Technological Unemployment and the Resurgence of Political Economy

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Abstract

The aim of this paper is to discuss the possible impact of the "third wave" of technological unemployment on economic theorizing. Twenty-first century technological progress, heavily impacting on employment, is a process that just started but whose main new feature is already well known. This feature concerns robots (and artificial intelligence) and their entry into the production process. Robots do not simply increase labor productivity in cooperation with humans but can substitute for human labor, producing commodities without human input possible and hence, possibly, giving rise to long-term mass unemployment which will require some form of public policy intervention. This scenario exhibits important implications for economic theorizing, since mainstream theory, rooted in the general equilibrium approach, faces difficulties in dealing with a reality where social classes and the class struggle (a few robot owners vs. many unemployed humans) regain a role, labor productivity becomes irrelevant and uncorrelated with the (subsistence) wage/subsidy that must be paid to the unemployed, the labor market does not clear, redistributive policies replace the optimal allocation of scarce means, and so on. This scenario returns economic theorization to the years of classical Political Economy, when the main focus of theoretical investigation was on social classes, the class struggle and redistribution of the surplus. In particular, Sraffa's 1960 model might represent a good foundation for further theoretical development.

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Introduction

The debate on the possibility that technological progress causes long-term unemployment regained importance in recent years, with the advent of the Fourth Industrial Revolution. The first three industrial revolutions (1765–1830, 1870–1914, and 1969–today) initiated two different waves of short-term technological unemployment, but their effects were reabsorbed in the longer term by the operation of effective compensating forces. In contrast, according to a number of recent contributions, (e.g., Brynjolfsson and McAfee 2011, 2014; Freeman 2015; Ford 2015; D'Orlando 2018; for some aspects Acemoglu and Restrepo 2017, 2019), the Fourth Industrial Revolution, which started to affect the economy at the beginning of the 21st century, will be radically different from the others and will give rise to a third wave of technological unemployment that traditional compensating forces might be unable to reabsorb.

Conflicting views were always present in the theoretical literature on the theme of technological unemployment, but the debate that developed during the first three industrial revolutions somehow reached the majority conclusion that technological progress cannot generate long-term unemployment because of the effectiveness of the compensating forces. These forces were mainly founded on wage reductions and (demand and) production increases that reabsorbed unemployment. Furthermore, the theoretical analysis was confirmed by empirical evidence of employment increases during periods of strong technical progress, even though supporters of the hypothesis of technological unemployment imputed such a result mainly to the simultaneous reduction of per capita working hours.

Nowadays, the scenario changed, because, unlike in the first three industrial revolutions, machines no longer merely cooperate with human workers but now substitute for them in the production process. Although not yet the case, in the next few years, the possibility exists that robots endowed with artificial intelligence will be capable of substituting for both skilled and unskilled workers in almost all industries, as well as for workers performing routine and non-routine tasks, so that realizing production without human input will be possible. Moreover, if robots are more productive and less expensive than human workers, their substitution for humans will be both feasible and economically convenient. The likely result is long-term mass unemployment.

The above described scenario bears important implications for both the theoretical analysis and the effectiveness of compensating forces. On the first point, i.e., the theoretical analysis, it is immediately evident that the introduction of robots into productive processes implies that all the conclusions reached by previous theoretical studies are irrelevant for the present case. Models built to study a world in which machines cooperate with humans but cannot substitute for them, except in very few tasks, are irrelevant in a world in which they can substitute for humans in all tasks at a lower cost, without cooperating with them. The same holds for the empirical conclusions reached for the past waves of technological unemployment, since we are in the presence of a completely new phenomenon that has only just begun impacting on employment.

Secondly, robots not simply might generate mass (technological) unemployment and condemn past theoretical studies to irrelevance, and they may also condemn the most important compensating forces to ineffectiveness. This is so because, to reabsorb this new type of technological unemployment, wage reductions would need to be huge, but wages exhibit a

subsistence minimum below which they cannot fall. Furthermore, the compensating force based on (demand and) production increase will be ineffective since this will result in an increase in employment mainly or uniquely for robots and not for humans if production can be realized by robots alone. Within such a framework, long-term mass unemployment becomes a realistic outcome that will require some form of public policy intervention.

Public intervention may take a number of different forms, from redistributive policies (taxing robots, subsidizing unemployed humans, introducing mandatory quotas for human employment, paying an unconditional basic income to all citizens, etc.) to collectivizing the ownership of robots or firms. This paper briefly indicates all these policies, but mainly focuses on the capability of mainstream, (i.e., neoclassical) economic theory to deal adequately with the whole scenario. Traditional models studying the impact of technical progress, and even automation, on the economy, are all rooted in the neoclassical general equilibrium approach, are built on "ad hoc" hypotheses, disregard the possibility that the wage exhibits a subsistence lower bound and above all, rest on some kind of market clearing assumption, so that involuntary unemployment is, with few exceptions, out of question. The point here is that such models, and the neoclassical approach in general, face great difficulties in dealing with technological unemployment being rather incapable to systematize a reality in which social classes and the class struggle (a few robot owners vs. many unemployed humans) exhibit a crucial role, labor productivity becomes irrelevant and uncorrelated with the (subsistence) wage/subsidy that must be paid to the unemployed, redistributive policies gain relevance with respect to the optimal allocation of scarce means, and so on. Indeed, social classes, the class struggle, subsistence wages, and redistribution of the surplus were the objects of study of the "old" Political Economy, rooted in the works of the classical economists and Marx. To better understand and theoretically discuss what will happen in the near future, going back to the remote past might therefore be necessary, referring to the hints and the theoretical structure of Political Economy rather than of neoclassical theory. In particular, Sraffa's 1960 model represents a good basic starting point for further, more refined, theoretical contributions on the theme.

The paper is organized as follows. Section 1 offers a brief description of the history of the first two waves of technological unemployment and of the building of a comprehensive theory called "compensation theory", which studies automatic forces capable of bringing the economy back to full employment. Section 2 illustrates the main characteristics of the third wave of technological unemployment, which jeopardize the effectiveness of compensation theory and points out the possible policy intervention solutions for this problem. Section 3 discusses the comparative capabilities of approaches rooted in neoclassical theory and in classical Political Economy, to theoretically systematize this new framework, showing that with respect to distributive questions, the latter appears to be more effective than the former, and hence Sraffa's 1960 approach can be successfully used to discuss the problem. Section 4 concludes the paper.

The First Two Waves of Technological Unemployment and the "Theory of Compensation"

The theoretical debate on technological unemployment was ignited by the First Industrial Revolution (roughly 1765–1830), when the invention of the steam engine represented a form of technological progress apparently capable of generating unemployment in a number of sectors. From then on, this debate played a marginal role during the Second

Industrial Revolution (roughly 1870–1914), when electric power was the basis of mass production, and during the Third Industrial Revolution (roughly 1969–today) when electronic and ITC technologies were used to automate production. The theme only regained relevance in the 21st century, when the advent of robots and artificial intelligence seemed capable of opening the way to what Schwab (2016) called the "Fourth Industrial Revolution".[i]

The first three industrial revolutions generated two different waves of technological unemployment. During the First and Second Industrial Revolutions, individuals saw a first wave of technological unemployment, as a result of technical progress that mainly relocated workers from one sector (firstly from agriculture and later from manufacturing) to another (firstly to manufacturing and later to services). During the Third Industrial Revolution, things changed a little, and researchers can find two main interpretations of the impact of technological progress. According to some scholars, skill-biased technical change[ii] mainly reduced employment for unskilled workers, as well reducing their wages and increasing the wages of skilled workers, the skill premium, and inequality.[iii] According to other scholars, task-biased technical change[iv] mainly affected workers performing routine tasks, so that this approach has also been named routine-replacing technical change (RRTC). However, all the above interpretations conclude that, in the general case, the impact of technological progress on unemployment was significant in the short term but small in the long term (Campa 2017, p. 5).

