Technological Unemployment in the Era of AI: Is Full Unemployment Worth Studying?

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Abstract

Integrating Artificial Intelligence (AI) into productive processes has raised concerns about its potential impact on unemployment. However, economic literature has (almost) always considered it impossible for this impact to be so high as to generate full unemployment. Hence, economists have not deemed the topic worthy of theoretical attention.

This article has three main objectives: (i) to argue that, regardless of their likelihood, full unemployment equilibria deserve attention from economists since it is entirely legitimate to undertake theoretical studies of phenomena that might or might not occur in the future; (ii) to define full unemployment equilibria, describing their possible theoretical characteristics; (iii) to discuss potential policy measures that can prevent full (and/or mass) unemployment caused by AI diffusion from occurring and/or mitigate its adverse effects if it does occur.

Keywords: *Technological Unemployment, Full Unemployment, Artificial Intelligence, AI, AGI, Androids*

JEL codes: *B41, E24, J23, J64, O33*

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Introduction

The success of Chat-GPT, Stable Diffusion, Dall·E, and other Artificial Intelligence (AI)[1] tools, together with the fast-growing research on androids[2] and Artificial General Intelligence (AGI)[3] agents, have contributed to diffuse the idea that today's technological progress might affect employment in a way radically different from what it did in the past and, above all, in a way that until today was not even possible to imagine. These AI tools are just a few examples of how artificial intelligence and machines endowed with AI already today impact many tasks and jobs, both manual and intellectual, routine and non-routine, and even artistic and, in general, creative. So, the question that can arise is whether AGI agents (or machines endowed with AGI, such as androids) might, in the future, fully replace human beings in all, or at least most, productive activities, potentially generating mass unemployment or even "full unemployment."[4]

It is undoubtedly true that we are not seeing such a massive impact of AI on the labor market today, but it is also true that AI is only in its first, rudimentary phase of development and that it learns quickly.

In such a scenario, it is unsurprising that traditional and less traditional media, scholars of various disciplines, and even politicians have considered the diffusion of AI and machines endowed with AI capable of having a relevant impact on the labor market. Some scholars have also asked themselves whether full unemployment might be a possible future outcome.[5]

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[1] According to Vincent-Lancrin and van der Vlies (2020, p 7), Artificial Intelligence (AI) can be defined as "a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy. AI system lifecycle phases consist of: 1) planning and design, data collection and processing, and model building and interpretation; 2) verification and validation; 3) deployment; and 4) operation and monitoring".

[2] In the text, "androids" refers to humanoid machines endowed with AI or AGI that resemble humans aesthetically and in behaviors capable of operating autonomously, i.e. without human control. Androids are, therefore, crucially different from "robots," the latter being machines programmed to perform specific automatized tasks that cannot operate autonomously. The circumstance that androids have human appearance helps make the argument proposed here more manageable, but it is not crucial for our conclusions. Instead, the circumstance that androids are endowed with AI or AGI is vital.

[3] Artificial General Intelligence can be defined as a "software program that can solve a variety of complex problems in a variety of different domains, and that controls itself autonomously, with its own thoughts, worries, feelings, strengths, weaknesses and predispositions", differently from "narrow AI … that demonstrates intelligence in one or another specialized area, such as chess-playing, medical diagnosis, automobile driving, algebraic calculation or mathematical theorem-proving" (Pennachin and Goertzel 2007, p. 1).

[4] Full unemployment can be defined as either a situation in which (almost) nobody is willing to work at the equilibrium wage rate or a situation in which no firm is willing to hire workers at a wage rate above subsistence. The term "full unemployment" was popularized by the futurist scholar James Dator (see, e.g., Dator 2016 and 2020), re-proposed in D'Orlando and Ferrante (2022, pp. 46-47) and developed in D'Orlando 2024; Korinek and Juelfs (2022) refer to a similar situation as "strong economic redundancy of labor".

[5] See, e.g., the "Android experiment" in Brynjolfsson and McAfee (2014, pp. 180-182); the Benchmark model in Berg et al. (2018, section 2); the "first scenario" in D'Orlando (2022, pp.14-16); the "strong economic redundancy of labor" in Korinek and Juelfs (2022, pp. 8-9); or D'Orlando (2024, chapter 1.4)

Nonetheless, till very recent years contributions in Economics Journals and by economists accepting the possibility that these new technologies could generate high levels of unemployment have been few, while contributions on wage polarization and rising inequality caused by robotization counted "by the dozen per year" (Guarascio et al., 2024, p.2). Moreover, even if in the last couple of years some theoretical contributions, and also a few empirical contributions, have begun questioning the conventional wisdom, most studies, often building on empirical evidence, still conclude that mass technological unemployment, either caused by the diffusion of AI, of machines endowed with AI, or by simple robotization, is out of the question, is confined to specific tasks and jobs or can easily be counteracted, as it has always been in the recent and remote past. The term "technological unemployment" also seems to embarrass economists and is almost always purged from theoretical studies. Only some scholars who try to measure the exposure of tasks to automation caused by the introduction of AI into the productive process, albeit not directly targeting unemployment, suggest that the impact of AI on employment might be huge. Furthermore, if most economists consider mass technological unemployment an unrealistic outcome, they also consider full technological unemployment even more unrealistic and prefer not to mention it.

Indeed, two arguments seem to be the main ones that economists use to justify their skepticism about AI's possibility of generating full unemployment and that can explain the consequent scarcity of studies on the topic: the empirical evidence and the compensation theory (old and new).

According to the partisans of the first argument, a phenomenon lacking empirical evidence does not deserve theoretical attention. And empirical data today do not support the possibility that AI generates full (or even mass) technological unemployment: only recent studies suggest a moderate unemployment impact of AI, while the bulk of empirical research supports the idea that AI has a mild unemployment impact even if it might raise wage inequality.

The second argument is founded mainly on an old theory and its contemporary developments, the so-called "compensation theory". In the past, the debate on technological unemployment was dominated by this approach, whose birth traces back to the first industrial revolutions, according to which exogenous shocks, such as technological progress, may well divert the system from full employment, generating waves of short-term and/or sectoral unemployment, but many compensation forces (from wage flexibility to demand increase) would automatically bring the system back to full employment. The underlying implicit assumption, which until today was quite reasonable, was that entirely substituting human workers with machines was impossible. Most economists seem to share a sort of "fideistic assumption" that also today and tomorrow, this assumption is, and will still be, valid: machines, even in the case they are endowed with AI, will never be able to substitute for human workers in all, or at least in most, jobs and tasks. Say it another way, the substitution rate between humans and machines will never be equal to one, so that no genuinely new phenomenon is underway and the results of the "old" compensation theory, i.e., the low impact of technological progress on unemployment, that proved capable of matching empirical data for the past waves of technological progress, are still valid for the new waves, as today's empirical data seem to confirm. So, according to this view, new theoretical studies are unnecessary: *this time, it is the same*. Consequently, in contrast with the abundance of *empirical* studies on the impact of automation (robotization, in particular) and/or AI on employment, we have few *theoretical* studies on the consequence of automation on employment and even fewer on the impact of AI on employment. Furthermore, these recent theoretical contributions are often rooted in a neoclassical general equilibrium framework, within which market-clearing assumptions hold, so that they can discuss growth, wage dynamics, and wage inequality, but can only implicitly draw conclusions on the impact of AI on unemployment. Not surprisingly, virtually none of these recent theoretical studies, albeit less optimistic than the original compensation theory or the empirical studies, arrive at the point of theorizing that full unemployment might occur, even if a couple of them use it as a benchmark scenario. However, they theoretically confirm the possible increase in wage inequality that also emerges from the empirical studies.

Therefore, according to economists' conventional wisdom, we should not worry about the possibility of a future of mass or even full technological unemployment: in the worst-case scenario, we might have a slow and mild process of rising unemployment and inequality that appropriate policy measures might easily counteract.

