

Review

Understanding Technological Unemployment: A Review of Causes, Consequences, and Solutions

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Abstract: Many studies have focused on estimating the impact of automation on work around the world with results ranging widely. Despite the disagreement about the level of impact that automation will have, experts agree that new technologies tend to be applied to every economic sector, thus impacting work regardless of substituting or complementing it. The purpose of this study is to move on from the discussion about the size of the impact of automation to understanding the main social impacts that automation will cause and what actions should be taken to deal with them. For this purpose, we reviewed literature about technological unemployment found in Scopus and Web of Science published since 2000, presenting an academic view of the actions necessary to deal with the social impact of automation. Our results summarize causes, consequences, and solutions for the technological unemployment found in the literature. We also found that the literature is mainly concentrated on the areas of economy, sociology, and philosophy, with the authors situated in developed economies such as the USA, Europe, and New Zealand. Finally, we present the research agenda proposed by the reviewed papers that could motivate new research on the subject.

Keywords: automation; social impact; technological change; future of employment



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1. Introduction

Whenever businesses have introduced a new technology that reduces the need for labor, many workers have lost their jobs [1]. Technological change is one of the top issues of the 21st century, and it will produce implications in the labor market. that may occur slowly, making it almost imperceptible to an inattentive observer [2].

Today, businesses are automating workplaces with more advanced technologies, mainly from the fields of artificial intelligence (AI) and robotics [3]. These new technologies are being used to create innovations such as driverless cargo trucks, AI mortgage analysis, and AI paralegals [4].

In recent years, several studies have been dedicated to estimating the impact of automation on jobs. The most prominent and cited of these is the seminal study first published online by Carl Benedikt Frey and Michael Osborne in 2013 in which 47% of the US workforce was estimated to be under high risk (70% probability or more) of computerization (automation by computer-controlled equipment) in the following decades [5]. Following the success of this study, many others applied its methodology worldwide finding different results: UK (35%), Canada (42%), Germany (42%), Switzerland (48%), Uzbekistan (55%), Brazil (60%), and Ethiopia (85%) [6–13].

Differently from Frey and Osborne [5], who focused on technology's impact on occupations and their tasks, Arntz, Gregory and Zierahn decided to focus on occupations' skills and studied 21 nations that are part of the Organisation for Economic Co-operation and Development (OECD) to find that, on average, 9% of jobs have a high risk of being automated [14]. The level ranges from 12% in countries such as Germany and Spain to 6%

in Korea and Estonia [14]. Building on this work, Nedelkoska and Quintini broadened the study to 32 OECD countries [15]. They estimated that 14% of jobs in these countries are highly automatable, ranging from 6% in Norway to 33% in Slovakia [15].

Independently of the level of impact that automation will have on jobs, understanding technological unemployment, one of its possible consequences, is necessary if we, as a society, want to fairly enjoy the benefits that the current wave of technological change can bring about [5,10,16]. This effort becomes even more urgent since the current COVID-19 pandemic could cause an acceleration of automation worldwide [17–21].

In this scenario, companies, governments, and workers must prepare themselves faster than ever to deal with the increased pace of automation work if it is to bring about positive results once again as it did in the past. Unfortunately, this does not seem to be the case so far. When it comes to companies' preparedness, a recent survey with over two hundred Chief People Officers (CPOs) showed that only 36% consider themselves prepared to respond to the future complexity of business and technology to support their business effectively [22]. In so far as nations' readiness for automation is concerned, even the more advanced economies such as Germany and East Asian countries are not prepared to deal with the current wave of automation [16].

Technological unemployment can be defined as "unemployment due to our ability to find ways to save the use of work be greater than the ability to find new uses for work" [23]. Throughout history, technological change did not cause unemployment in the long run even though it did cause some disruptions to the labor market in the short run while workers adapted themselves [24].

Past waves of technological change resulted in the reduction of the workforce in specific economic sectors while increasing in others, thus balancing the job market. Therefore, in the long run, technological change has been powering economic progress and increasing job quantity and quality [24]. Today, the technological unemployment thesis has been defended by several authors who believe that the industrial revolution that we are currently going through is different from previous ones and will cause an increase in unemployment [25].

Long-term unemployment can induce people to think they are living a meaningless life [3,4], without the needed financial and social self-governance [26]. Many believe that more education is the key to enhance their employability; however, a university degree no longer ensures reliable and secure work [27]. Governments, on the other hand, are under pressure to expand their social welfare programs such as Universal Basic Income (UBI) [3,4,28–33], which may be seen as an economic burden.

According to Marx [34], when a machine becomes an instrument of labor, it becomes a competitor of the worker; however, the machine by itself is not responsible for workers losing their means of subsistence. Thus, what actions should be taken to address technological unemployment?

In this paper, we aim to provide answers to this question and explore the causes and consequences of technological unemployment through a literature review. In summary, this study aims to answer four research questions as follows:

- RQ 1.** What are the causes of technological unemployment?
- RQ 2.** What are the consequences of technological unemployment?
- RQ 3.** Which solutions to technological unemployment are being proposed?
- RQ 4.** What is the research agenda for technological unemployment?

2. Materials and Methods

In this section, we describe in detail the literature review process performed in this work and present statistics from the selected papers. The purpose of this study is to move on from the discussion about the size of the impact of automation to the understanding of the main social impacts that automation will cause and the actions necessary to deal with or avoid them.

In order to understand the social impacts of technological unemployment, we performed searches in the Scopus and Web of Science databases. We started with a relatively narrow search by stipulating the following four inclusion criteria: (1) the title of the paper must include the term “technological unemployment”; (2) the language of the text must be in English; (3) the publication year must be after 2000; and (4) the publication type must be “journal article”. Criterion (1) is the most important in the search. We did not search for the term “technological unemployment” on the keywords or abstracts of the papers to avoid those that only marginally tackle the subject and are less likely to answer our research questions. Criterion (2) removes results that we may be unable to read, or worst, misunderstand. Criterion (3) removes older results to increase the probability that the selected literature is concerned with current challenges caused by the recent wave of technological change. In fact, most selected results are from 2013 or later. Finally, criterion (4) removes books, book chapters, and book reviews, etc. to make the analysis possible within a reasonable timeframe.