The mechanism that resulted in technological progress impacting on employment was the same for all the first three industrial revolutions and is quite simple. Within a neoclassical framework, the choice between hiring labor (workers) or capital (machines) represents the standard choice-of-technique problem: given the produced quantities, entrepreneurs will substitute capital for labor if the value of the marginal product of capital divided by the money price of the service of capital is greater than the value of the marginal product of labor divided by the money wage rate. Hence, machines destroy human jobs if the following occurs: (i) capital productivity increases and/or the price of the service of capital decreases or (ii) labor productivity decreases and/or the wage rate increases. It is worth noting that technological progress in the form of product innovation is generally considered to be employment friendly, whereas process innovation can, in some cases, increase capital productivity more than labor productivity and can reduce the price of the service of capital, leading to the possibility that unemployment rises with technical progress if process innovation is strong. Nonetheless, according to the consensus view, unemployment should be reabsorbed, due to the simultaneous operation of a number of converging mechanisms, which were described by many authors and which constitute the theoretical approach referred to by Marx as *compensation theory* (Vivarelli 2007, p. 2).[v] Various scholars described some of these mechanisms (see, e.g., Vivarelli 2007, 2014; Blien and Ludewig 2017; Campa 2017; Peters 2017; Calvino and Virgillito 2018), but their lists were never, and probably cannot be, exhaustive.

The compensating forces can be divided into automatic mechanisms and deliberate intervention mechanisms. Automatic mechanisms are mainly rooted in the neoclassical approach, whereas deliberate intervention mechanisms are mainly rooted in the Keynesian approach.[vi]

Among the automatic mechanisms, the following are the most important: (i) Wage flexibility, which allows wages to reduce in the presence of unemployment, thus increasing firms' labor demand and allowing full employment to be regained. (ii) Employment increases

in the sector that produces the machines, due to an increase in demand for, and production of, machines. (iii) Fall in production costs, and hence in prices of commodities produced by the machines, leading to an increase in the demand for these commodities, an increase in production, and hence an increase in employment.[vii] (iv) Fall in production costs, and hence in prices of commodities produced by the machines, leading to an increase in real income and hence demand for goods, an increase in production, and finally an increase in employment. (v) Fall in production costs which, in the presence of price rigidities, increases profits and hence investment, in turn increasing production and employment in the sector that produces investment goods. (vi) Fall in production costs which, in the presence of price rigidities, increases profits, leading to higher demand from entrepreneurs for goods and hence increases in production and employment in the sector that produces consumption goods. (vii) Product innovation which creates new sectors of activity and employment in these sectors. (viii) Increase in the wages of the employed, increase in their demand for commodities, and increase in production and employment in these sectors. (ix) Transition of employed humans from the primary to the secondary sector when jobs are destroyed in the primary sector, and then from the secondary to the tertiary sector, when jobs are destroyed in the secondary sector. (x) Increase in the marginal productivity of labor caused by an increase in capital accumulation, and hence modification of the choice of techniques in favor of labor. (xi) Fall in machines' marginal productivity caused by their increased use, due to capital accumulation, and hence modification of the choice of techniques in favor of labor. (xii) Fall in production costs and hence in prices of commodities, leading to an increase in the real supply of money, a reduction in the interest rate and hence an increase in investment and employment in the sector that produces investment goods. (xiii) Within the task-biased (and/or routine-replacing-biased) approach, technological progress results also in the introduction of new tasks, thus coupling the *displacement* effect of labor caused by technological progress with a *reinstatement* effect that increases labor demand (see, e.g., Acemoglu and Restrepo 2019; Gregory et al. 2019).

Among deliberate intervention mechanisms, the most important are the following: (i) an increase in public expenditure, which increases aggregate demand, production, and hence employment and (ii) public subsidies for education and investment in human capital, which increase labor productivity and hence make workers competitive with machines.

The idea that compensation theory suffers some drawbacks is certainly true, mainly caused by wage and price rigidity, the absence of a further sector beyond the tertiary one to which workers can be displaced and public debt, which could prevent massive public expenditure.[viii] That said, until the end of the 20th century, the majority of theoretical contributors seemed to agree that compensating forces were effective in counteracting technological unemployment, although a number of dissenting opinions did persist.[ix]

Things changed slightly in recent decades, when the empirical debate focused on the fact that, from 1980 onwards, skill-biased technical change reduced unskilled workers' wages and increased skilled workers' wages (and employment), increasing inequality. Later, the new task approach[x] discussed the impact of technological progress on workers performing different tasks, in particular routine and non-routine tasks, rather than on skilled and unskilled workers, again with the emphasis on inequality and wage polarization. In any case, at least since the contributions of Acemoglu and Restrepo (2107, 2019), the belief that technical progress (mainly in the sense of process innovation) does not increase long-term unemployment, appeared to be still predominant among economists.

The great majority of theoretical models studying the impact of technological progress on the economy being strictly rooted in the neoclassical general equilibrium tradition is worth noting, with market-clearing equilibria and overlapping generations (see, e.g., Berg et al. 2018; Sachs and Kotlikoff 2012; Sachs, Benzell and LaGarda 2015). In most of these approaches, the idea that the wage demonstrates a subsistence lower bound is absent, the market clears, and hence the problem is not unemployment but the level of wages or the share of wages in income.

At least until the end of the 20th century, empirical studies seemed to confirm the conclusions reached by majority of theoretical analyses. A thorough description of these studies can be found in Vivarelli (2014), Gregory et al. (2019), and Calvino and Virgillito (2018).

Most contributions confirmed the results of the theoretical models, (i.e., no long-term mass unemployment) for the economic system as a whole in the presence of flexible markets, high demand elasticity for both products and factors, and high substitutability between factors (see, e.g., Piva and Vivarelli 2017, pp. 11–13). Furthermore, similar results were obtained at firm and industry levels. For example, Evangelista and Vezzani (2012) found that at firm level in (some selected countries of) the European Union, technological and organizational innovation exhibited a positive effect on employment because they increased the growth of firms, even though in manufacturing firms the contemporary presence of technological innovation and organizational change actually displaced workers. At a sectoral level, Ciriaci et al. (2016) showed the positive employment effect of small innovative firms in Spain. Bogliacino et al. (2012) found a positive impact of investment made by technological firms on employment but not of investment made by manufacturing firms in general, in 677 European companies. Coad and Rao (2011) showed that in the United States, high-tech firms' employment rose with innovation, and Van Reenen (1997) showed that in UK manufacturing firms, employment rose with innovation too. The conclusions of a study by Lachenmaier and Rottmann (2011) were somewhat different; although they confirmed the positive impact of innovation on employment in Germany, these authors found that this impact was positive mainly for process innovation. Piva and Vivarelli (2005) found a similar effect for the case of Italy, with a positive effect on employment of product innovation but no evidence of labor displacement by process innovation. Again, Piva and Vivarelli (2018) found that for 11 European countries, R & D innovation exhibited a positive impact on employment mainly in the case of product innovation in the medium- and high-tech sectors. With reference to imported technological innovations through trade and foreign direct investment, Haile et al. (2017) found a positive effect of technological progress on employment in Ethiopian firms. Acemoglu and Restrepo (2017, 2019), within a task-biased technical change model, found an acceleration of the displacement effect and hence a reduction of labor demand, especially in manufacturing, in the United States, for the period 1987–2017, compared with the period 1947–1987. Finally, Gregory et al. (2019), using a routine-replacing technical change approach, found evidence of both displacement and reinstatement effects in Europe between 1999 and 2010, but with the reinstatement effect prevailing and hence employment increasing.