The problem is that the fourth industrial revolution, which is centered on the diffusion of AI into productive processes, makes it possible to assume, or at least discuss the possibility, that not today but in the future, AI (and/or AGI) and machines endowed with AI (and/or AGI), for example, androids, might develop to the point of entirely replacing most or all workers in all jobs and tasks. Say it another way: nobody can maintain today that the future substitution rate among humans and machines endowed with artificial intelligence cannot equal one and full unemployment cannot occur. Past theories or empirical data cannot help us since what happened in the past and today is irrelevant for inferring what will happen tomorrow: AI is not similar to the steam engine or computers, and androids are not similar to robots. Furthermore, if we accept the possibility of a substitution rate equal to one, almost all compensation forces, old and new, lose their validity since they are (nearly) all based on the assumption that complete substitution is impossible.

Yes, nobody knows what will happen in the future and if the substitution rate will be equal or close to one. Also, forecasts on the exposure of tasks to AI substitution are more likely to be contradicted than confirmed by facts, as happened to similar forecasts in the past. In any case, even if we admit that we do not know what will happen in the future (and this seems a somewhat reasonable assumption), it is nonetheless entirely legitimate to develop a theoretical analysis of the possible future evolution of new phenomena that are only in their preliminary phases of development, when these phenomena are unanimously considered potentially relevant for economic outcomes. And, maybe even more important, in the specific case of technological unemployment, developing such an analysis before full (or at least mass) unemployment eventually occurs could allow us to theoretically study the best policy tools that can be proposed to counteract it and/or its consequences in case it comes about. A-priori refusing to discuss theoretically new phenomena based on the assumption that the future cannot be different from the past is a choice that cannot be defended on scientific grounds.

All the above said, this article does not aim to demonstrate that full (or even mass) unemployment is an inevitable market outcome but only to demonstrate that it is a concept that deserves greater theoretical attention by economists. In doing so, the article proposes a thought experiment based on a preliminary formalization of mass and full unemployment equilibria that can represent the basis for further analysis.

The article is organized as follows.

The first section focuses on the main novelties of the Fourth Industrial Revolution, characterized by the diffusion of AI into the productive processes, arguing that we are in the presence of a new phenomenon, utterly different from past Industrial Revolutions, which requires a complete paradigm shift; the second section describes the two arguments that have mainly be advocated to deny the possible realization of, and the opportunity to study, (mass and) full unemployment equilibria, namely empirical data and the theory of compensation, old and new; the third section argues that empirical data are irrelevant for evaluating the likelihood of a process that will or will not come about only in the future, and that the theory of compensation and its contemporary neoclassical heirs is unapplicable in the context of the fourth industrial revolution, so that (mass and) full unemployment equilibria deserve greater attention, possibly on new theoretical basis; the fourth section introduces the concept of "full unemployment", differentiating it from mass unemployment, and proposes a preliminary formalization of the main characteristics of both; the fifth section suggests some policy measures that can prevent full unemployment (and mass unemployment) from occurring and/or mitigate its adverse effects if it does happen; the sixth section concludes.

1. The Fourth Industrial Revolution and the diffusion of AI

Curiously enough, the possibility that mass technological unemployment might occur has been at the very center of economists' interest in the (remote and less remote) past, when the impact of technological progress on long-term unemployment ultimately proved to be mild empirically and almost non-existent theoretically; and seems not to be at the very center of their interest today, when at least theoretical (even if not yet empirical) reasons appear much more robust in hypothesizing a massive negative impact of technological progress on employment. Only partially different has been the fate of the notion of "full unemployment", which was (correctly) neither discussed nor mentioned by economists in the past when the state of technology (of that time and foreseeable) was such to make its realization not only impossible but even impossible to be forecasted; and that is still (almost) ignored today when the interest of many social scientists different from economists together with robust theoretical considerations might suggest putting the topic center stage.

Although this contribution focuses on the possible (future) impact of AI on employment, let us start by briefly describing the main characteristics of the (past) debate on technological unemployment. These characteristics represent an essential element in thoroughly understanding the crucial paradigm shift represented by the introduction of AI into productive processes.

The historical events that, in the past, led economists to discuss the relationship between technological progress and unemployment can unambiguously be identified in the Industrial Revolutions: the First and the Second Industrial Revolutions (1760-1900 and 1900-1960)[6] by increasing labor productivity, reduced labor requirement for a given amount of production in some sectors, while the third (1980-today)[7] reduced labor demand for unskilled workers[8] and/or workers performing routine tasks[9]. All industrial revolutions were, therefore, thought

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[6] The exact period of each Industrial Revolution is controversial, but this controversy is of little relevance to the present study. In any case, we here share the dating proposed by Prisecaru (2016) and Xu et al. (2018).

[7] The dating of the Third Industrial Revolution, and particularly the dating of its beginning, is quite uncontroversial: see, e.g. Schwab (2016), Prisecaru (2016), and Xu et al. (2018).

[8] "'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). On skill-biased technical change, see also Bound and Johnson (1992), Katz and Murphy (1992), Krueger (1993), Berman et al. (1994), Goldin and Katz (1996), Aghion et al. (1999), Card and Di Nardo (2002), Acemoglu (2002), Violante (2008), Acemoglu and Autor (2011), Murphy and Topel (2016).

[9] Differently from Skill-biased Technical Change, Task-biased Technical Change or Routine-Replacing Technical Change does not focus "on the fact that technological progress increases labor productivity, but on the fact that machines can replace human workers, and in particular workers whose jobs mainly consist of routine tasks. Therefore, labor demand, employment opportunities, and wages decrease for workers engaged in predominately routine tasks. As in the skill-biased technical change approach, the result is rising income inequality, but those who are most negatively affected by technological progress are workers engaged in routine tasks,

to bear the potential side effect of lowering labor demand for the social categories involved. In such contexts, it was somehow inevitable that economists questioned whether technological progress could raise long-term aggregate unemployment. However, both empirical considerations and theoretical analysis brought most of them to conclude on the actual non-existence of a problem of technological unemployment.

But today? Are the above considerations still valid for the Fourth Industrial Revolution and the dawn of the Age of Artificial Intelligence?

The term “Fourth Industrial Revolution” was introduced into theoretical debate by Schwab (2016), who refers to it as a phenomenon that “began at the turn of this century and builds on the digital revolution. It is characterized by a much more ubiquitous and mobile internet, by smaller and more powerful sensors that have become cheaper, and by artificial intelligence and machine learning” (Schwab, 2016, p. 11).

The crucial point here is that there are many differences between past Industrial Revolutions and the contemporary one. In the beginning, these differences seem to have not been fully perceived, not even by Schwab himself: many scholars thought to be simply in the presence of an evolution of the Third Industrial Revolution since most of the development of Artificial Intelligence was still to come, and the primary attention was on robots and further mechanization of the productive process, only mentioning AI as an element of a longer list containing also the internet of things, nanotechnologies, blockchain, etc.[10] In particular, in those days, robotization was considered to be a relevant technological progress, capable of bearing enormous implications for economic outcomes and income distribution (mainly in the form of wage polarization and rising income inequality), so many scholars considered this process, and/or these outcomes, as key elements of the Fourth Industrial Revolution.[11] Other scholars began to perceive the relevance of AI's development, and some considered it the main characteristic of a further Industrial Revolution, the Fifth, different from mere robotization.[12] However, only in the last couple of years, with a greater understanding of the potentiality of AI, some economists[13] emphasized the enormous differences of this revolution, which in this article will anyway be considered as the Fourth Industrial Revolution (so that robotization will be included in the Third), compared to all the preceding ones.

Indeed, the Fourth Industrial Revolution introduced a significant paradigm shift in the debate on technological unemployment: entering the steam engine, or computers, and even robots, into the productive process is utterly different from entering AI, machines endowed with AI, and androids. During the past industrial revolutions, unemployment could be caused by machines cooperating with human workers by raising labor productivity and reducing the labor requirement for a given amount of production. In the Fourth Industrial Revolution, the possibility exists that machines and AI no longer cooperate with human workers by increasing their productivity but might substitute for them in all (or most) jobs and tasks, entirely (or

who can more easily be replaced by machines, irrespectively of their skill endowment” (D’Orlando 2024, p. 16). On task-biased technical change, see also Autor et al. (2003), Goos and Manning (2007), Acemoglu and Autor (2011), Acemoglu and Restrepo (2021), Schmitt et al. l (2013). This approach is based on the task approach developed mainly by Autor (e.g., Autor et al. 2006, Autor 2013, and Autor and Handel 2013).