Our initial search was conducted in March 2021 and returned 27 papers from Scopus and 20 papers in Web of Science, a total of 47 papers. In the first stage of our analysis, we compared and removed duplicated papers, leaving 29 distinct papers. In the second stage, we performed a verification of the paper tackling the problem of technological unemployment from a future perspective instead of a historical one. We found and removed two papers focused on discussing the history of the term and debates from the 1920s. In the third and final stage, the remaining 27 papers were thoroughly read to answer the research questions. This process is summarized in Figure 1.

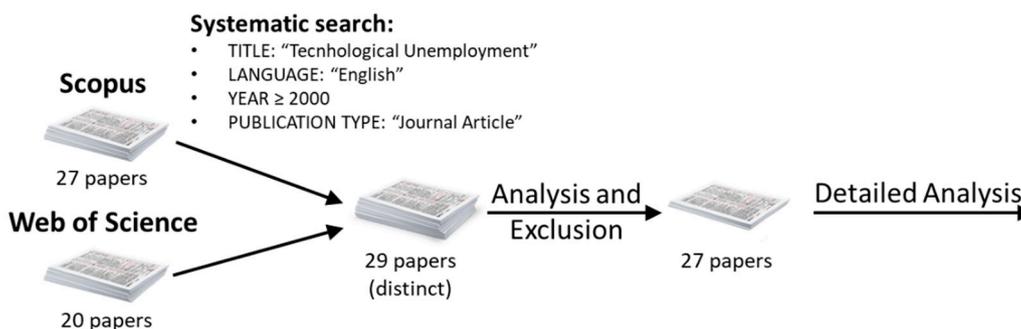


Figure 1. Overview of the selection process of the corpus, aiming to identify papers that tackle the subject of technological unemployment.

To provide context to the selected literature, we present some statistics about the 27 selected papers. The publication timeline of the selected papers is presented in Figure 2. They show that the “technological unemployment” subject is becoming increasingly important, especially since 2017 when we have at least three papers each year.

We also analyzed where the selected papers were published, as presented in Table 1. The papers were distributed on 21 different journals, with only 3 journals having more than one paper published on the subject. We also analyzed the subject area of the publications, as shown in Table 2. The data show that the publications are from three areas: economy, sociology, and philosophy/ethics. Among these three subject areas, economy is the one with the most papers, with a total of 14 out of the 27 papers, representing over 50% of the corpus.

Finally, we present the geographic distribution of the institutions where the authors of the papers worked at the time of publication (Figure 3). The data show that the United States leads the publication rank with six papers, followed by New Zealand, and the United Kingdom, with three papers each. Australia, Italy, Romania, Russia, and the Netherlands have two papers each. The remaining countries have only one paper published.

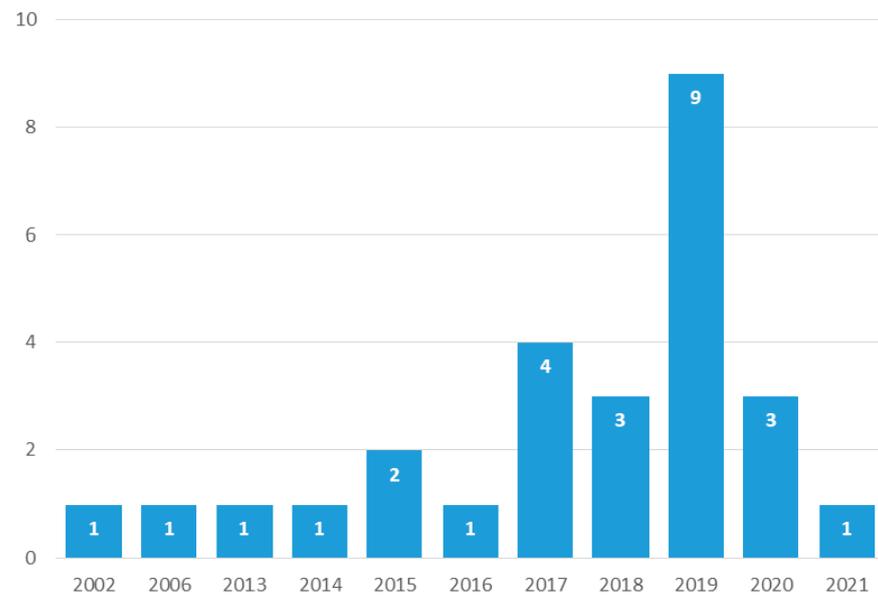


Figure 2. Timeline of the publication years of the papers in the corpus. Note that 2021 is not fully covered by the review methodology, and the years in which no paper was published are omitted.

Table 1. The distribution of the source titles of papers in the corpus.

Source Title	# of Papers
Educational Philosophy and Theory	3
Journal of Evolutionary Economics	2
Science and Engineering Ethics	2
Ad-Minister	1
Cutter IT Journal	1
Economic and Political Weekly	1
Economic Theory	1
Economics, Management, and Financial Markets	1
Ethics and Information Technology	1
Ethics and Social Welfare	1
Futures	1
International Economic Review	1
International Journal of Automation and Computing	1
Journal of Business Ethics	1
Journal of Regional Analysis and Policy	1
Journal of Research in Gender Studies	1
Journal of Siberian Federal University—Humanities and Social Sciences	1
Kybernetes	1
Philosophy and Technology	1
Russian Journal of Economics	1
Social Research	1
Sociología y Tecnociencia	1
Technology in Society	1

Table 2. The distribution of subject area of papers in the corpus.