The majority view also emphasized the circumstance that, consistently with these results, the global trend of labor productivity and employment showed co-movement.[xi] Technological shocks could generate waves of short-term unemployment but, in the longer run, the trend of employment appeared capable of tracking that of technical progress.

However, with few exceptions, these studies were mainly backward-looking, since they were studying the Third rather than the Fourth Industrial Revolution, i.e., they discussed the

relation between technical change and employment within both a traditional and a task-/routine-replacing technical change approach but did not discuss the impact of robots endowed with artificial intelligence on employment. They are important for emphasizing what happened in the past (particularly, but not exclusively, for skill- and task-biased technical change), but almost irrelevant for discussing the Fourth Industrial Revolution. This is also shown by the fact that the core of the analysis is represented by the logical concept of task-biased technical change, and in particular of routine-replacing technical change, a theoretical construct which is relevant in a context in which machines can perform only routine tasks, but which completely loses relevance with the advent of artificial intelligence, which allows robots to substitute for humans in both routine and non-routine activities (and potentially in all tasks).

The Third Wave of Technological Unemployment and "New Compensation Theory"

In the new century, with the advent of the Fourth Industrial Revolution, different ideas began to spread. The book by Brynjolfsson and McAfee (2011) testifies to this change, even though today their approach still remains a minority approach among economists. According to this new approach, the progressive development of artificial intelligence allows machines to substitute for human beings in (almost) all jobs: robots, computers, and computer programs demonstrate the potential to replace doctors, truck drivers, accountants, bank clerks, teachers, etc.[xii] Even though the Third and Fourth Industrial Revolutions were based on apparently similar technological progress, their impact on wages and/or employment is likely to be rather different, since today unemployment can affect skilled and unskilled workers in the same way, independently of whether they perform only routine tasks, and long-term mass unemployment became a concrete possibility. For the first time, some authors arrived at the point of envisaging the theoretical possibility of full unemployment (see, e.g., D'Orlando 2018; or the benchmark model in Berg et al. 2018). Up to the present time, this was completely out of the question.

The main drawback of the new approach is the fact that, since the process is only in its very preliminary phases, empirical evidence confirming the hypothesis of technological unemployment is still poor. However, the contributions of Acemoglu and Restrepo (2017, 2019) represent a crucial change of perspective; for the first time, they present strong empirical evidence that "this time it might be different", although much more empirical work is certainly necessary. In any case, theoretical analysis is perfectly capable of interpreting the new phenomenon (see, e.g., Brynjolfsson and McAfee 2011, 2014; Ford 2015; West 2015; D'Orlando 2018; from a more neoclassical perspective, Acemoglu and Restrepo 2019), even if economists appear reluctant to deal with this matter before empirical evidence becomes robust.

The theoretical novelty of the new approach, and the concrete difference with respect to the other industrial revolutions, rests upon the role played by robots and artificial intelligence. During the former three industrial revolutions, capital, such as machines, cooperated with labor in the productive process and could also increase human productivity, meaning that unemployment could only rise if demand and production did not rise sufficiently, and compensation theory appeared rather effective in preventing the impact of technological progress on employment. However, in the Fourth Industrial Revolution, robots endowed with artificial intelligence substitute for humans within the productive process, rather than cooperating with them (for a clear, albeit rather optimistic, discussion of this point, see, e.g.,

Acemoglu and Restrepo 2018, p.3). Thus, commodities can be produced by robots alone, without any contribution from labor.

In such a scenario, if robots' productivity is higher than humans' productivity *and* robots' remuneration is lower than workers' wages in *almost all sectors of the economy*, firms will hire robots and fire humans, thereby increasing human unemployment.

In the "old" scenario, with the rise of unemployment, compensating forces would have started operating and, in the long run, would have driven the system back to full employment. In this new framework, traditional compensation theory exhibits limited space, since only a few of the automatic and deliberate mechanisms might work. In particular, the main elements that impact on the validity of traditional compensation theory are substitutability between robots and workers and elasticity of demand. According to some authors (see, e.g., Berg et al. 2018; Bessen 2018), the demand elasticity reduced over time, so that even if the use of robots in productive processes reduces the prices and increases the quality of produced commodities, the demand for goods, and hence production and labor demand, does not rise, or shows only small increases. In any case, given a certain demand elasticity (and more so if the elasticity is low), the greater the substitutability ratio among robots and human workers, the lower the strength of compensating forces. If demand elasticity is particularly small, and in any case if the substitutability ratio is equal to one, most compensation mechanisms are ruled out.[xiii]

Indeed, in terms of automatic mechanisms, considering cases of both high substitutability and total substitutability, the following points apply: (i) Wage flexibility can play a role if, and only if, the wage lower bound is not reached, i.e., if the wage level necessary to compensate for humans' lower productivity is not below the subsistence level. (ii) An increase in the demand for robots and the production of robots might cause only a minor increase (or no increase at all if the substitutability ratio is equal to one) in human employment in the sector that produces robots, if robots can be produced mainly by means of robots (or by robots alone). (iii) Reduction in production costs and hence in prices of commodities produced by robots increases the demand and the production of these commodities, but this increase might cause only a minor increase (or no increase at all if the substitutability ratio is equal to one) in employment, if these commodities can be produced mainly by means of robots (or by robots alone). (iv) Reduction in production costs and hence in prices of commodities produced by robots can cause an increase in the real income and hence the demand and production of goods, but this increase might cause only a minor increase (or no increase at all if the substitutability ratio is equal to one) in employment, if commodities can be produced mainly by means of robots (or by robots alone). (v) Reduction in production costs, in the presence of price rigidity, may increase profits and hence investment, but this increase might cause only a minor increase (or no increase at all if the substitutability ratio is equal to one) in employment in the sector that produces investment goods if investment goods can be produced mainly by means of robots (or by robots alone). (vi) Reduction in production costs, in the presence of price rigidity, may increase profits, entrepreneurs' demand for goods and hence production, but this increase might cause only a minor increase (or no increase at all if the substitutability ratio is equal to one) in employment in the sector that produces consumption goods if consumption goods can be produced mainly by means of robots (or by robots alone). (vii) Product innovation can create entirely new sectors of activity but might cause only a minor increase (or no increase at all if the substitutability ratio is equal to one) in employment in these sectors if commodities can be produced mainly by means of robots (or by robots alone) in these sectors also. (viii) An increase in the wages of employed humans appears out of the question,