[10] See, e.g., Acemoglu and Restrepo (2016), Prisecaru (2016), Frey and Osborne (2017), Xu et al. (2018).

[11] See e.g. Schwab (2016), Morrar et al. (2017), Xu et al. (2018).

[12] See, e.g., Muir (2018), Mourtzis (2021), Ali et al. (2022).

[13] See, e.g., Acemoglu and Johnson (2023), Luo (2023), Korinek and Juelfs (2022), D’Orlando (2024), Korinek (2024).

almost entirely) replacing human employment.[14] A circumstance that in the past was not even conceivable. In such a context, we inevitably have to ask ourselves what would happen if this total (or almost total) replacement of human workers took place, generating waves of mass unemployment: Do adequate compensation forces or adequate intervention policies capable of allowing the system to regain full (or close to full) employment equilibrium still exist?

To answer this question, we should inevitably start by building a thought experiment based on the extreme hypothesis that technological progress can develop to make machines endowed with AI capable of substituting for human workers in all jobs and tasks, even the intellectual and creative ones, at a lower remuneration/productivity ratio. However, before building our thought experiment, a necessary preliminary step is to discuss why conventional economists' wisdom has reputed similar thought experiments unnecessary and why, on the contrary, we believe they are crucially necessary.

2. The conventional wisdom: Why we should not study full unemployment

As mentioned in the introduction, most conventional economic theory says mass technological unemployment caused by AI diffusion is out of the question. And if mass unemployment is out of the question, full unemployment is even more out of the question. Two main arguments have often been advocated to support this conclusion: the absence of any empirical evidence of its occurrence and the theory of compensation (old and new).

2.1 Empirical evidence

The empirical evidence on the impact of technological progress on employment has been substantially uncontroversial for the last two centuries and a half: The first two industrial revolutions mainly relocated workers from one sector (to begin with, from agriculture; later from manufacturing) to another (at the outset, to manufacturing; later to services), and the third mainly generated wage polarization and income inequality, without long-term impact on unemployment.[15] Similar results have been reached by the first studies on the fourth industrial revolution and the diffusion of AI, while less optimistic results emerged in the last couple of years.

It is worth noticing that the great majority of contemporary empirical studies on the theme of technological unemployment not only rarely base their analysis on a clear distinction between the third and the fourth industrial revolutions but also (somehow consistently) tend to mix robotization, automation and the introduction of AI, making things a bit too confused if the scope is evaluating the impact of the sole AI on employment. So, it might be helpful to

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[14] Brynjolfsson and McAfee (2011 and 2014), Ford (2015), and West (2015) made seminal contributions to the novelty represented by the above-described substitution process. However, even these scholars did not fully understand AI's true potential in those days: it was still too early.

[15] The impact of the first two Industrial Revolutions on employment in the primary and secondary sectors is effectively described by Campa (2017, p. 2): "The transition from traditional agriculture to intensive agriculture, through the use of agricultural machinery, herbicides, fertilizers, fungicides, etc., has led to demographic emptying of the countryside. The evaporation of jobs in the primary sector of the United States of America offers impressive numbers: in 1900 41% of the population was employed in agriculture. A century later, in 2000, only 2% of Americans still worked in same sector (…). A similar phenomenon was observed in the secondary sector, or manufacturing, at the turn of the twentieth and twenty-first century. In the United States, the ratio between employment in the factories decreased from 22.5% in 1980 to 10% today and is expected further decline to below 3% by 2030 (…)". On this point, see also Schettkat and Yocarini (2003), Campa (2007, 2014, and 2017), Carboni (2015), and Wladawsky-Berger (2015).

distinguish between contributions that study the impact of automation and robotization on employment, wages, and inequality and studies that examine the effects of artificial intelligence on the same topics.

Many empirical contributions studying the impact of automation (and robotization) on employment conclude that automation (and robotization) increases,[16] or at least does not reduce in a significant way,[17] aggregate employment, even if it might increase wage polarization and inequality[18]. Few have dissenting views on unemployment,[19] and none have arrived at the point of detecting the occurrence of mass unemployment phenomena from data. When the theme is AI and not simply automation or robotization, these results appear empirically confirmed for what concerns inequality[20] and unemployment[21], even if some authors are less optimistic about the impact on unemployment for some groups of workers, tasks, or regional areas.[22]

Most of the studies on the theme,[23] therefore, conclude that the diffusion of AI can generate waves of sectoral unemployment and wage reduction for some categories of workers, with the rise of income inequality, but mass technological unemployment seems to be any way out of the question[24] and "the fear of a jobless future… may be exaggerated and lacks an empirical base" (Hötte et al., 2023, p. 16), "or at the very least lacks empirical support so far" (Guarascio et al., 2024, p. 4).

Apparently, these results confirm that "this time is not different" from the past: the "old" results of the "old" studies on the past Industrial Revolutions, when technological progress caused sectoral short-term waves of unemployment but no long-term increase in unemployment, are still valid, and the possible occurrence of mass unemployment caused by AI diffusion is empirically disproved.

2.2 the theory of compensation (and its heirs)

From the theoretical viewpoint, the traditional element supporting the absence of a relevant adverse employment effect of AI can be considered as found in the so-called "theory of compensation," according to which some (automatic and deliberate) compensation forces would prevent technological progress from impacting long-term unemployment. The theory of

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[16] See, e.g., Van Reenen (1997), Coad and Rao (2011), Bogliacino et al. (2012), Ciriaci et al. (2016), Piva and Vivarelli (2017, pp. 11–13), Haile et al. (2017), Calvino (2019), Barbieri et al. (2019), Gregory et al. (2019), Aghion et al. (2020 and 2022).

[17] See, e.g., Evangelista and Vezzani (2012), Dauth et al. (2018), Lachenmaier and Rottmann (2011), Piva and Vivarelli (2017 and 2018), Feldmann (2013), Graetz and Michaels (2018), Korinek (2023).

[18] See, e.g., Dustman et al. (2009), Acemoglu and Restrepo (2020), Acemoglu (2024), Graetz and Michaels (2018).

[19] See, e.g., Acemoglu and Restrepo (2017, 2019 and 2020), Chiacchio et al. (2018).

[20] See, e.g., Freeman (2015), Felten et al. (2019), Felten et al. (2019), Acemoglu (2024).

[21] See, e.g., Felten et al. (2019), Felten et al. (2021), Albanesi et al. (2023), Guarascio et al. (2023), Korinek (2023), Damioli et al. (2024), Shen and Zhang (2024).

[22] See, e.g., Bordot (2022), Acemoglu et al. (2022), Acemoglu (2024), Demirci, Hannane, Zhu (2023), Hui, Reshef, Zhou (2023), You et al. (2024).

[23] For a review, see Vivarelli (2014), Calvino and Virgillito (2018), Hötte et al. (2023), Montobbio et al. (2023), and Guarascio et al. (2024).

[24] Hötte et al. 2023 reviewed 127 studies published between 1988 and 2021, finding "larger support for the labor-creating effect of technological change" (Hötte et al., 2023, p. 2) and concluding that "[o]verall, our findings strongly suggest that technological progress has not resulted in a negative net employment effect in the past decades" (Hötte et al., 2023, p. 16).

compensation, developed during the first industrial revolutions and obviously not built by referring to the diffusion of AI, has been considered by many economists as somehow still valid for the fourth industrial revolution. Ultimately, this theory is based on the implicit (and, at its birth, highly realistic) assumption that the complete substitution of machines for human workers is impossible, and mass substitution is impossible in many industries. On these bases, the theory describes several mechanisms capable of returning the system to full employment once technological progress has generated (sectoral) unemployment.[25]

These mechanisms can be either automatic or deliberate, with the automatic mechanisms mainly rooted in the neoclassical tradition and the deliberate ones in the Keynesian one.[26]

The most important among the automatic mechanisms described in economic literature are the following (even if some of them describe in different ways the same dynamics):[27]

(i) Wage downward flexibility: In times of low employment, workers may accept lower wages, and firms may hire them at these reduced wages.