Subject Area	# of Papers
Economic	14
Social	7
Philosophy/Ethics	6

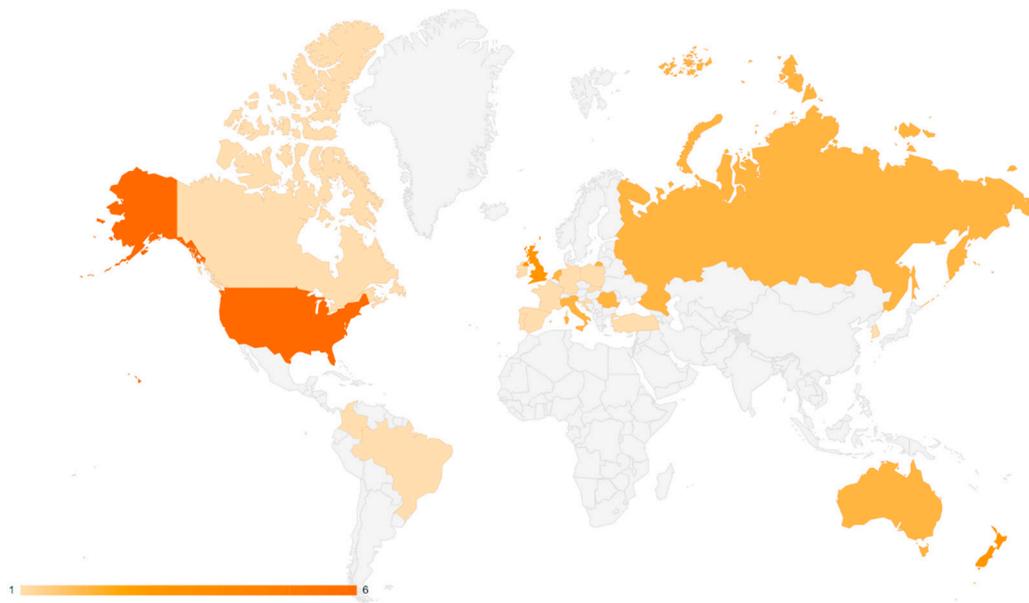


Figure 3. Author’s geographic distribution. Countries shown with a darker color on the map have more publications.

3. Results

To answer the research questions presented in the Introduction, we divided the presentation of the literature review into the following parts:

1. Causes: what factors cause or accelerate technological unemployment?
2. Consequences: what are the consequences caused by technological unemployment?
3. Solutions: what are the actions that could mitigate either the causes or the negative consequences of technological unemployment?
4. Research agenda: which opportunities for future research are indicated by the authors?

In Figure 4, we summarize the causes, consequences, and solutions of technological unemployment found in the literature review. In this section, we list and briefly describe them. Next, we further detail them, discussing their interconnections.

As regards causes of technological unemployment, we can highlight the following:

- Technological Oligopoly: USA and China lead the technology development that will provoke worldwide labor displacement in the near future [28]. Companies such as Amazon, Apple, Facebook, Google, IBM, and Microsoft (in the US) and Alibaba, Baidu, and Tencent (in China) invest heavily in AI technology [29]. These profit-maximizing practices bring economic benefits to the US and China [31] but ignore that developing countries have to deal with its negative consequences, such as technological unemployment [28];
- Outdated International Tax Systems: The international tax system is slow to solve problems related to the digitalized world, especially inequalities between economically developing and developed countries [28];
- Skills Mismatch: Digital technologies are changing faster than organizations and workers’ skills can keep pace [35]. Automation is eroding the demand for human skills in the middle range while increasing skill demand for high and low skills [32]. Finally, if the technology change becomes exponential, workers might be unable to retrain their skills fast enough [3];
- Fast Technological Change: The increasingly faster advance in technology development and automation will substantially reduce future labor demand [2], changing jobs and wages more fundamentally than in the past [1];
- Inadequate Tax Systems: The current tax system charges labor more than capital, stimulating automation since considerably less tax is collected per amount produced by automated processes [36]. The tax system can be used to invert such stimu-

lus by charging more for automated production or providing tax exemptions for “humanized” production [4].

As regards consequences of technological unemployment, we can highlight the following:

- Fiscal Risk: Technological unemployment decreases the tax revenues from the taxation of labor [28] while requiring increases in the expenditure on social aid to alleviate the shift between jobs [36];
- Increased Inequality: Technological unemployment may increase new forms of inequalities, such as the skill-based divide, due to different levels of professional skills, and the digital divide, due to the lack of access to digital devices and the internet, especially in Africa and Latin America [28]. The skill-based divide can contribute to even higher wage inequality between untrained and highly qualified employees [36];
- Lack of Minimum Living Standards: Unemployment may create a crowd of workers left out of the economic production [37]. If welfare programs cannot help them, we may see the consolidation of a small elite while masses of unemployed people are left to starve [38];
- Workforce Outdated Skills: New jobs created by technological development will require different skills than the ones that were destroyed [39]. Thus, workers will have to learn new and more advanced skills to reintegrate successfully into the employment market [40];
- More Free Time/Boredom: If our society becomes a leisure society, we face the risk of people being bored, demotivated, and undecided about what to accomplish [38]. Nevertheless, we could use this free time to develop better education and health care and produce personal projects, research, philosophy, and the arts [31];
- Less Demand/Consumption: A large-scale technological unemployment may distort the relationship between offer and demand. If many workers lose their jobs at the same time, the effective demand for new products will shrink [31]. This massive loss of purchasing power has the potential to collapse the economy [41].
- As regards solutions to technological unemployment, we can highlight the following:
- International Tax Cooperation: An international tax cooperation may be used to cope with technological unemployment. Its goal should be to slow down the adoption of new production methods and to finance a global UBI [28];
- New Economic Sectors: Sectors such as tourism and health care rely strongly on human interaction and may see a surge in the future as their jobs are unlikely to be automated soon [2];
- Fiscal Reform: A wide reform of the tax policy is needed, including personal and corporate taxation, since personal taxation does not reach wealthy people as it could [28]. Stronger international taxation rules, negotiated through international agreements can mitigate economic effects between the more and less-developed worlds [28]. Companies should pay taxes when they replace workers with robots [36], and staff education and retraining should produce tax incentives [28];
- Minimum Income: Technological unemployment brings greater income for few and social inequality [3]. UBI is one mechanism designed to distribute wealth [38] from the capital owners to the displaced workers [3]. This policy is not the only option to be implemented [35];
- Charitable Donations: Wealthy people usually donate a certain proportion of their wealth. If this trend persists, they will be increasing richer and such donations may become help mitigating the negative consequences of technological unemployment [30];
- Produce Own Goods: People might have the alternative to produce their own essential goods. It may take the form of communal farming, building, and teaching, or they may build their own AI or robot that will accomplish some of the work for them [30];
- Change Higher Education: Technological unemployment shows that higher education institutions have to change to be capable of retraining workers quickly to meet the rapidly changing needs of the workplace [2]. Thus, these institutions must offer certificates and degrees faster and more efficiently since more adults with dependents