but even if this happened, this increase might result in an increase in demand for goods and hence production, generating only a minor increase (or no increase at all if the substitutability ratio is equal to one) in employment in the sector that produces consumption goods if consumption goods can be produced mainly by means of robots (or by robots alone). (ix) At the moment, no new sector of relevance beyond the tertiary sector, which is capable of absorbing human workers, seems to exist. (x) If robots are humanoid, humans' marginal productivity does not rise more than that of robots with an increase in capital accumulation, meaning that no chance exists that human productivity will rise above that of robots. (xi) If robots are humanoid, the marginal productivity of labor reduces with that of robots, and the choice of techniques does not modify in favor of labor. (xii) A reduction in production costs and hence prices of produced commodities increases the real supply of money, reduces the interest rate, and in turn increases the production of investment goods, but if investment goods are also produced by robots alone, employment might not rise or might rise in only a minor way. (xiii) With the introduction of artificial intelligence, the number of new tasks that can be performed only by humans in the production process will fall, so that the displacement effect will be dominant over the reinstatement effect - this is also the main empirical conclusion of Acemoglu and Restrepo (2019).

Concerning traditional deliberate intervention mechanisms: (i) an increase in public expenditure might demonstrate only a minor impact (or no impact at all if the substitutability ratio is equal to one) on employment, if an increase in the demand and production of goods generates only an increase in the demand for goods produced mainly by means of robots (or by robots alone) and (ii) public subsidies for education and investments in human capital might likely be unable to increase human productivity above that of robots (incidentally, the skill premium ceases to demonstrate a role, and both skilled and unskilled workers are affected in the same way by technological unemployment).

Compensating forces might therefore be ineffective in the Fourth Industrial Revolution, so that the final result of long-term mass unemployment is not only a possible but also a rather likely scenario.

The peculiarity of the Fourth Industrial Revolution is worth emphasizing again, which jeopardizes compensation theory and cannot be studied by using the assumption that capital cooperates with humans in the productive process. Models must explicitly assume that robots endowed with artificial intelligence can substitute for human workers, both skilled and unskilled, performing both routine and non-routine tasks (so that routine-replacing technical change is a completely useless concept for discussing this topic). To put this another way, studying the Fourth Industrial Revolution requires a completely different framework and not simply the old approach used to study the Third Industrial Revolution (or the first two). Furthermore, empirical data are again of little utility, and of no utility at all if they refer to what happened more than a decade ago, since the Fourth Industrial Revolution and the introduction of artificial intelligence into production processes is a phenomenon that began in this decade and will impact on empirical data only in future decades.

However, although in the presence of the third wave of technological unemployment market forces alone might be ineffective in returning the system to full employment, some deliberate intervention mechanisms can (and indeed should) be implemented.

In the literature, we can find a number of intervention policies, the most important of which are as follows.

i. Subsidize the hiring of humans by paying employment subsidies to firms that hire humans.
ii. Tax the hiring of robots.[xiv]
iii. Allow workers to accept wages below the subsistence level by paying an unconditional basic income to all citizens, both employed and unemployed. Once the subsistence basket is obtained, workers can decide whether or not to accept a low wage competitive with robots' remuneration for being hired and increase their consumption above subsistence, or to stay voluntarily unemployed and receive only the subsistence income.[xv]
iv. Boost education and/or professional training, cutting the costs of private investment in human capital, or directly offering this education and/or training for free to humans, to increase human productivity and make workers competitive with robots.[xvi]
v. Impose minimum human employment quotas, or maximum robot employment quotas on firms.[xvii]
vi. Nationalize firms, assign the ownership of robots (or firms) to citizens or encourage workers to buy shares in firms.[xviii]
vii. Accept long-term mass unemployment and subsidize all humans with an unconditional basic income or subsidize only the unemployed with huge unemployment allowances.[xix]

The most debated and well known among these possible policies is the payment of an unconditional (or universal) basic income to all citizens, irrespective of whether they are employed or unemployed. The unconditional basic income is "a cash grant provided to every citizen […] without any other eligibility requirement" (Tanner 2015, p. 3), with different specific goals, from fighting poverty and inequality to counteracting technological unemployment. In this latter case, the basic income must be high enough to ensure subsistence, as the assumption exists in what follows.

Few studies in the economic literature on the consequences of the payment of an unconditional basic income exist (see, e.g., Van der Linden 1997, 2002; Bowles 1992; Gamel et al. 2006; Pech 2010; Marchant et al. 2014; Tanner 2015).[xx] Among the positive aspects of the payment of an unconditional basic income, some scholars emphasize the circumstance that a basic income "would be simpler and more transparent than the current welfare bureaucracy… would reduce paternalism and government involvement in the lives of poor people… would more effectively alleviate poverty… could provide better incentives – or at least fewer disincentives – for work" (Tanner 2015, p. 7; see also Widerquist 2017). Other scholars reach the opposite conclusion that the basic income "fails to provide an incentive to find work or engage in other meaningful and beneficial activities […], provides an automatic government handout to individuals while reducing their esteem in their own eyes and those of their neighbors and contacts [and] would be very expensive" (Marchant and Stevens 2017, p. 1). Studies based on income and substitution effects were developed, but they are quite inconclusive concerning the impact of a basic income on labor supply, the wage equilibrium and work effort (see, e.g., Martinelli 2017, p. 51 ff). However, the idea that the basic income reduces labor supply and work effort, inducing people to remain idle, is quite widespread. Leaving traditional for less traditional economic approaches, we again find different opinions.

Some scholars refer to behavioral economics and evolutionary game theory to conclude that when altruistic behavior and behaviors based on habits or heuristics substitute for self-interest and maximizing behavior, "individuals may not shirk when given income guarantees" (Widerquist, Lewis, Pressman 2005, p. 590). However, insights from the debate on the role of intrinsic motivations suggest that when subsistence is ensured, motivating people to work (and/or to exert high work effort) might be difficult, or at least might be difficult for certain kinds of jobs if the incentive is merely monetary (or extrinsic). Furthermore, "for those tasks in which a person demonstrates a high intrinsic motivation to perform, the introduction of an extrinsic incentive (in the form of a monetary reward or a fine) undermines her intrinsic motivation, which may cause her to decrease the level of effort" (Pech 2010, p. 8). Thus, according to most contributions, the possibility exists that the basic income reduces the incentive to work, work effort, and economic efficiency, even if different opinions exist.

The basic income may also present some relevant problems related to well-being. On this aspect, the main conclusion reached by D'Orlando (2019) is that the payment of an unconditional basic income will, in many cases, reduce well-being with respect to alternative policies. In particular, hedonic adaptation and loss aversion can be used to show that the payment of a basic income cannot adequately compensate people for the psychological costs of unemployment, which all empirical studies consider as one of the worst experiences in life. Furthermore, unemployed earners of the basic income will be unable to generate envy in other people, whereas they will envy the employed and robot/firm owners. They will suffer problems of self-esteem and social stigma. Finally, they will be unable to escalate to higher-grade consumption behaviors (as well as being aware of this inability) and to realize their aspirations, which are also circumstances that reduce well-being. The payment of a higher basic income might compensate for the first problem, the psychological costs, but not for others. On the contrary, employed earners of the basic income will enjoy a significant increase in well-being due to the possibility of both generating envy over the unemployed and escalating to higher-grade consumption behaviors. As a result, well-being inequality will increase.