(ii) Increase in demand for machines: The increased demand for machines caused by mechanization raises the employment in the sector that produces machines[28].

(iii) Increase in demand for goods due to price reduction: The mechanization of production reduces production costs, leading to lower prices for goods. This increases demand, boosts production, and creates more jobs, offsetting job losses caused by mechanization.

(iv) Increase in real income: Lower production costs and prices of goods from mechanized firms increase real individual income, leading to higher demand for goods and boosting production and employment.[29]

(v) Increase in profits and investments: In the case of price rigidity, lower production costs from mechanized firms can lead to increased firms' profits and, therefore, investments, boosting production and employment in the sector that produces investment goods.[30]

(vi) Increase in profits and consumption: Price rigidity and lower production costs from mechanized firms can lead to increased firms' profits and, therefore, greater demand from entrepreneurs for consumer goods. This results in increased production and employment in the sector that produces these consumer goods.[31]

(vii) New sectors: Product innovation creates new sectors, increasing employment in these sectors.[32]

(viii) Increase in high-skilled workers' consumption: The use of machines requires higher skills possessed by only a few workers, increasing demand for these high-

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[25] For a comprehensive list and discussion of compensation mechanisms, see Vivarelli (2007), Blien and Ludewig (2017), Campa (2017), and Peters (2017). Similar analyses have also been proposed by D'Orlando (2020a, pp. 4-5 and 2024, pp. 10-14).

[26] "To 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" (Campa, 2017, p. 10).

[27] Vivarelli (2007), Blien and Ludewig (2017), Campa (2017), and Peters (2017) proposed detailed descriptions of some of the compensation mechanisms listed in the text.

[28] see, e.g., Say (1964), Vivarelli (2007, p.2 and 2022, pp. 4-5), Campa (2017, p. 5), Dosi et al. (2021)

[29] D'Orlando (2020a, p. 5).

[30] Ricardo (1951), Vivarelli (2007, p. 3, and 2022, p. 5).

[31] Campa (2017, p.5).

[32] Vivarelli (2007, p. 4, and 2022, p. 5).

skilled workers and raising their wages. This, in turn, leads to higher demand for goods, increased production, and more employment[33].

(ix) Transitioning from one sector to another: Technological progress can reduce employment in some industries while creating new sectors with increased employment in these new sectors.

(x) Increase in labor productivity: An increase in the use of production factors other than labor, such as capital, raises labor marginal productivity, favoring techniques that require higher human employment.

(xi) Reduction in machines' productivity: An increase in the use of production factors other than labor, such as machines, reduces these factors' marginal productivity. This leads to changes in techniques that favor higher human employment.[34]

(xii) Increase in real money supply: The mechanization of the production process reduces production costs for firms, which can lower the price level in the economy. This can lead to a rise in the real money supply, causing interest rates to decrease. As a result, investments may increase, and employment may rise in sectors that produce investment goods.

(xiii) New job opportunities: New technologies can create new job opportunities, offsetting job displacement caused by technological progress. In some recent contributions,[35] this argument has been translated into the prevalence of the reinstatement effect, i.e., the creation of new tasks for humans determined by technological progress, over the displacement effect, i.e., a reduction in employment for those tasks in which machines can substitute for humans. However, some scholars[36] disputed this conclusion.

The principal deliberate intervention mechanisms might work as follows:

(xiv) Increase in public expenditure. By definition, $Productivity = \frac{Production}{Employment}$ and therefore $Employment = \frac{Production}{Productivity}$, so that increased public expenditure, by generating increased aggregate demand and production, can offset reduced employment caused by increased productivity from mechanization (see D'Orlando 2020a, p. 5).

(xv) Luddite policies: Public policies may include mandates on minimum labor hiring, limits on robot use, machine usage taxes, or worker hiring subsidies.

(xvi) Reduction in per-capita working hours: Reducing per-capita working hours can offset the need for less human workers for a given production.

At the beginning of the twenty-first century, compensation theory has been integrated by several contributions (almost always built within a neoclassical framework[37]) that study from a logical or formalized theoretical viewpoint the impact of automation (and/or

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[33] Campa (2017, p.5).

[34] D'Orlando (2020a, p. 5).

[35] Gregory et al. (2019), Dosi et al. (2021 and 2022).

[36] See, e.g., Acemoglu and Restrepo (2019), Acemoglu et al. (2022).

[37] See e.g., Violante (2008), Acemoglu and Autor (2011), Berg et al. (2018), Sachs and Kotlikoff (2012), Sachs et al. (2015), Korinek (2019), Gasteiger and Prettner (2020).

robotization) on growth, wages, inequality,[38] and less often (because of the market clearing assumption present in most of the models) unemployment[39]. Other, more recent, contributions[40] focus explicitly on AI. Differently from the majority of empirical studies, and albeit with some exceptions,[41] these twenty-first-century theoretical contributions are more pessimistic on the impact of technological progress in general, and AI in particular, on employment, even if almost none of them make the hypothesis of a substitution rate equal to one and therefore do not consider full unemployment: among the most relevant contributions only Korinek and Juelfs (2022) consider a full unemployment scenario in their third concern, i.e. strong economic redundancy of labor, whereas Berg et al. (2018), as well as Korinek (2019), depict merely benchmark scenarios that they seem to consider implausible. Also those contributions that try to measure the exposure of tasks to automation caused by AI introduction into the productive process do not predict a substitution rate equal to one, even if they predict that a considerable number of tasks will be automated[42] (albeit some scholars only propose indicators to measure tasks exposure to AI[43], and in other cases projections drive the authors to the conclusion that job creation will prevail on job destruction[44]).

On the contrary, the results of theoretical contributions on wages and inequality appear entirely consistent with those of empirical studies: technological progress and AI seriously risk increasing wage polarization and income inequality[45], even if this is not always the case,[46] and appropriate policies can counteract these negative consequences.[47]

All the above considered, we can conclude that until the most recent years, economists' attitude towards the possibility that technological progress might generate mass unemployment was relatively uncontroversial: both empirical and theoretical considerations excluded this possibility. In the last couple of years, in particular when the focus was on AI and not on technological progress and automation/robotization, theoretical models have begun emphasizing that AI might generate not only rising inequality but also sectoral, task-specific unemployment, and some empirical studies suggested that in single sectors the impact on employment might be harmful already today. However, as we have seen above, with very few exceptions, mass unemployment and a fortiori full unemployment were out of the question, also because counteracting policies were considered highly effective in preventing the negative impact of AI diffusion. Say it another way: automatic or deliberate compensation forces would

[38] See, e.g., Violante (2008), Acemoglu and Autor (2011), Sachs and Kotlikoff (2012), Sachs et al. (2015), Benzell et al. (2015), Acemoglu and Restrepo (2016 and 2018), Berg et al. (2018), Gasteiger and Prettner (2020).

[39] See, e.g., Acemoglu and Restrepo (2017, 2019, and 2020); Dosi et al (2021 and 2022).

[40] See, e.g., Berg et al. (2018), Korinek (2019), Korinek and Stiglitz (2019), Korinek and Stiglitz (2021), Korinek and Trammell (2023), Korinek and Suh (2024), Acemoglu (2024), Aditya (2024).

[41] See, e.g., Dosi et al. (2021 and 2022) and, at least in part, Korinek and Stiglitz (2021) and Korinek and Trammell (2023).

[42] See, e.g., Elondou et al. (2023), Webb (2020).

[43] See, e.g., Brynjolfsson et al. (2018), Felten et al. (2021).

[44] Vermeulen et al. (2018)

[45] Sachs and Kotlikoff (2012), Sachs et al. (2015), Benzell et al. (2015), Berg et al. (2018), Gasteiger and Prettner (2020), Violante (2008) Acemoglu and Autor (2011), Acemoglu and Restrepo (2016 and 2018), Berg et al. (2018), Korinek and Stiglitz (2019), Korinek and Suh (2024), Aditya (2024).

[46] See, e.g., Korinek and Trammell (2023), according to whom AI raises growth and has various effects on labor share when different assumptions are made.