require public support during their training for a different occupation [2], which may be funded by a tax on labor-modifying technological applications [2];

- On-the-Job Corporate Retraining: On-the-job corporate retraining may be considered as worker training programs on steroids: the company teaches tailored skills to their workforce while they work. The high costs associated with the training may cause significant changes in the employer/employee contract, including temporary wage deductions or limited noncompete contract clauses if the employee leaves the firm before a specified period [2];
- Track Occupational Change: The systematic tracking of occupational change may reduce the unpredictability of the labor market, providing a faster response from the government. Such systems must use occupational statistics data to detect patterns and trends in occupational shifting, collect skill demands from sites such as LinkedIn, and tracking the hiring trends; finally, they should survey firms to collect their desired hiring skills [2];
- Change Unemployment System (Private/Public): Current unemployment compensation systems are designed to support cyclical unemployment. However, technological unemployment represents structural unemployment that can be permanent and usually requires retraining for a new occupation. Therefore, the unemployment compensation system should provide retraining aid and monthly checks to support the workers and their families during the retraining period [2]. Private unemployment insurance and personal income savings in preparation for technological unemployment may also play an important role [30].

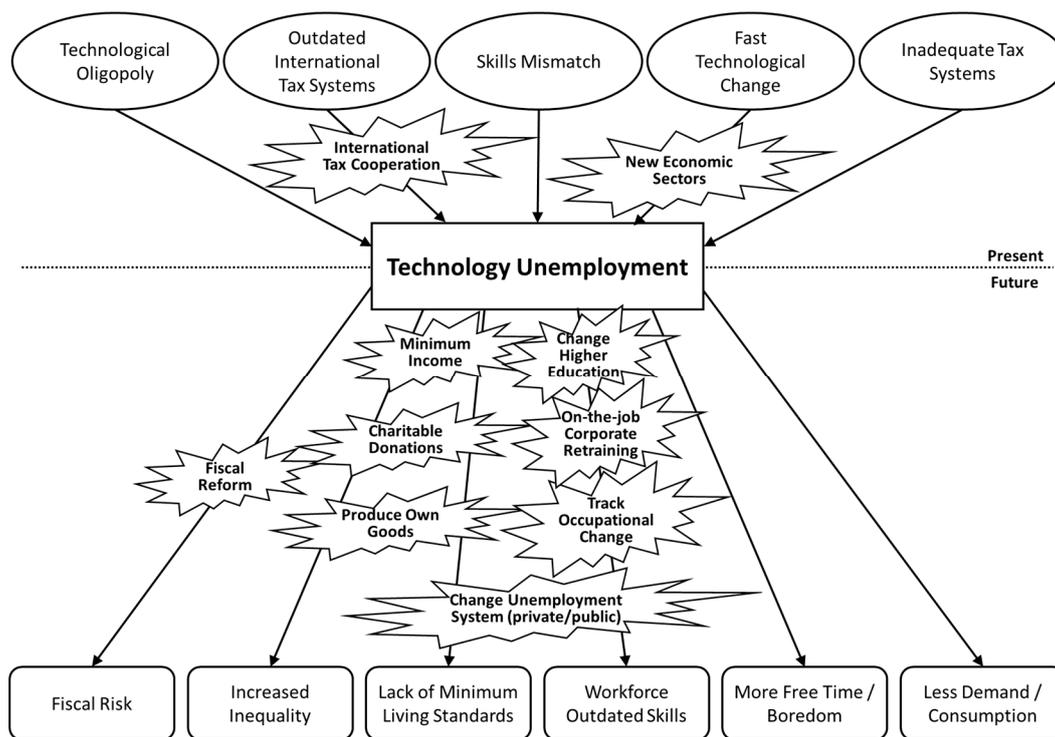


Figure 4. Summary of the technological unemployment’s causes, consequences, and solutions found in the literature review.

3.1. Causes

Before discussing the causes of technological unemployment, a first division of the literature should be noted. The reviewed articles about technological unemployment can be divided into two broad categories. The first category is composed of those articles that take as a starting point the idea that technological unemployment is a possible negative consequence of automation that should be discussed and mitigated [1–4,26–28,32,33,35,36,39–46].

Most of the reviewed literature falls into this first category. The second category includes the articles that somehow dispute the fact that automation will cause long-term technological unemployment [29–31,47–49]. It is interesting to present these articles because they bring new perspectives to the discussion about automation and its possible consequences.

As shown in the Introduction, the concept of technological unemployment, as defined by Keynes, already gives an idea of the causes of this phenomenon: we, as a society, adopt technologies to replace human workers at a faster rate than our capacity of creating new work.