Therefore, possible alternative solutions to the basic income should be considered. Among these solutions, the most promising appear to be a reduction in per capita working hours and the possible implementation of a "cap-and-trade" solution, which mimics that of Tietenberg's (1990, 2003) traditional tradable-permits approach to environmental problems, imposing quotas of workers to be hired by firms, but with the opportunity to trade these quotas. These two solutions also incur some drawbacks, but, according to D'Orlando (2019), combining both with the payment of a basic income, which rises over time, could guarantee efficiency, almost full employment, and acceptable results in terms of well-being.

Political Economy or Economics?

The world emerging from the third wave of technological unemployment will be radically different from the world that neoclassical theory more or less successfully dealt with from 1870 onward. Since the new scenario appears similar in many aspects to the pre-1870 scenario, which saw the predominance of a completely different economic theory, questions may arise regarding whether the traditional neoclassical approach is the best theoretical tool for systematizing this new reality, or whether a return to older theories might be appropriate.

In the history of economic thought, we saw an important theoretical evolution when the class conflict between landlords and capitalists ended with the victory of the latter. The traditional classical approach, rooted in the works of Smith, Ricardo, and (somehow) Marx, progressively lost relevance, whereas the neoclassical approach rooted in the works of Walras, Jevons, Marshall, and Clark, progressively acquired relevance. Indeed, with the success of capitalists in the class conflict against landlords, and the fear that a new class struggle could arise between capitalists and proletarians, a less conflictive theory for describing economic reality became more consistent with the interests of the new ruling class. The neoclassical approach met this latter requirement perfectly. This circumstance can therefore (at least partially) contribute to explaining its success.

The crucial differences existing between classical and neoclassical theory were not immediately perceived (or emphasized) by economists. Indeed, the conventional view considered classical authors as mere precursors of neoclassical authors. However, after the publication of Sraffa's book *Production of Commodities by Means of Commodities* (Sraffa 1960), the idea that the two theories were radically different in a number of relevant aspects became clear.[xxi] On the basis of these differences, and in consideration of the different role that classical economists gave to political and social factors, classical theory is often referred to as "Political Economy", whereas neoclassical Economics is often referred to simply as "Economics".[xxii]

Classical Political Economy demonstrates a number of key distinguishing features with respect to Economics. Here, we shall only focus on the most relevant of them (and/or on those that appear more useful for discussing the implications of technological unemployment). These key characteristics are as follows.

1. Classical Political Economy studies social institutions and their relations with the decisions of production and consumption and with the distribution of income among the different social classes.
2. The social classes of capitalists, landlords, and workers are considered to be at the center of economic dynamics and hence are at the center of economic theoretical investigation.
3. Workers possess only their capacity to work, and the real wage they earn is given at the subsistence level. Forces exist that are capable of driving the wage back to a subsistence level if by accident it departs from that level.[xxiii] The circumstance that wages are in general lower than the value of workers' contribution to production can be used to provide a theoretical basis for exploitation (although the foundations of exploitation represent a rather controversial topic in classical theory).[xxiv]
4. Capitalists possess capital. Their productive share, i.e., the surplus they obtain, is residual: it is what remains of the value of production once wages (to workers) and rents (to landlords) were paid.[xxv]
5. It follows that the class struggle among capitalists and the other classes to modify the distribution of the surplus is not just possible, but somehow inevitable.[xxvi]
6. The value of produced commodities is rooted in the cost of production, and in general, this value is considered to be linked with the labor content of the commodity, although the labor theory of value represents the most critical drawback and the most debated topic in classical and classical-type theories.[xxvii]

7. The theory studies long-period positions, i.e., fully adjusted equilibria characterized by the realization of long-period equilibrium prices in all sectors of the economy, with cleared markets and the same rate of profits in all sectors.[xxviii]
8. Although many classical economists believed that in a freely competitive market, forces existed capable of driving the system towards optimal equilibrium and full employment, others, (i.e., Malthus and Marx) came to different conclusions.[xxix]

In contrast, the key characteristics of neoclassical Economics are as follows.

1. According to the famous definition by Lionel Robbins, Economics is "the science which studies human behavior as a relationship between ends and scarce means, which exhibit alternative uses" (Robbins 1935, p. 16). As a consequence, neoclassical authors believe that the main goal of theoretical investigation is to describe the optimal behavior of single (fully rational) individuals who aim at maximizing their objective functions.[xxx]
2. The concept of social classes is useless for understanding economic reality. Fully rational maximizing individuals are considered to be at the center of economic dynamics and hence at the center of economic theoretical investigation.[xxxi] Maximizing individuals possess different quantities of the three factors of production (land, labor, and capital).
3. The wage is the remuneration for the service of one of the three factors of production, i.e., labor, and is determined by the same criteria governing the remuneration for the services of the other factors, i.e., on the basis of marginal productivity. In particular, the real wage is determined in the market by labor demand and labor supply. This corresponds to the marginal product of labor. Since the marginal product of labor corresponds also to workers' productive contribution, the wage also corresponds to workers' productive contribution and exploitation cannot exist.
4. The same is true for capital (and for any other factor). The remuneration for the service of capital corresponds to the marginal product of capital. Since the marginal product of capital corresponds to the productive contribution of capital, the factor receives a remuneration which corresponds to its productive contribution.[xxxii]
5. From the points above, they show that class struggle between capitalists and other classes is impossible; not only social classes do not exist, but each factor earns a remuneration equal to its contribution to the productive process, so that income distribution is inevitably fair.[xxxiii]
6. In a neoclassical approach, the value of the produced commodity is meaningless; the price of the good is the key variable, and this is determined in the market by demand and supply. Demand and supply ultimately depend upon utility (this also explains why we consider commodities in classical theory and we consider goods, i.e., objects that generate utility, in Economics).
7. Although the first models maintained the reference to long-period equilibria and equal rates of profits, the theory soon focused on short-period equilibria.[xxxiv]
8. Price signals and price flexibility in a free competitive market drive the economic system towards optimal equilibrium and full employment.[xxxv] Public intervention is considered inappropriate, since the market is itself capable of reaching the optimal allocation of resources.

The neoclassical approach dominated theoretical analysis from 1870 up to the present, and in the last century, this approach further extended its boundaries. In particular, Nobel laureate Gary Becker, during the second half of the 20th century, "extended the domain of microeconomic analysis to a wide range of human behaviors and interactions, including non-market behavior."[xxxvi] Put another way, nowadays neoclassical Economics is considered capable of dealing with any decision problem, from the optimal intertemporal allocation of time between criminal activities to the choice of a partner.

Possible reasons for the past loss of relevance of Political Economy and the success of neoclassical Economics may be found in the evolution of concrete economic problems and/or in the different kinds of theoretical reality that the new ruling class wanted to represent. Now that economic reality is likely to radically change again, a new evolution in the theoretical framework seems possible. If with the Fourth Industrial Revolution economic reality evolves in the way we sketched in the preceding sections, Political Economy will be more suitable than neoclassical Economics for furnishing hints for interpreting such a different reality.