[47] Korinek and Stiglitz (2021).

also be effective in the AI era so that we do not have to worry about the possible occurrence of (mass and/or) full unemployment. The implication is that most economists still today repute full unemployment as not deserving of theoretical study.

3. The unconventional view: Why we should study full unemployment

We, therefore, can agree that, in the past, the "consensus view" had robust empirical and theoretical grounds for denying the possibility that technological progress could generate mass long-term unemployment. Needless to say, if both theoretical and empirical considerations caused economists to deny the possibility of technological progress impacting long-term unemployment, the concept of "full unemployment" was indeed (correctly for those times) not imagined even by the most prescient (and forward-looking) economists. We have also seen that even if some past certainties have been questioned in the last couple of years, the concept of (mass and/or) full unemployment has nonetheless remained almost always outside the arguments that economists considered deserving theoretical attention.

But is ruling out the twin concepts of mass and full unemployment from the economic analyses really an attitude that can be considered defensible?

We can argue that this is not the case since both empirical data, the theory of compensation, and many of the most recent theoretical and empirical considerations, are all useless for disproving the possibility that the fourth industrial revolution could generate (mass or) full unemployment.

Let us start with the empirical data.

3.1 The irrelevance of empirical data

The essential characteristic of the diffusion of AI into productive processes is that we are dealing with a phenomenon that has not yet occurred. Not only is AI in its very early stage of development (and AGI even in an earlier stage), but its introduction into the productive process barely began and was limited to particular sectors and tasks, so it will affect employment in a relevant way, if it is ever going to affect employment in a relevant way, only in the future. Indeed, despite its early phase of diffusion, we can already see the first, not yet fully developed, novel characteristics of the Fourth Industrial Revolution impacting the labor market, so it is not particularly difficult to infer realistic forecasts on its future development. Differently from the Third Industrial Revolution, which, albeit being based on similar technologies (i.e., Information and Communication Technologies and robotization), mainly impacted manual workers and/or workers performing routine tasks, AI appears already today capable of affecting a higher number of jobs and functions, also the creative and intellectual ones. The most famous contemporary example of this impact are AI tools like Generative pre-trained Transformers (Gp-T) that can autonomously write texts, although the quality of these texts is lower than literary masterpieces, with the result that all jobs and tasks that require writing skills may already today easily be affected. Human beings must indeed drive these tools if they aim to produce high-quality results, but AI learns very fast, so in the coming few years, human assistance might become superfluous with the advent of AGI. The same considerations can be extended to figurative arts since tools like Dall·E and Stable Diffusion appear already capable of producing better-quality artistic images than those produced by the average painter or photographer. High-skilled and non-routine jobs are at the same risk in almost all sectors of the economy: AI is potentially capable of producing diagnosis of illness and therapy better than skilled physicians, having access to petabytes or exabytes of medical data and possessing the full capability of processing them; taxi drivers and truck drivers have only to wait for that self-driving cars and trucks will be fully developed, and it seems a question of few years; streaming lectures might substitute school teachers and university professors, and integrating AI (and the full access to the knowledge of the internet) with existing recorded video could allow deep-fake technology to modify the lectures in response to the questions or the attitude of the listeners.

Almost all public bureaucracy might easily be substituted by AI. And so on. Therefore, even if such a substitution has not yet fully manifested in all these areas, it appears only a matter of time: today, we cannot reasonably think of one single task that AI (and/or machines endowed with AI), and furthermore AGI, cannot perform better than human workers in a not so far future.

Indeed, some of the newest empirical studies are already showing that in specific sectors, this substitution is beginning to take place: one significant typical example is the reduction of employment for online freelancers, testified by Demirci et al. (2023) and Hui et al. (2023). Nonetheless, unemployment remains a small sectoral problem, and the rise of employment in some sectors might easily counteract the reduction in others (as testified, for example, by Korinek 2023).

It must be crystal clear: I am not claiming that a complete substitution will occur. It might easily happen that in some sectors, or even in most sectors, the mass substitution of machines endowed with AI for human workers will not occur. I am only maintaining that today, we cannot think of a single sector, job, or task in which we can reasonably affirm that such a substitution is impossible, as it is massively testified by the studies on the measure of the exposition of tasks to AI proposed for example by Elondou et al. (2023) and Webb (2020). And these forecasts concern the simplest case, i.e., the diffusion of AI, and not the advances in AGI.

In any case, the key point is that AI is entering the productive processes only nowadays, and we should add that such an entry is taking shape uniquely in some sectors and some countries. So, it is unsurprising that empirical data do not prove its capability to generate aggregate (mass or) full unemployment *today* since the point is whether it will generate (mass or) full unemployment *tomorrow*: today's data cannot disprove a phenomenon that will happen only tomorrow. Therefore, today's empirical studies cannot be used to disprove the rise of mass (or full) unemployment because of the diffusion of AI.

Even Hötte et al. (2023), who find ample support in the literature for the idea that "technological progress has not resulted in a negative net employment effect in the past decades" (Hötte et al., 2023, p. 16), maintain that their "systematic review is subject to a number of limitations. First, empirical studies can only cover the impact of technologies already available today, but the scope of tasks that may be automated in the near future continuously expands (…). Hence, empirical evidence on the impact of artificial intelligence, quantum computing, virtual reality, biotechnology, nanotechnology, renewable energy, and other emerging technologies that will soon impact our economy remains limited. None of the studies in our review assessed the impact of this new wave of technological innovation. To that end, it is unclear to which extent our findings can be extrapolated into the future" (Hötte et al., 2023, p. 19). Similar considerations have been proposed by Thierer (2024, p. 4): "AI will cause job dislocations, of course, but no one can accurately predict which or how many jobs will be affected. Forecasting the future workforce is haunted by the same problem experts have always faced: We do not even possess a vocabulary to describe the jobs or skills of the future. When skimming old Bureau of Labor Statistics reports, such as the agency's mammoth 1969 Tomorrow's Manpower Needs: National Manpower Projections and a Guide to Their Use as a Tool in Developing State and Area Manpower Projections, one finds no mention of any of the jobs that would eventually flow from the personal computing or internet revolutions." On the same line of thought is Saam (2024, pp. 23-24): "The public debate often focuses on the job losses resulting from automation. Empirical evidence to date, however, does not point to any aggregate job losses … Whether the current wave of technological progress based on machine learning technologies has different effects is yet to be seen."

So, *today's* empirical evidence, albeit showing results less optimistic than those of past studies in some cases, refers only to single, specific sectors, is often inconclusive, and is, in any case, useless for supporting or denying AI's *future* negative employment impact. However, even without empirical evidence, theoretical analysis might nonetheless be undertaken. In particular, we should evaluate whether the compensation theory and its more recent heirs remain valid in the new scenario, i.e., the fourth industrial revolution.

3.2 The uselessness of the (old and new) compensation theory

We can argue that the validity of the "original" compensation theory ultimately rests on two assumptions: (i) that the substitution rate between human workers and machines will never be equal to one, and (ii) that human workers' wage-to-productivity ratio will not be higher than machines' remuneration-to-productivity ratio in a relevant number of industries. If these assumptions remain valid for the fourth industrial revolution, compensation theory, which proved valid for the last three Industrial Revolutions, will also be valid for the diffusion of AI.

To explain the role played by these assumptions, let us begin by sketching the main characteristics of our thought experiment, which describes a possible scenario generated by the diffusion of AI. Let us call "androids" humanoid machines endowed with AI (or most likely with AGI) that can perform the same tasks a human worker can perform but with higher productivity. The choice of referring to androids and not simply to machines endowed with AI (or AGI) simplifies the analysis without affecting its main results.[48] Let us also assume that androids are rented out by their owners, i.e., by capitalists, to entrepreneurs, i.e., to firms. Given the produced quantities, firms will hire androids (A) instead of human workers (L) if the value of androids' marginal product $\bar{p}\cdot\frac{\partial Q}{\partial A}$ divided by androids' rent price (or remuneration) w_A is higher than the value of labor marginal product $\bar{p}\cdot\frac{\partial Q}{\partial L}$ divided by workers' wage rate w_L, i.e. if

$$1) \qquad \frac{\bar{p}\cdot\frac{\partial Q}{\partial A}}{w_A} > \frac{\bar{p}\cdot\frac{\partial Q}{\partial L}}{w_L}$$

where $\bar{p}$ is the price of the produced commodity Q.