In previous industrial revolutions, automation already substituted human work for machine work. At first, machines would substitute for repetitive and manual tasks. Then, repetitive cognitive and manual tasks were within the reach of automation. Now, as AI gets ever smarter and robots more skilled, nonrepetitive cognitive and manual tasks seem to be increasingly automatable [2,3,35,49,50]. As an example of the increasing capacity of technologies, we can look at the automation of case research performed by paralegals, the use of facial recognition coupled with cameras that automate part of security work [2], or the development of self-driving cars, which may lead to the unemployment of truck drivers [4,49]. The advance of the current wave of technology over skills that were previously exclusive to humans puts in check the Luddite Fallacy that held true in earlier industrial revolutions and implies that the jobs lost in a given economic area will be created in another one [1,2,35]. For instance, 90% of the jobs in the USA economy are in the service sector where smart information and communication technologies can create huge waves of unemployment [38].

It is also interesting to track the quality of the current job change by verifying if the jobs or activities being automated are more or less dangerous, boring, and exhausting than the ones being created in other areas [32]. If the current wave of automation is really set out to cause a hollowing out of the jobs at the middle of the skill spectrum, then we might see an increase in the demand for both low-skilled and high-skilled jobs in the next decades [1,5,32].

Something else that is particularly concerning about the current industrial revolution is the accelerated pace at which the advances in technology are taking, which could speed up the job market remodeling [2,35]. Currently, many automation technologies rely heavily on software, which is something easily distributed across the globe, when compared with the main technologies of previous industrial revolutions such as steam machines [51].

Moving forward from the causes that are part of the definition of technological unemployment—rapid pace of technological change and skills mismatch—there are other, less straightforward factors that can also be considered accelerators of automation.

National and international tax systems are two of these factors. At the national level, tax systems that are currently formulated to charge more labor than capital can act as a stimulus to the automation of work by helping to tip the cost balance in favor of machines instead of humans [4,36,42]. At the international level, critics point at the fact that the international tax system is incapable of quickly adapting itself to solve issues of distribution of the tax base, particularly between developed and developing countries [28]. Another issue with the international tax system would be its current basis on the distribution of rights for the taxation of income due to the cross-border transfer of capital and technology. That transfer happens between a “residence” country—usually, more developed countries with advanced technologies, and primary and often exclusive rights to tax such profits—and a “source” country whose rights to tax profits tend to be either not fully realized due to a lack of necessary technical competences among their local tax authorities or limited by the international agreements [28].

One last important factor that can act as an accelerator of technological unemployment is the control of the technology development agenda by very few companies located in a small number of countries [3,28,29,31]. The current development of digital solutions is dominated by companies from the world’s two largest economies: China and the USA [28]. Digitalized goods and services allow replication at near-zero marginal cost; nondigital

goods have near-global distribution networks, leading to the “winner-takes-all” problem: the income tends to flow to one dominant participant [3]. For example, in the field of AI, a fundamental technology for the current automation wave, the main players are nine big tech companies: Baidu, Alibaba, and Tencent from China; and Google, Amazon, Microsoft, Apple, IBM, and Facebook from the USA [29]. These companies have to face the challenge of technological unemployment in their own countries, and it is hard to believe that they will care about the impact of their technologies on jobs in less economically developed countries unless it brings some benefit to themselves [28].

To some, the very fact that the growth of human knowledge, here in the form of technological change, is left to be determined by profit-maximizing companies is a problem in itself [4,31]. From this perspective, technological unemployment is a consequence of the use of capital that is freed up by automation to investments that seek to create “superabundant capital” or “cash pools” that are separated from the real economy [31]. Thus, changing the way society understands the very function of capital would avoid technological unemployment if it was used to fund human improvement as a whole instead of increasing the richness of very few people [31]. Therefore, technological unemployment is a challenge to the field of business ethics [4].

Working provides a sense of aspiration, meaning, and enjoyment and improves financial and social self-governance. Thus, unpredictability at work generates a significant sense of insecurity and discomfort [26].

History shows that the technological revolutions greatly affected the environment, as previous economic growth implied more energy consumption—usually covered by oil and coal. Investments to make the transition to a green economy may improve employment, compensating partially the jobs lost due to technological unemployment [42].

3.2. Consequences

This section of our literature review is dedicated to presenting the different consequences of technology unemployment. As it can be expected, most of these consequences can be considered negative. Still, two of them—more free time and less consumption—have both positive and negatives sides, which will be explored.

Starting with the negative consequences of technological unemployment, two of the direst ones presented by the reviewed literature are increased economic inequality and lack of minimum living standards for a share of the population.

Economic history demonstrates that previous technological revolutions caused a disruption in the labor market in the short run, but in the long run, the situation has stabilized [24]. Nevertheless, Keynes reminds us that “in the long-run, we are all dead” [52]. That perspective is important since we do not know how long society will take to adapt to the current industrial revolution, and how badly can inequality grow during this period of adjustment [28].

A couple of factors can make the current adaptation more challenging [28]. First, disruptive technologies tend to demand increasing skills if the individual is to make a positive transition in the labor market. Second, in some regions of the planet, such as Latin America and Africa, there is a significant digital divide that could leave whole regions out of the industrial revolution. Third, workers’ rights are experiencing growing general insecurity, which can make automation adoption more abrupt and leave workers in hardship. Fourth, a general slowdown in the global economy has been furthered by the COVID-19 pandemic, which can make it harder for workers to find new jobs.

In this scenario, workers that are already part of the high-qualified job market can experience a surge in their demand and salaries, while the wages of untrained workers have been declining, as has been happening lately and could worsen in this adaptation period [32,36]. Human enhancement using new technologies such as gene editing or chip implants could become yet another catalyst of this process of increasing inequality. This can happen since these technologies will have a high starting price, being accessible to only a

small part of the workforce who might benefit from their enhancement while the majority of the population is relatively “disenhanced” [32,37].

Thus far, we have discussed elements of the growing economic inequality caused by technological unemployment, but they could also result and be influenced by a lack of minimum living standards of part of the population. A possible consequence of technological unemployment is the creation of what some might call the “useless masses” that are left out of economic production [37]. That can be a possibility if our society keeps on being organized around the idea of profit maximization and the use of capital [38]. Figuring out the meaning of life can become the new “first-world problem”, which could be a concern of only a small and rather sadistic elite who will free the masses from this preoccupation by leaving them out to starve [38].