This is so, since neoclassical Economics was constructed for dealing with the problem of scarcity, not of distribution. According to Autor (2015, p. 28), "[i]f machines were in fact to make human labor superfluous, we would have vast aggregate wealth but a serious challenge in determining who owns it and how to share it". Indeed, neoclassical Economics was not constructed for dealing with a reality in which class struggle between a few robot owners and many unemployed humans exists, labor productivity demonstrates no theoretical relevance and is uncorrelated with the subsistence wage/subsidy received by workers, redistributive policies gain relevance with respect to the optimal allocation of scarce means, and so on. These characteristics may return economic theorization to the years of classical Political Economy, with the focus on social classes, class struggle, and the redistribution of surplus. These are precisely the themes that will be in the spotlight in the near future, when the problem will be extracting surplus from robots and redistributing the surplus to the unemployed, in order to guarantee subsistence for humans and a demand for commodities produced by robots.

In particular, neoclassical Economics faces significant difficulties when trying to systematize the four main implications of the third wave of technological unemployment: subsistence wages, class struggle, the determination of profits, and a long-term unemployment equilibrium (and the consequent inevitability of public policies). Political Economy appears better equipped for dealing with these topics.

The first difficulty concerns the determination of the equilibrium wage and the equilibrium level of employment. We saw in the preceding sections that in the presence of the third wave of technological unemployment, leaving the determination of wages and employment to market forces is not possible, otherwise equilibrium wages might fall below subsistence, and long-term mass unemployment would result. In such a context, public policies act to guarantee humans at least subsistence, either by subsidizing firms who hire human workers or by guaranteeing an unconditional basic income to all citizens. In the presence of policies other than subsidies and a basic income (for example when mandatory quotas of workers to be hired are imposed on firms), the wage does not determine the number of workers hired by a firm. As a result, the theoretical mechanism which, according to neoclassical Economics, rules wages and employment determination is no longer consistent with actual wages and employment determination in the scenario of the third wave of technological

unemployment: the concepts of marginal productivity, supply and demand for (the service of) labor, the disutility of labor, etc., no longer demonstrate any role. On the contrary, the classical notion of a subsistence wage and the idea that forces capable of driving the wage towards subsistence exist appear to be consistent with the economic dynamics realized within this new scenario. However, classical authors gave greater importance to automatic mechanisms capable of driving wages towards subsistence (albeit with differences between one author and another), whereas in the technological unemployment framework, greater relevance is to be attributed to public policies. In any case, the wage level becomes independent of economic forces and depends upon public policies and hence, ultimately, upon the relative contractual power of social classes.

Indeed, the central role played by the contractual power of social classes, and hence by the class struggle, is the key characteristic of the scenario depicted above, since the third wave of technological unemployment will ultimately divide society into the two conflicting classes of unemployed humans and robot owners. The resulting class struggle appears to be difficult for economic theory in general to deal with, and in particular, almost impossible for neoclassical Economics to deal with. This is so also due to a political circularity. The rise of technological unemployment calls for redistributive policies. However, many of these policies, for example the introduction of an unconditional basic income or collectivizing firms, allow humans not to work and hence reduce their contractual power, while others hide but do not suppress the fact that workers are (at least almost) useless for production. With low contractual power, humans will not demonstrate enough political strength to defend the basic income or the redistributive policies they succeeded in obtaining when they exhibited residual contractual power. Thus, mass poverty would be a possible outcome. Proposing fair solutions is (relatively) simple, but implementing them requires a political and social strength that humans only possessed, if they possessed this strength at all, when they were irreplaceable workers, and will not possess when they are replaceable and replaced by robots. In any case, class struggle becomes a key characteristic of the new era, together with the need for a contamination of economic theory by politics. As we saw above, neoclassical Economics, in contrast to Political Economy, was not built for dealing with social classes and their conflicts.

Class struggle exhibits a crucial role also in the determination of profits, since the relative contractual power of humans and robot owners, mediated by government policies and not by market forces, determines distributive shares. In particular, firms' profits will (also) depend upon government subsidies, wages paid to humans, and taxes paid to the government, all elements determined by political rather than economic forces. Again, in this case, classical Political Economy appears better equipped than neoclassical Economics to deal with questions regarding the distribution of surplus.

Finally, within the scenario of the Fourth Industrial Revolution, maximizing subjects, price signals and freely competitive markets will not drive the system towards full employment but towards long-term mass unemployment. Therefore, the free market outcome would be a market failure. Hence, market forces cannot be left free to operate alone, and public intervention will be necessary. Now, neoclassical Economics accepting public intervention in the presence of market failures is certainly true. However, the superiority of free markets over regulated economies represents one of the key philosophical foundations, rather than just a simple theoretical implication, of the traditional approach. Even though the works of some classical economists, for example Smith, did in fact act as precursors for neoclassical ideas on

the optimality of free markets, Political Economy is still superior to neoclassical Economics in dealing with this problem. Furthermore, neoclassical Economics is not at all equipped for dealing with one of the possible solutions to technological unemployment, namely, assigning the ownership of firms to the collective. This would be considered the worst possible solution.

Neoclassical models that till today are used to discuss the consequences of the Fourth Industrial Revolution are often rooted in a general equilibrium framework, with a labor market that should clear like all other markets, ad hoc hypotheses in production functions, sometimes with the use of the representative agent and overlapping generations hypotheses. These models can deal with equilibrium unemployment only with enormous difficulty, and they face even greater difficulties in dealing with long-term technological unemployment, which challenges this approach also with the problems depicted above. Political Economy faces fewer structural problems in building models aiming at studying technological unemployment.

Obviously enough, Political Economy must be purged by the labor theory of value, which is highly inconsistent with a framework within which production can be realized without human contribution. However, after Sraffa's (1960) book, the labor theory of value has no longer been present in the contemporary classical-type approach.

The starting point for treating technological unemployment in a classical-type way may indeed be Sraffa's *Production of Commodities by Means of Commodities* model. Considering the case in which robots do not exist, Sraffa's system of equations, or a slightly modified version of Sraffa's system of equations, can be written as follows:

$$\boldsymbol{p}^* = \boldsymbol{A}\boldsymbol{p}^*(1+r) + \boldsymbol{l}\boldsymbol{x}\,\boldsymbol{p}^*, \tag{1}$$

where $\boldsymbol{A}$ is the square matrix of technical coefficients, $\boldsymbol{l}$ is a column vector representing labor input per unit of output, r is the rate of profits (which is equal across sectors), $\boldsymbol{p}^*$ is a column vector representing the relative prices of output commodities, and $\boldsymbol{x}$ is a row vector representing the quantities of commodities contributing to the real wage. The unknowns are the prices $\boldsymbol{p}^*$ and the rate of profits r; the technical coefficients and the labor input vector are considered as known. The classical economists considered also the real wage vector as given, but nothing prevents the assumption that the rate of profits instead is given.

The system (1) can be solved in a well-known way (see, e.g., D'Orlando 1997, pp. 52–55).