In the aggregate, the firms' behavior would suggest that full technological unemployment (or at least mass unemployment), can emerge in the economic system (i) if androids can replace human workers in all (or most) productive processes and tasks and (ii) if androids employed in these processes have a productivity-to-rent price (or productivity-to-remuneration) ratio higher than workers productivity-to-wage ratio. Both conditions must occur; otherwise, full unemployment (or mass unemployment) will not exist.[49]

Until the diffusion of AI (and still today), the above conditions appeared unrealistic, particularly the first, i.e., the assumption that the substitution rate among human workers and machines could equal one. The problem is that nothing will ensure these conditions remain unrealistic in the future after the complete diffusion of AI (and even more so of AGI).

We have already extensively discussed the main novelty of the Fourth Industrial Revolution. Nowadays, it is possible to imagine that machines endowed with artificial

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[48] Referring to androids also allows us to avoid the problem of "machines measurability," which appears similar to and bears implications similar to those of the problem of "capital measurability" that was at the very center of the so-called "two Cambridge debate," i.e., the Cambridge capital controversy of the mid-1950s - mid-1970s: on this point, see D'Orlando (2024, pp. 43-44) , but similar concepts can also be found in Saam (2024).

[49] Our full unemployment scenario is similar to Korinek and Juelfs' (2022, p. 8) concept of Strong Economic Redundancy of Labor: "Machines are able to perform any economic valuable task cheaper than humans, valued at their subsistence cost"; and our mass unemployment scenario is similar to Korinek and Juelfs' (2022, pp. 8-9) concept of Weak Economic Redundancy of Labor.

intelligence (or AGI) can substitute for human workers in all jobs and tasks, not simply increase their productivity. Therefore, we are in the presence of a completely new scenario; things that in the past were inconceivable now are possible, and in this new scenario, nothing prevents the substitution rate from being equal to one for most, if not all, jobs and tasks. Indeed, this case appears more likely than unlikely, as the first preliminary studies on measuring the exposition of tasks to AI seem to suggest (e.g., Elondou et al. 2023 and Webb 2020). It also seems complicated to imagine that machines' remuneration-to-productivity ratio will be higher than human workers' wage-to-productivity ratio. It is significant that until today, no theoretical proof has been furnished that the substitution rate cannot be equal to one or that workers' wage-to-productivity ratio cannot be higher than machines' remuneration-to-productivity ratio (for a wage rate above subsistence) in most or all tasks and economic sectors. Furthermore, such proof is probably impossible to furnish since it depends uniquely upon AI's future (and today unpredictable) capability to replace humans in the productive process. Most importantly, we cannot infer it by considering past substitution rates since what we are looking for will depend on the technological progress that will affect the economy in the future. In contrast, past rates depended on the technological progress that affected the economy in the past. And no correlation at all exists between these two elements. To say it another way, the fact that until now, the substitution rate has been low does not imply that such a rate cannot be high in the future.

Condition (ii) is also (but not solely) linked to economic considerations, but again, nothing from the past can help us forecast the relative remuneration and productivity of both human workers and androids in the future.

Now, in the spirit of our thought experiment, let us start from the extreme hypotheses that (i) androids can substitute for workers in all jobs and tasks, and (ii) androids' productivity-to-remuneration ratio is higher than humans' productivity-to-wage ratio in all sectors of the economy (for a wage rate above subsistence). So, firms substitute workers with androids, and the system converges to full unemployment equilibrium. Now, compensation forces should, in principle, operate and should allow the system to return to a situation of full employment. The problem is that under the two assumptions above, compensation forces will not work as they were assumed in the first three technological revolutions. In particular, the greater the substitutability rate among androids and human workers, the lower the strength of compensating forces. "So, if production can be realized by androids alone (or mainly by androids), …, most compensation mechanisms are ruled out, independent of demand elasticity" (D'Orlando, 2020b, p. 603). To discuss this point, consider each compensation force addressed in section 2 and see if they work in the above-described scenario.

Starting with automatic mechanisms, we have:

(i) Wage downward flexibility: Nothing prevents wages from dropping below the minimum subsistence level before human workers' productivity-to-wage ratio surpasses that of androids. In such a case, workers would not accept hiring, and downward wage flexibility will not increase employment.

(ii) Increase in demand for machines: if androids can self-produce and are more productive than human workers, the rising demand for androids will increase the production of androids, but firms producing androids will only hire more androids and not more human workers.

(iii) Increase in demand for goods due to price reduction: if androids can handle all the production, there may be a greater need to hire androids rather than human workers when the production of goods increases.

(iv) Increase in real income: An increase in real income can lead to a rise in demand and production for goods, resulting in increased employment for androids instead of human workers if androids can handle all the production.

(v) Increase in profits and investments: If investment goods are only produced by androids, increasing the demand for investment goods will mostly lead to hiring more androids, not more human workers.

(vi) Increase in profits and consumption: Entrepreneurs' increased demand for goods due to higher profits leads to more android hires if goods are only produced by androids.

(vii) New sectors: If androids can fully replace human workers, increased production in new sectors will lead to more android hiring if goods are only produced by androids.

(viii) Increase in high-skilled workers' consumption: In this context, it is unlikely that wages for highly skilled workers will increase due to the potential for androids to replace them. And even if wages rise for specific tasks, the resulting increase in production will likely lead to a higher reliance on androids for production.

(ix) Transition from one sector to another: It is difficult to predict the growth of industries relying only or mainly on human workers, as new sectors already today appear highly automated or based on AI.

(x) Increase in labor productivity: In a scenario where androids are indistinguishable from human workers, an increase in the use of androids will reduce both human and androids' productivity, preventing an increase in human labor demand.

(xi) Reduction in machines' productivity: Also in this case increased androids usage in production can lower both androids' and human workers' productivity if androids are indistinguishable from human workers, leading to unchanged advantages of hiring androids and no increase in human employment.

(xii) Increase in real money supply: Mechanization of production and lower prices of goods can reduce interest rates and increase investments. However, this may not result in increased employment for human workers, as the increased production of investment goods only leads to hiring androids, not human workers.

(xiii) New job opportunities: New tasks will likely require androids, not human workers. Put another way, the reinstatement effect will imply the hiring of androids, not of human beings, so that reinstatement and displacement will be the same thing.

As regards deliberate intervention mechanisms, we have:

(xiv) Increase in public expenditure: Increasing public expenditure typically leads to increased production. If production is only carried out by androids, there will be an increase in hiring androids rather than human workers.

(xv) Luddite policies: These policies could play a role in increasing human employment. The question is whether these strategies will be sufficient to restore full employment.

(xvi) Reduction in per-capita working hours: A reduction in per-capita working hours may not be effective if the substitution rate is equal to one and human workers' productivity-to-wage ratio remains lower than androids', as firms will not hire any human workers.

Finally, with regard to the recent theoretical contributions that have somehow integrated compensation theory in more recent years[50], we have seen that they are more

[50] See, e.g., Violante (2008), Acemoglu and Autor (2011), Sachs and Kotlikoff (2012), Sachs et al. (2015), Benzell et al. (2015), Acemoglu and Restrepo (2016, 2017,2018, 2019 and 2020),

pessimistic than empirical studies on the impact of automation and robotization on employment, and these results appear confirmed by the few models that explicitly consider AI.[51] It is so even when they exclude the possibility of a substitution rate equal to one, as they almost always do. When this assumption is removed, for example in the benchmark model by Berg et al. (2018), or in Korinek and Juelfs (2022), it is possible to have mass or full unemployment outcomes. The main problem with most of these recent contributions, which model the impact of technological progress on growth, wages, and inequality, is that, as we have already pointed out, they are rooted in the neoclassical framework with market-clearing equilibria. This framework faces, in general, relevant difficulties when it is called to systematize the AI scenario, as discussed in section 4 below. However, in particular, it suffers from its market-clearing assumption, which prevents it from consistently studying involuntary unemployment equilibria.