Having more free time is a consequence of technological unemployment that has a positive and a negative side. Keynes long recognized that the technological advances would eventually solve the problem of meeting societies’ material needs and would leave humans with the challenge of finding purpose for their free time—what he called humanity’s real, permanent problem [23,31,38]. Therefore, long-term unemployment could make workers’ lives feel meaningless [3,4] and without financial and social self-governance [26]. According to Danaher [3], work is viewed as virtuous; thus, the lacking of paid employment may lead to idleness, boredom, and depression. The void left by work in our life could be filled by education, self-care, and care for others, improving our society by improving our institutions and dedicating our life to research, philosophy, and arts [31]. To move to a leisure society, we must decouple working from income while changing the social role of the paid employment in personal dignity [38]. This transition from economic-focused to leisure-occupied individuals requires a preparation that is entirely different from the one we have that reflects on how awful investors of free time our society can currently be [38,53].

Even if mass and long-term unemployment is not reached, jobs in the future are likely to demand more education including higher technical and emotional skills, which means that part of the time freed by automation could be invested in better educating ourselves [40].

As previously discussed, the fast pace of technological change is one of the causes of technological unemployment because it causes a skills mismatch in the labor market. Additionally, as a consequence of technological unemployment, societies might perceive that their workforces have outdated skills, when compared with the ones demanded by the new technologies, thus leaving part of the population behind in terms of economic possibilities [39]. Therefore, there is an outpacing problem with retraining/reskilling for the new advanced technologies: the needed skills are more complex and harder to be learned; meanwhile, the newer skills are becoming obsolete increasingly faster [3,39,40]. The acceleration in technology development is a trend that could lead to newer advanced technologies automating the new jobs created by the previous generation before the displaced workers are even ready to perform them [4], making reskilling useless.

Many believe that higher education is the key to acquiring and keeping quality jobs; however, a university degree no longer ensures reliable and secure work [27]. A large number of graduates from outmoded educational systems have mismatched or outdated skills for the labor market [1]. Moreover, the costs of higher education are increasing rapidly, while wages are stagnated [49].

As technological unemployment advances, governments will be increasingly put under pressure to expand their social welfare to include programs such as UBI [3,4,28–33]. These programs are extremely expensive and may be seen as an economic burden, mostly due to the need to increase taxation to cover their costs since the traditional welfare state is unable to face these new costs without more funding [48].

Furthering this challenge, technological unemployment brings a fiscal risk that could destabilize the existing social safety net, which is the decrease in tax revenues coming from labor if labor’s contribution to the economic production is reduced [28,36].

One last consequence of technological unemployment that could be highlighted from the reviewed literature is a possible reduction in demand. This is another consequence that

has positive and negative perspectives. The advance of automation means that less labor is required to produce the goods needed by people if the demand stays stable. Historically, automation increased the efficiency in the use of labor [42], increasing production and lowering prices [47]. Thus, until now, automation led to more new jobs than those that were lost [4] and increased wages [4,33], increasing the demand for products [4]. Still, there is no guarantee that this process will repeat this time. Without redistributive policies, as the one previously discussed, the unemployed will lose purchasing power, and demand will shrink [31,41]. Of course, this consequence has a limit because if no one can buy anything then nothing needs to be produced and the economy will collapse, but up to this limit, the disbalance between the demand and the production of goods can happen because of technological unemployment.

3.3. Solutions

Having presented the causes that can bring about or accelerate technological unemployment, and the consequences of this phenomenon, we now turn our attention to the solutions proposed by the literature to this challenge. While reviewing the literature, we came across a considerable number of proposals from researchers. Here, we decided to categorize these solutions into two groups. The first group of solutions dealt with mitigating the causes of technological unemployment, thus minimizing or avoiding it. The second group of solutions aimed at helping society to deal with the consequences of technological unemployment.

3.3.1. Solutions to Causes

According to the reviewed literature, avoiding or reducing technological unemployment can involve several measures. One of these measures is augmenting workers instead of replacing them [30–32,39]. This is not possible or desirable in every single role [39]. In the cases where it can be applied, augmentation might bring the (sometimes temporary) benefit of allowing for a longer period of adjustment for the workers serving as an intermediary step from total automation [30].

To be augmented, workers will need to have higher skills, mainly digital skills, which could result in a rise in the general level skill of the workforce increasing the offer of high-skill work and reducing the wages thus renewing the middle class [32].

Another measure that could be adopted is sharing work. Instead of laying off the workers displaced by automation, companies could reduce the number of hours in the working week [35,44]. A reduced workweek was one of the economic possibilities put forward by Keynes back in the 1930s when he believed that their grandchildren would have a 15 h workweek when they came of age [23]. The shared work policy can also bring some relief to the social safety net, particularly to unemployment systems, since workers would not depend on it if allowed to remain working less time [35]. Sedai suggests that this strategy should be limited to a reduction of 20–40% and that companies should provide the same employee benefits when reducing the working hours [35].

Nostalgia or technology aversion might motivate the revival of certain occupations that could help to balance the unemployment caused by the increased use of technology. In the future, as automation replaces more and more humans, there could be a rejection of technology leading to an increase of jobs in traditional fields such as handcrafted products [2]. Chomanski shows that this nostalgic work already exists, as in the example of the hiring of horse-drawn carriages and, as technology advances, humans could be hired to be nannies, painters, or chefs [30]. Kim and Scheller-Wolf [4] states that we must search for new business ideas to create a market for human labor. One idea is the creation of a “made-by-humans” campaign to create a market demand for human labor.

As it happened before, it might be the case that new economic sectors, some still unknown, might be created to replace the ones in which little or no labor is needed. Walden suggests some possibilities: an increase in the services provided for time-constrained households; development and implementation of new technology; data production, man-

agement, and analysis; a possible surge in world tourism; and expansion of health care workers as the world population continues to increase its life expectancy [2]. Technological change sometimes renovates jobs instead of eliminating them. In this case, workers need to update their knowledge and skills but can remain in their jobs [48].