What changes when robots enter the scene? For the sake of simplicity (and since classical economists studied only fully adjusted long-period equilibrium positions), let us assume that the substitutability between humans and robots is complete in any task and that the wage/productivity ratio of robots is lower than that of humans, so that humans are all unemployed and only robots produce all the commodities. In this elementary extreme model, we can also assume that robots are humanoid machines and capitalists who own robots rent them out to entrepreneurs, who organize the production and earn the profits. In these circumstances, nothing changes with reference to the system of equations (1), but now we substitute $\boldsymbol{l_R}$ for $\boldsymbol{l}$, where $\boldsymbol{l_R}$ is a column vector representing robot input per unit of output rather than labor input, so that $\boldsymbol{l_R}\,\boldsymbol{x_R}\,\boldsymbol{p_R^*}$ is the robot owners' revenue, and the technical coefficients of production become $\boldsymbol{A_R}$ $(\neq \boldsymbol{A})$. In addition, the equilibrium prices change $(\boldsymbol{p_R^*} \neq \boldsymbol{p}^*)$, as well as the rate of profits $(r_R \neq r)$. The resulting system of equations can hence be written as: [xxxvii]

$$\boldsymbol{p_R^*} = \boldsymbol{A_R}\boldsymbol{p_R^*}(1+r_R) + \boldsymbol{l_R}\boldsymbol{x_R}\boldsymbol{p_R^*} \tag{2}$$

l_R Due to the presence of mass technological unemployment, government is likely to implement intervention policies, for example imposing mandatory quotas on firms for hiring humans. The system of equations is therefore modified as follows:

(3) $$\boldsymbol{p}^*_{\boldsymbol{RH}} = \boldsymbol{A_{RH}}\boldsymbol{p}^*_{\boldsymbol{RH}}(1 + r_{RH}) + \boldsymbol{l_H}\boldsymbol{x_H}\boldsymbol{p}^*_{\boldsymbol{RH}} + \boldsymbol{l_{RH}}\boldsymbol{x_{RH}}\boldsymbol{p}^*_{\boldsymbol{RH}}$$

Firms are forced to hire a certain number of workers, and the remaining production is realized by robots. Now, $\boldsymbol{l_H}$ is a column vector representing labor input per unit of output, $\boldsymbol{l_{RH}}$ is a column vector representing robot input per unit of output, $\boldsymbol{l_H}\,\boldsymbol{x_H}\,\boldsymbol{p}^*_{\boldsymbol{RH}}$ is workers' revenue, and $\boldsymbol{l_{RH}}\boldsymbol{x_{RH}}\boldsymbol{p}^*_{\boldsymbol{RH}}$ is robot owners' revenue. It is worth noting that by acting in this way, the government induces firms to modify also the technical coefficients of production, the equilibrium prices, the rate of profits, and robot owners' revenue ($\boldsymbol{A_{RH}} \neq \boldsymbol{A_R} \neq \boldsymbol{A}, \boldsymbol{p^*}_{\boldsymbol{RH}} \neq \boldsymbol{p}^*_{\boldsymbol{R}} \neq \boldsymbol{p}^*, r_{RH} \neq r_R \neq r$ and $\boldsymbol{l_{RH}}\boldsymbol{x_{RH}}\boldsymbol{p}^*_{\boldsymbol{RH}} \neq \boldsymbol{l_R}\boldsymbol{x_R}\boldsymbol{p}^*_{\boldsymbol{R}}$).

Furthermore, in the system of equations (3), by considering the row vector of produced quantities $\bar{\boldsymbol{q}}$ and labor force as givens, determining human employment $\bar{\boldsymbol{q}}\,\boldsymbol{l_H}$, robots employment $\bar{\boldsymbol{q}}\,\boldsymbol{l_{RH}}$, and unemployment is possible.

The above model is only a first, elementary example of the way in which a classical-type approach can deal with the theme. Similar models can easily be developed, in order to discuss other public intervention policies and their consequences, testifying that the economic reality emerging from the third wave of technological unemployment is capable of revitalizing Political Economy, which appears better equipped than neoclassical Economics for theoretically systematizing the peculiar problems that emerge when distributive questions are on the scene but scarcity is not. Substituting Political Economy for Economics does not substitute for the huge amount of theoretical work that economists must do in order to deal with the quickly approaching problem of long-term technological unemployment, but such a solution constitutes a key preliminary step, without which the near future will be much more obscure.

4. Conclusions

As discussed above, the third wave of technological unemployment exhibits characteristics and implications radically different from the first and the second waves. While the first two waves reduced human employment in specific sectors (agriculture at first, manufacturing later on) or reduced wages and/or employment for unskilled workers and/or workers performing routine tasks, leading to rising inequality, the third wave will eventually be capable of destroying (almost) all jobs for humans (both skilled and unskilled, both routine and non-routine) in all sectors of the economy. This is due to the fact that, while the first two waves of technological unemployment were caused by the development of more productive machines, the third wave resulted from the introduction of robots into the production process. Unlike machines, robots do not cooperate with workers, but they substitute for them in the production process. As a result, traditional compensating forces, which in the past proved to be capable of preventing the impact of technical progress on employment, will be ineffective. Due to the relatively high productivity and low cost of robots, a wage reduction should be significant enough to compensate for technological unemployment and to guarantee human employment, but the existence of a lower bound for the wage corresponding to the subsistence level may easily prevent such a huge wage reduction to happen. In addition, an increase in demand could result in an increase in the production of commodities produced by robots alone, and hence in employment for robots alone. Therefore, long-term mass unemployment is not only a possible but a rather likely scenario, calling for redistributive policies.

Among the solutions that were proposed, taxing robots, subsiding the hiring of humans, collectivizing the ownership of firms, implementing a basic income, and imposing quotas for human (or robot) employment appear to be the most popular suggestions. All these solutions present drawbacks and generate untenable class conflicts, and therefore much more theoretical study is necessary to identify the less dangerous ones.

However, theoretical study on the topic is problematic if the tools used are those rooted in neoclassical Economics, and in particular in its general equilibrium version, currently the dominant approach, which appears to be incapable of dealing with a reality characterized by the renewed importance of social classes, a class struggle between a few robot owners and many unemployed humans, subsistence wages, or basic income uncorrelated with labor productivity, an important renewal of the relevance of redistributive policies, public ownership of the means of production, and so on. The old approach, rooted in the work of the classical economists, i.e., Political Economy, appears to be better equipped than neoclassical Economics for dealing with these themes.

Envisaging a renewal of the relevance of the old classical Political Economy is therefore possible, or at least a renewal of the relevance of a theoretical approach very similar to classical Political Economy, without the labor theory of value, as a consequence of the third wave of technological unemployment. Sraffa's approach could be a robust starting point for such a purpose.

As a final consideration, the idea that the absence of significant empirical evidence should not be considered as an obstacle to the study of a possible future scenario of long-term mass unemployment emanating from the last wave of technological progress is worth emphasizing. In general, empirical evidence precedes theoretical studies; in this case, it would be better to exhibit a thorough theoretical analysis and possibly full consciousness of the policy tools that could be implemented, long before long-term mass unemployment becomes an empirical reality. However, consciousness of the need for developing a theoretical study of the problem also before robust empirical evidence manifests will not succeed in generating theoretical models capable of systematizing the new reality (and dealing with the crucial problem of long-term mass unemployment) if a crucial preliminary step is ignored. This preliminary step is the acknowledgment of the limited ability of the traditional neoclassical approach to deal with the new reality emerging from the third wave of technological unemployment and the consequent choice to use some hints from, and the theoretical structure of, the old classical Political Economy, in trying to understand the future.