We can easily conclude that if the substitution rate is equal (or close) to one, the great majority of compensation forces presented above, particularly those based on automatic mechanisms, appear relatively ineffective in counteracting the rise of unemployment caused by the dissemination of Artificial Intelligence. So, under the extreme hypotheses here assumed, (long-term mass unemployment, or even) full unemployment, is not only a possible but a likely scenario in the absence of “ad hoc” policies that should be, for a large part, considerably different from the ones theorized by traditional compensation theory.

All the above implies that defining full unemployment and describing its characteristics might not be useless.

4. Full unemployment and its characteristics

Full unemployment can be defined as a situation in which no human worker accepts being hired since the equilibrium wage is below subsistence (and therefore below all human workers’ reservation wage) or in which no firm is willing to hire workers paying them a wage above subsistence.

This “pure” theoretical definition of full unemployment implies that no human worker is hired in the entire economy. However, a more operational definition might consider the possibility of full unemployment in some markets and close-to-full unemployment, i.e., mass unemployment, in other (possibly in many other) markets since frictional resistance to unemployment might be persistent.

Full and mass unemployment equilibria are depicted in Figures 1 and 2, respectively. We have already seen (see relation 1 above) that given the produced quantities, firms will hire androids (A) instead of human workers (L) if the value of androids’ marginal product $\bar{p}\cdot\frac{\partial Q}{\partial A}$ divided by androids’ rent price (or remuneration) w_A is higher than the value of labor marginal product $\bar{p}\cdot\frac{\partial Q}{\partial L}$ divided by workers’ wage rate w_L.

Here the implications of the main novelty of the fourth industrial revolution (i.e. the circumstance that androids can substitute for human workers in all jobs and tasks) clearly emerge: if androids and human workers were two different productive factors and $\frac{\bar{p}\cdot\frac{\partial Q}{\partial A}}{w_A} > \frac{\bar{p}\cdot\frac{\partial Q}{\partial L}}{w_L}$, by substituting androids for human workers androids’ marginal product $\frac{\partial Q}{\partial A}$ decreases and human workers’ marginal product $\frac{\partial Q}{\partial L}$ increases, till the point in which $\frac{\bar{p}\cdot\frac{\partial Q}{\partial A}}{w_A} = \frac{\bar{p}\cdot\frac{\partial Q}{\partial L}}{w_L}$ and for firms

Berg et al. (2018), Gasteiger and Prettner (2020), Dosi et al. (2021 and 2022), Dosi et al (2021 and 2022).

[51] See, e.g., Berg et al. (2018), Korinek and Stiglitz (2019), Korinek and Juelfs (2022), Korinek and Suh (2024), Acemoglu (2024).

hiring human workers becomes profitable again. But the circumstance that androids are humanoid machines indistinguishable from human workers also implies that when androids' marginal product varies (because of an increase or decrease in the number of androids that enter the productive process), the same happens to human workers' marginal product, so condition 1 will always remain valid, independently of the number of androids hired by firms. In other words, the co-movement of human workers' and androids' productivity implies that if humans are less productive than androids, they will always remain so, independent of how many androids and/or human workers are hired by firms. In these circumstances firms will hire human workers only if they accept a lower remuneration than androids.

If androids have a higher productivity than human workers, we can write

2) $$\bar{p}\cdot\frac{\partial Q}{\partial A} > \bar{p}\cdot\frac{\partial Q}{\partial L}$$

or

3) $$\bar{p}\cdot\frac{\partial Q}{\partial A} = \alpha\cdot\bar{p}\cdot\frac{\partial Q}{\partial L} \text{ (with } \alpha > 1\text{).}$$

This implies that firms will hire (also) human workers only if they accept a wage rate equal to

4) $$w_L = \frac{w_A}{\alpha}$$

so that

5) $$\frac{\bar{p}\cdot\frac{\partial Q}{\partial A}}{w_A} = \frac{\bar{p}\cdot\frac{\partial Q}{\partial L}}{\frac{w_A}{\alpha}}$$

and

6) $$\frac{\bar{p}\cdot\frac{\partial Q}{\partial A}}{w_A} = \frac{\bar{p}\cdot\frac{\partial Q}{\partial L}}{w_L}\ .$$

Suppose the equilibrium wage rate w^* for both androids and human workers (since they are indistinguishable) is determined in a competitive market. In that case, firms will hire human workers only if they accept a wage rate $w_L^* = \frac{w^*}{\alpha}$. In contrast, androids can be hired at the equilibrium wage w^*. But in the AI era, the difference in productivity among androids and human workers might likely be huge, as well as the value of α. The problem is that if α is high enough, the wage rate that human workers should accept to be hired by firms may easily fall below subsistence, and hence below all human workers' reservation wage.

The easiest way for furnishing a graph representation of the implications for the labor market of the above considerations, and for depicting the main characteristics of full unemployment equilibrium, is that of considering human workers' labor supply *LS* as a function of $w_L = \frac{w}{\alpha}$:

7) $LS = f\left(\frac{w}{\alpha}\right)$, with $LS'>0$ and

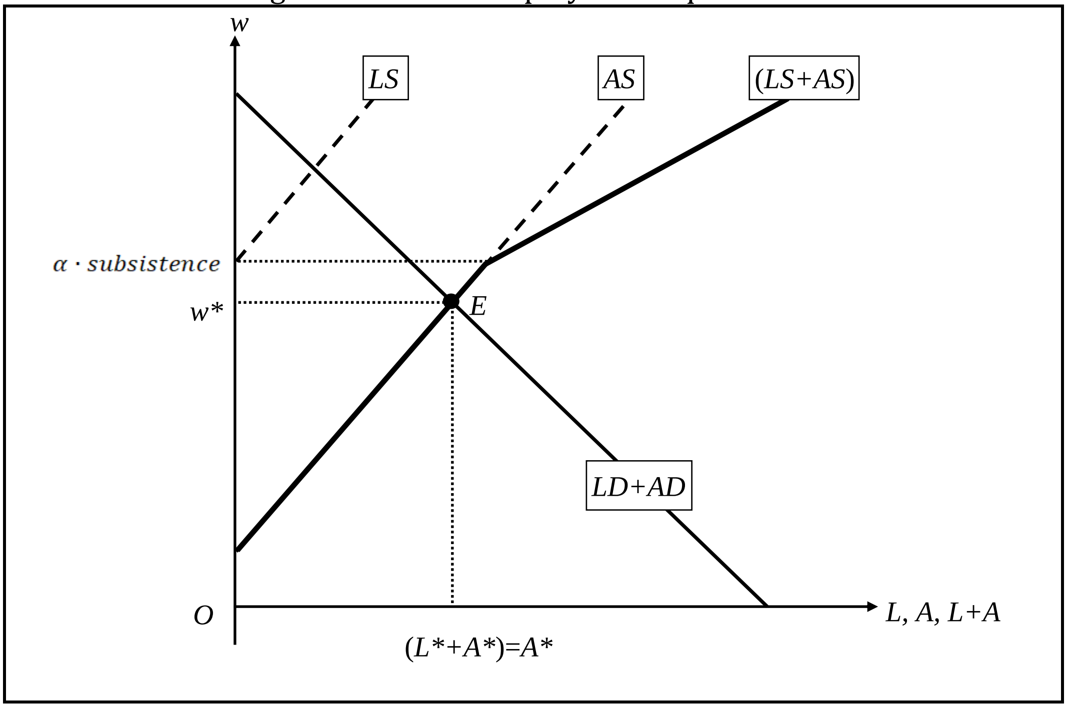
8) $LS = 0$ if $\frac{w}{\alpha} < subsistence$, i.e. if $w < \alpha\cdot subsistence$,

and androids' "labor" supply *AS* as a function of *w*, i.e.

9) $AS = f(w)$, with $AS'>0$.