Finally, the inequality between countries could be mitigated by international tax cooperation to address technological unemployment [28]. In Berberov and Migolov's view, developed economies could collect resources through an ephemeral global tax tool (e.g., a robot tax) to pay a universal basic income to the citizens of developing countries [28]. Although, as discussed previously in the causes of technological unemployment, the international cooperative mechanisms might be limited to implement this, and the current limit of such international actions might be the incentive of research and knowledge sharing about strategies to combat technological unemployment, an example of which could be close to the United Nations recommendations [28].

3.3.2. Solutions to Consequences

If technological unemployment happens, there are some measures indicated by the literature to mitigate or eliminate some of its consequences. Here, we made an effort to indicate the relationship between consequences and the proposed solutions, but it should be noted that some solutions might affect more than the one or two consequences of technological unemployment that are considered.

Related to the possibility of increased inequality and the lack of minimum living standards, the literature proposes basic income guarantees, charitable donations, the production of ones' own goods, and a change in the social safety systems.

There are different versions of basic income guarantees, such as the UBI, in which every citizen receives a certain amount of cash regardless of their economic situation, mandatory profit-sharing by firms, and minimum employment schemes [35]. Sedai defends that regardless of the chosen mechanism, providing a minimum living standard for its citizens is "exactly the kind of public good that government should create" [35]. Such redistributive systems reduce the financial stress from most vulnerable citizens with minor impacts on the rich [44].

If automation reaches a high level, and wealth is still or further concentrated in the hands of a few, future elites could become rich enough to help mitigate the technological unemployment with their charitable donations [30].

Another possible solution to the lack of minimum living standards that could be caused by technological unemployment is the production of goods by the people who need them. As technology cost lowers and people have more free time, they could invest in learning how to code, for instance, to create their own machines to perform at least part of the work needed for subsistence [30].

Changing the social safety net is also indicated as a possible course of action that could mitigate the consequences of technological unemployment [2,41]. Particularly, the unemployment compensation system was created to support workers during temporary unemployment due to economic downturns while they waited to be once again employed in the same function [2]. Technological unemployment is not a case of a temporary economic downturn but a more permanent transformation of the economy that requires workers to learn new skills to find new jobs [2]. To counter this problem, Walden proposes that the current unemployment system could be changed to include an upfront aid to be used for education costs [2]. The government-provided safety net could also be complemented by "unemployment insurance" sold by companies, and by workers' personal savings that could be increased in a "post-automation" society that allows for a reduction of goods prices [30].

These changes to the social safety net could also help with the update of the workforce's outdated skills. Here, three other solutions might help: tracking occupational change, changing higher education, and increasing on-the-job corporate retraining.

Besides being an important measure by itself, tracking occupational change is an enabler of the other solutions to the workforce's outdated skills and even to solutions to other consequences of technological unemployment [2]. For the case of the USA, Walden proposes the creation of an early warning system of occupational change that would examine annual Bureau of Labor Statistics to detect how occupations are shifting, combined with the tracking of market trends in hiring with data from job postings and social media, and regular direct surveys of companies to access their hiring necessities in terms of skills and tasks [2].

One of the uses of the tracking of occupational change would be to help higher education institutions in the analysis of their courses portfolio and the following (rapid) reallocation of resources to meet demand [2]. Coupled with this rapid response to the market regarding their traditional undergraduate courses, institutions may also need to provide shorter courses focused on retraining workers [2,40]. The standard curriculum should heavily focus on science, technology, engineering, and mathematics (STEM) to ensure that graduates can work with the machines at their workplaces [1,44]. Another required change to the educational system would be the decoupling of the training in core competencies needed for any occupation in the future (e.g., computational competencies, and complex communication) and the specific skills required by a certain occupation [2,40]. These changes will require more investment in higher education, which could be supplied by government funds and by private companies' resources as the private sector gains a certain level of control over the courses curricula [2]. Workers should be prepared to learn the advanced skill sets [49]. Massive open online courses (MOOCs) promise to change higher education, providing flexible and affordable courses [45].

Companies could help with this challenge by complementing higher-education institutions' financing and by providing on-the-job retraining. As companies are the locus where automation takes place—they have a privileged position to analyze which new skills the workforce should have. This process could be incentivized by limited labor compensation deductions or noncompete contract clauses for a certain period to defend themselves in the case of the trained employee decides to leave the company [2].

Finally, the negative consequence of fiscal risk could be mitigated by a fiscal reform. One of the proposals for fiscal reform is the robot tax, which requires that companies that replace humans with robots pay a tax that could then be used to provide a safety net for displaced workers; an idea that is already introduced in South Korea and is being considered in Canada, India, and China [28,36]. Other proposals involve a tax rate on profit that is larger than the tax rate on wages [41], progressive consumption taxes coupled with income taxation [38], and the joint consideration of corporate and personal taxation [28]. Automation cannot be used to reduce tax revenue [42].

For the case of Russia, Berberov and Milogolov suggest that the tax reform should go in the direction of supporting Russian IT companies, reviewing personal income tax to reduce the burden on the people with relatively small incomes, incentivizing staff education and retraining, and reforming tax residence criteria of Russian digital specialists [28].

For the case of Latin America, Aguilera and Ramos Barrera [33] highlight three previously mentioned strategies to face technological unemployment: the use of income guarantees such as the universal basic income, retraining workers and stimulating them to live lifelong learning, and reducing the weekly working hours by sharing work.

Another proposed solution that is worth mentioning was made by Danaher [3]: an increased integration with the machines. Merging our bodies and minds to machines would bring the benefits from the new technologies without the associated problems, such as technological unemployment.

3.4. Research Agenda

This section of our literature review is dedicated to presenting the different research roads that will lead to more knowledge about technological unemployment. We reviewed several papers with different backgrounds and goals and, although they all have some

relation to the technological unemployment subject, they present different research agendas that could be taken as a starting point for future research.