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[i] For a synthetic but rather complete description of the classical and neoclassical contributions concerning the impact of technological progress on unemployment, see Vivarelli (1995, 2007), Feldmann (2013), Abbott and Bogenschneider (2017), and Campa (2017). From the perspective of the history of economic thought, the concept of technological unemployment gained momentum in orthodox economic theory after Ricardo's contributions and lost relevance when Wicksell relaunched the neoclassical approach to compensation theory, while theoretical interest was reignited by Keynes' 1930 short essay (Campa 2017, p. 7).

[ii] " 'Skill-Biased Technical Change' (SBTC thereafter) is a shift in the production technology that favors skilled (e.g., more educated, more able, more experienced) labor by increasing its relative productivity and, therefore, its relative demand. Ceteris paribus, SBTC induces a rise in the skill premium – the ratio of skilled to unskilled wages" (Violante 2008, p. 2).

[iii] The conclusion according to which, in recent decades, technological progress increased the polarization of wage income, negatively affecting unskilled workers, was widespread albeit rather controversial. On this point, see Card and Di Nardo (2002), Autor et al. (2003, 2006, 2008, 2013), Violante (2008), Dustmann et al. (2009), Acemoglu and Autor (2011), Freeman (2015) and Acemoglu and Restrepo (2016).
[iv] On task-based (and routine-replacing) technical change, see, e.g., Vivarelli (2014), Acemoglu and Restrepo (2017, 2019) and Gregory et al. (2019).
[v] "Indeed, in the first half of the XIX century, economists put forward a theory that Marx later called the 'compensation theory' (…) This theory is made up of different market compensation mechanisms which are triggered by technological change itself and which can counterbalance the initial labor-saving impact of process innovation" (Vivarelli 2007, p. 2).
[vi] According to Campa (2017, p. 10), "[t]o put it briefly, while marginalist economists keep denying the problem of technological unemployment, Keynesians are sure that the problem exists, but they are also confident that it can be solved with opportune public policies".
[vii] The traditional argument, first discussed by Neisser (1942), is that the impact of technical progress on employment depends upon demand elasticity: "if product demand increases enough there is no unemployment effect of technological progress" (Blien and Ludewig 2017, p. 9). As we shall see below, such an argument becomes ineffective when used with reference to robots and the last wave of technological unemployment.
[viii] For a detailed analysis, see Vivarelli (2007, pp. 4–7) and Calvino and Virgillito (2018, pp. 7–8) who discuss many of, although not all, the compensation mechanisms.
[ix] Dissenting opinions range from those who affirm that technological unemployment exists but is hidden by the historical reduction of per capita working hours (i.e., Vivarelli 1996) to those who maintain that "the economic theory does not have a clear-cut answer about the final employment effect of R & D and innovation" so that "attention should be turned to empirical analyses" (Piva and Vivarelli 2017, p. 14).
[x] On the task approach in general, see, e.g., Autor, Katz and Kearney (2006), Autor (2013) and Autor and Hendel (2013).
[xi] See, e.g., Brynjolfsson and McAfee (2014, p. 165).
[xii] According to Campa (2017, p. 14), "Artificial Intelligence develops exponentially, and it not only promises to further reduce the workforce in manufacturing, but it will begin to erode the work of specialists in the service sector. In the near future, unemployment could concern economic actors who attended higher education institutions and invested much time and money to acquire their professional skills, such as journalists, physicians, teachers, lawyers, consultants, managers, etc."
[xiii] In particular, if production can be realized by robots alone, without a human contribution, the traditional "elasticity argument" does not hold.
[xiv] Taxing robots, as well as subsidizing the hiring of humans, mimics a Pigouvian tax/subsidies scheme. A number of policies built to counteract technological unemployment mimic policies, which were implemented to deal with market failures (and externalities in particular), so that the theoretical analysis could also benefit from spillover, mainly from environmental protection studies that deal extensively with market failures.
[xv] It is worth noting that the basic income is not an unemployment benefit, as humans receive it whether they are employed or unemployed.
[xvi] On this point, see Campa (2017, p. 13).
[xvii] Firms could later trade quotas, in a similar way to the tradable permits approach to pollution control. The main difference would be that they pay for selling quotas and are paid for buying quotas. On this point, see D'Orlando (2018).
[xviii] Freeman (2015, p. 1) emphasizes the relevance of such a strategy. According to him, "workers could own shares of the firm, hold stock options or be paid in part from the profits".
[xix] The unconditional basic income can indeed play two roles: it can allow humans to remain unemployed and obtain the subsistence income, with only robots being employed, or it can allow humans to accept a wage below the subsistence level when being hired by firms. In addition, a combination of the two roles appears possible.
[xx] The debate on the basic income dates back to Paine (1797) and, over time, has involved various social scientists and their studies, from economic historians, (e.g., Polanyi 1944) to economists, (e.g., Friedman 1962; Tobin 1966; Hayek 1987) and political philosophers, (e.g., Van Parijs 2004).
[xxi] Kurz and Salvadori (2014, p. 4).
[xxii] It is a puzzling circumstance that a fully neoclassical approach has recently been named "Political Economy", despite being radically different from the classical approach, due to its (peculiar) attempt to merge social and political considerations within economic theory.

[xxiii] On the level and dynamics of wages in the classical theory, see, e.g., Smith (1937, Book I, chapter VIII, p. 64 ff), Ricardo (1821, pp. 58–59), Malthus (1798, pp. 9–10) and Hunt and Lautzenheiser (2011, p. 53).
[xxiv] For a short discussion of the debate on the foundations of exploitation in the classics, see King (1983, p. 346 ff) but also Marx (1887, Book I, p. 135).
[xxv] On the residual nature of profits, see, e.g., Ricardo (1821, pp. 71–73).
[xxvi] On class struggle in the classics, see, e.g., Smith (1937, pp. 66–67) and Hunt and Lautzenheiser (2011, p. 62 ff)
[xxvii] On the role of the labor theory of value in classical theory, see Hunt and Lautzenheiser (2011, p. 49 ff).
[xxviii] D'Orlando (2005, p. 634).
[xxix] On the eventual convergence to full employment in the classics, see, e.g., Smith (1937, Book II, chapter III, pp. 314–332) and Hunt and Lautzenheiser (2011, p. 83 ff and p. 115 ff).
[xxx] On the maximizing principle in neoclassical theory, see, e.g., Walras (1954, p. 115 ff) and Wolff and Resnick (2012, p. 57).
[xxxi] On this point see Hunt and Lautzenheiser (2011, p. 305).
[xxxii] For a thorough analysis of the determination of the distributive quotas in neoclassical theory, see, e.g., Wolff and Resnick (2012, p. 89 ff).
[xxxiii] On the fairness of income distribution in the neoclassical theory, see, e.g., Clark (1891, p. 304).
[xxxiv] For a thorough discussion of the evolution of neoclassical theory from focusing on long-period positions to focusing on short-period equilibria, see Garegnani (1976).
[xxxv] On the path to full employment in the neoclassical approach, see Hunt and Lautzenheiser (2011, p. 260) and Wolff and Resnick (2012, p. 97).
[xxxvi] The Royal Swedish Academy of Sciences (1992), Nobel Prize motivation.
[xxxvii] The alternative specification $\boldsymbol{p}^* = \boldsymbol{A}\boldsymbol{p}^*(1+r)$, within which robots are simply considered as included in the matrix of technical coefficients, does not allow the specificity of robots to be captured and is of little utility in the discussion of technological unemployment.