisions requested on the basis of the language or clarity of communication, you might benefit from a Peerwith expert's input. For a full list of Peerwith services, visit: <https://authorservices.emeraldpublishing.com/> Please note that there is no obligation to use Peerwith and using this service does not guarantee publication.

IMPORTANT: Your original files are available to you when you upload your revised manuscript. Please delete any redundant files before completing the submission.

Because we are trying to facilitate timely publication of manuscripts submitted to the Journal of Economic and Administrative Sciences, your revised manuscript should be uploaded as soon as possible. If it is not possible for you to submit your revision in a reasonable amount of time, we may have to consider your paper as a new submission.

Once again, thank you for submitting your manuscript to the Journal of Economic and Administrative Sciences and I look forward to receiving your revision.

Sincerely,

Prof. Hassan Selim Ahmed

Editor, Journal of Economic and Administrative Sciences

hassan.selim@uaeu.ac.ae

Reviewer(s)' and Associate Editor Comments to Author:

Reviewer: 1

Recommendation: Reject

Comments:

The idea of the paper is nice but the approach adopted is only theoretical and there are no clear implication of the results. A more detailed explanation of the parameters' choices may help the reader in order to understand the implication for the business or for the industry. Moreover a more detailed analysis of empirical studies of technology innovation effects on job opportunities may help in understanding your new contribution.

Additional Questions:

Originality: Does the paper contain new and significant information adequate to justify publication?: The paper presents a standard theoretical model for the impact of Robotics on the job market.

Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Literature review is well developed but there is not reference to other papers that are doing similar research in the field and try to measure empirically the impact of robotics on the employment rate

Methodology: Is the paper's argument built on an appropriate base of

theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: The paper does not justify a lot of the assumptions done in the model and there is no evidence about the coherence of the approach with respect to similar analysis done in the literature

Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Results are properly described

Practicality and/or Research implications: Does the paper identify clearly any implications for practice and/or further research? Are these implications consistent with the findings and conclusions of the paper?: The implication of the industry is very limited because the parameters' estimation seems to be not founded on data or empirical evidence

Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Good

Reproducible Research: If appropriate, is sufficient information, potentially including data and software, provided to reproduce the results and are the corresponding datasets formally cited?:

Reviewer: 2

Recommendation: Major Revision

Comments:

While this topic area is very interesting and timely, significant work needs to be done in tying the two parts together. The main work here

will be in justifying the choice of model and use of the results in the context of the findings from the lit review. Using the "future research" that comes from both the lit review and from the numeric portion will help to tie the work together as well. I would also strongly suggest language editing since, while it reads well overall, there are numerous small problems. To name a few mistakes:

p. 4 line 48 "to foster" what?

p. 5 line 10 "synonymous WTH"

p. 5 line 21 "PROVIDE the best possible use"

p. 5 line 52 "complement TO labor", "helped RAISE"

p. 5 line 56 "organizationS"

p. 6 line 20 "extremeLY"

Finally, the very popular book "average is over" by the GWU author and economist Cowen clearly needs to be cited in here given its popularity and importance right now.

Additional Questions:

Originality: Does the paper contain new and significant information adequate to justify publication?: Yes. This is an interesting paper that touches on very current questions and attempts to bring them together into a coherent whole. While I am not sure about the relative merits of putting the two sections together, I think the general topic area and approach are interesting and important.

Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes, however, the authors CLEARLY need to put in the work of Professor Cowen at G.M.U. who also recently had a very popular book on the topic entitled "average is over".

Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent

intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: The literature review is standard, although it is a bit drawn out and could use a tighter construction. There are also numerous typographical and English writing issues (mentioned later) that would need to be addressed before publication. I also thought that it was a bit odd to do a numeric estimation along with the literature review and then also to make no effort to draw real implications from the results. If the authors work so hard to put in the results in a strict numeric sense from a theoretical model, then I believe it is very important to interpret them as well.

Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: No. The results of the numeric estimation, while generally presented well, are not discussed in context and given their full implications and significance. The authors need to use this to work harder to tie together the two parts of the analysis.

Practicality and/or Research implications: Does the paper identify clearly any implications for practice and/or further research? Are these implications consistent with the findings and conclusions of the paper?: No. The authors can work on this as well. They should state what future research on the topic should explicitly do. While they have reviewed previous research and showed the results of one instantiated estimation, it is not clear from their work where they should go from there.

Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: While the writing is better than average in the area, there are still numerous typographical and language issues to address in the work. They need a good editor to look at all of these

specifics before the paper is ready for final acceptance. A few examples are as follows:

p. 4 line 48 "to foster" what?

p. 5 line 10 "synonymous WITH"

p. 5 line 21 "PROVIDE the best possible use"

p. 5 line 52 "complement TO labor", "helped RAISE"

p. 5 line 56 "organizationS"

p. 6 line 20 "extremeLY"

Reproducible Research: If appropriate, is sufficient information, potentially including data and software, provided to reproduce the results and are the corresponding datasets formally cited?:
N/A. Numeric instantiation from a theoretical model and a literature review.

Associate Editor

Comments to the Author:

This is an interesting paper that touches on very current questions and attempts to bring them together into a coherent whole. The literature review is comprehensive; However, the authors CLEARLY need to put in the work of Professor Cowen at G.M.U. who also recently had a very popular book on the topic entitled "average is over". It is a bit odd to do a numeric estimation along with the literature review and then also to make no effort to draw real implications from the results. If the authors work so hard to put in the results in a strict numeric sense from a theoretical model, then it is very important to interpret them as well.

The results of the numeric estimation, while generally presented well, are not discussed in context and given their full implications and significance. The authors need to use this to work harder to tie together the two parts of the analysis.

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