Aguilera and Ramos Barrera [33] investigated the technology impact on labor markets in the Latin American context. They found the investments in SandT have no significant impact on the unemployment rate. They claim that further research is needed for the region since their results differ from the ones obtained in developed countries. In addition, in the field of employment, they indicate the need to formulate tentative scenarios to identify unintended consequences of machines being the dominant form of production and value creation.

Feldmann [47] empirically analyzed the impact of technological change on unemployment. His results indicate that faster technological change is likely to increase unemployment substantially. However, more research is needed about the transmission channels from technological change to unemployment and in the time pattern of the effect on unemployment. Finally, policy implications must be discussed as well as the government's role in helping workers to fully benefit from the technological progress.

Carvalho and Di Guilmi [41] consider that their model to analyze the relationship between technological unemployment and income inequality could be extended in several ways such as using a more sophisticated treatment of fiscal and monetary policy, and the inclusion of the possibility for households to buy shares during a stock-market boom.

Walsh [39] asked experts and nonexperts to give their opinion about the automatability of the occupations used by Frey and Osborne [5] to train their model. The author considers that future work could be dedicated to extrapolating from jobs at risk to a percentage of the workforce unemployed by automation.

Fernández-de-Córdoba and Moreno-García [43] modeled involuntary unemployment to find which conditions in the labor market prevent wages from falling due to the supply of unemployed workers. They focused on noncooperative solutions, and they claim that further research considering cooperative solutions is needed.

Peters et al. [27] discussed the higher education policies, and why the simple "more education" solution has been failing to solve the problem of technological unemployment. They claim that we should give more agency to researchers, teachers, and students. Moreover, they stated that we need new visions of different social orders in which education, technology, and employment have radically different meanings.

Loi [32] called for more research from normative political and moral philosophy about technological unemployment. According to the author, there is a wealth of relevant data about the issue, attention from the media, and research by economists, while philosophy is giving surprising little attention to the subject.

4. Discussion

There seems to be an agreement among the reviewed authors that technological unemployment is a plausible consequence of the current wave of automation. As we have shown, this issue is of interest from the most diverse areas such as sociology, economy, and philosophy.

The causes of technology unemployment are diverse and involve long-known factors such as the increasing pace at which new technologies are being adopted outpacing our capacity to reskill the labor force [3,32,35]. Despite being a known challenge, the skills mismatch takes a new form as the current wave of technological change takes much less time to be diffused around the world [1,2,51].

This fast rate of change puts pressure on current tax systems and can jeopardize the social security programs that they are intended to finance, thus creating other challenges that need to be solved if the impact of automation is to be controlled and directed [28,36].

When looking at the possible solutions to technological unemployment, the literature shows that different social actors need to act, but economically developed countries have more power to produce effective change. In itself, international cooperation is usually a

challenge [28] that can be aggravated in the current economy in which the most powerful companies know no borders and are located in few economic potencies [29].

From a broader perspective, the challenges related to technological unemployment could be avoided or better dealt with if the current profit idea of maximizing profits to generate small elites is changed [31], something arguably harder than international cooperation. If this change in the social role of capital does not happen and automation advances as it is expected to, we can expect to see an increase in economic inequality, which might require a share of the workforce to live out of a combination of charitable donations of the elites, “nostalgic” jobs, and production of their own goods [30].

The reviewed literature indicates a middle ground between these two possibilities, which, in our understanding, should involve or even start at the tracking of occupational and technological change to better understand and anticipate the necessary retraining of workers [2]. Higher education needs to be constantly updated, possibly with the support of private companies, to remain relevant for the future economy [2,27,45]. Governments will need to review tax systems to ensure that displaced workers have the means to survive and to invest their time in acquiring new skills that can provide higher quality and better-paying jobs [28,36]. Finally, companies can assist by considering work-sharing strategies [35,44] and on-the-job corporate retraining [2] instead of firing displaced workers without a clear strategy on how to deal with this challenge.

5. Conclusions

Automation has happened before in previous industrial revolutions, and its results have been, in general, positive. In this Fourth Industrial Revolution, we are experiencing a new wave of automation that supersedes human skills that were previously considered impossible to be replaced by machines. As it becomes harder to perceive what is left for humans to accomplish, the fear of technological unemployment reappears.

In this paper, we set out to contribute to the literature and discussion about the impact of technological unemployment by understanding the causes, consequences, and possible solutions to this phenomenon.

In the future, if technological unemployment does concretize as a reality, society might look back and consider that these authors were concerned with fruitless matters. This is the curse of those who research the future; if their negative forecast is taken seriously, their work can motivate or help society adjust, which will then render their forecasts wrong. This phenomenon is known as a self-defeating prophecy [54].

If technological unemployment becomes a reality, the most dystopic scenario involves the exclusion of part of the population from society [32,37]. A “Brave New World” where “... poor pre-moderns were mad and wicked and miserable. Their world did not allow them to take things easily, did not allow them to be sane, virtuous, happy” [55].

Massive technological unemployment might also bring about a utopian future where humans, freed from the economic obligations of work, may dedicate themselves to finding the true meaning of life with total freedom to pursue leisure full time if this is what they want [31,38]. This scenario also has a drawback—as one of Voltaire’s characters in *Candide* reminds us, work can free us from three evils: weariness, vice, and want [56]. It remains an open question if humans will find a replacement for work that also keeps these, and other, evils at bay.

As it happened before, reality can be expected to fall somewhere between these two extreme predictions, and what will bring us closer to one or another is the actions that we take in the meantime. In our literature review, we showed several solutions that could be adopted to help society reducing technological unemployment impact such as reforming tax systems, rethinking higher education, creating minimum income guarantees, and reducing the working week.

Dealing with technological unemployment will require a joint effort from different social actors such as companies, governments, educational institutions, unions, and workers.

There is not a single solution for the challenge, but the adoption of different measures might allow society to reach the long-envisioned goal of removing the economic demand from work and providing humanity with the (good) problem of finding a purpose for its life.

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