In this scenario, the circumstance that human workers' reservation wage cannot fall below subsistence can easily generate full unemployment. In Figure 1 *LS* curve represents labor supplied by workers, *AS* "labor" supplied by androids, *LS*+*AS* is the aggregate "labor" supply curve, *LD*+*AD* is aggregate "labor" demand (for firms, it is indifferent to hire workers or androids if the former accept a wage $w_L = \frac{w}{\alpha}$), L^* and A^* are, respectively, labor and androids equilibrium levels of employment. If the equilibrium remuneration w^* that equates "labor" demand *LD*+*AD* and "labor" supply *LS+AS* is such that human workers' wage $w_L^* = \frac{w^*}{\alpha}$ is below subsistence (i.e. $w^* < \alpha \cdot subsistence$), competitive forces will push the system, or at least this sector of the economy, to a full-unemployment equilibrium E, in which no human worker and A^* androids will be hired, since workers will not accept to be hired for a remuneration below subsistence.

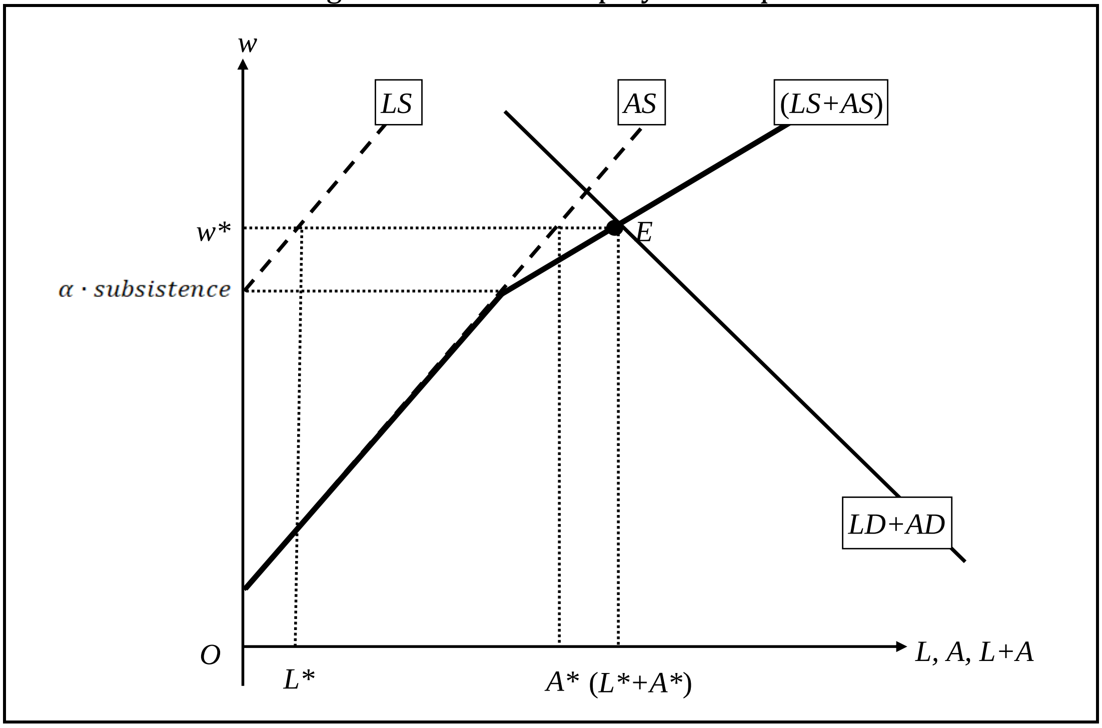
Figure 1 – Full unemployment equilibrium



It is important to recall that here, we are not assuming that such a situation is realistic or will occur in the near future; we are asking ourselves what the characteristics of a full unemployment equilibrium could be if it occurs. In other words, we are only performing a thought experiment.

Things change slightly in the case of mass (or close-to-full) unemployment equilibrium, represented in Figure 2, a situation in which most sectors of the economy are in full unemployment equilibria, so that the graph of Figure 1 can represent them, and other sectors are in mass unemployment equilibria, with an equilibrium wage w^* higher than $\alpha \cdot subsistence$, (i.e. $\frac{w^*}{\alpha} > subsistence$) so that a certain number of workers accepts being hired. In Figure 2 L^* shows the number of human workers hired in equilibrium, and A^* is the number of androids hired.

Figure 2 – Mass unemployment equilibrium



An important weakness of the analysis proposed in this section is the explicit assumption of market clearing dynamics, which is not fully convincing if we aim at studying full unemployment equilibria. Remember that we define full employment as a situation in which all individuals willing to work at the equilibrium wage are hired, while others remain voluntarily unemployed. On the other hand, full unemployment is when no workers are willing to accept employment because the equilibrium wage is below the subsistence level. If we adhere to the traditional market clearing framework, in a state of full unemployment, we would face the paradoxical situation of being both in full unemployment (since nobody would accept a job if the wage offered is below what they need to survive) and in full employment (because all unemployed workers are choosing not to work at the equilibrium wage). Moreover, in the case of (mass and) full unemployment equilibrium, mainstream (neoclassical) economic theory faces also other relevant problems when it is called to systematize the resulting equilibria characteristics (see D'Orlando 2024). Among these problems, the one that probably bears more critical implications, apart from the market clearing assumption, is the circumstance that income distribution will no longer depend upon factors endowment but upon the bargaining power of social classes since society will probably be divided into the two (conflicting) classes of entrepreneurs (and/or android owners) and workers (either unemployed or, in case of mass but not full employment, employed). Each social class will have different and, in some cases, incompatible goals. Class struggle will therefore be a concrete possibility, and the classical economists' (and Marx's) idea that the behavior of social classes determines economic outcomes and income distribution becomes more suitable for systematizing such a situation than the idea of economic outcomes and income distribution ruled by the maximizing behaviors of single individuals that possess different endowments of productive factors. It is worth noting that we would be in the presence of a particular kind of class struggle: indeed, the social class of workers will possess far less bargaining power than in the past since, in the past, workers were necessary and irreplaceable for production, while in a world of full technological unemployment, they are unnecessary for production and fully replaceable. According to Brynjolfsson (2022, p. 273):

> "when AI replicates and automates existing human capabilities, machines become better substitutes for human labor and workers lose economic and political bargaining power. Entrepreneurs and executives who have access to machines with capabilities that replicate those of human for a given task can and often will replace humans in those tasks. A fully automated economy could, in principle, be structured to redistribute the benefits from production widely, even to those who are no longer strictly necessary for value creation. However, the beneficiaries would be in a weak bargaining position to prevent a change in the distribution that left them with little or nothing. They would depend precariously on the decisions of those in control of the technology. This opens the door to increased concentration of wealth and power."

These circumstances may also have important implications for the capability of the many losers to impose on the few winners the implementation of adequate redistributive policies. This is because it is the economic power in production, not just the number of people, that determines political strength; and if humans are not productive and do not participate in productive activities, they have no political strength. As a result, social stability will be at risk. Political violence, riots, and insurrections will be likely, which ultimately will make the survival of democratic institutions unlikely.

5. Compensative and mitigative forces

However, even if automatic compensation forces are ineffective in the above-described scenario, some deliberate intervention mechanisms can (and indeed should) be implemented, independently from the effective capability of unemployed humans to impose their adoption. We can generally divide these deliberate intervention mechanisms into two broad categories. In the first, we find those policies that aim to guarantee employment and subsistence for humans (and demand for the goods produced by androids); within the second, we find those policies that aim to guarantee subsistence for humans (and demand for the goods produced by androids), but not employment for humans. However, as shown below, some overlapping exists among the different policies, and a complex policy mix might represent the best solution.

To ensure employment and subsistence for humans (and demand for the goods produced by androids), public policy could implement several strategies. The most important of these strategies are as follows:

i. Public policy could increase the cost of hiring androids for firms by taxing their hiring, with the goal of making workers' productivity-to-wage ratio competitive with that of androids.
ii. Public policy could increase humans' productivity, again to make workers' productivity-to-wage ratio competitive with that of androids. To achieve such a result, public policy could boost education, professional training, or both, cutting the cost of private investment in human capital or directly offering it for free to humans (Campa, 2017, p. 13). A more radical but future strategy could be building cyborgs, i.e., humans with cybernetic parts.
iii. Public policy could reduce the cost of workers for firms, also in this case with the goal of making them competitive with androids. To achieve this, public policy could subsidize the hiring of humans by paying employment subsidies to firms that hire humans.
iv. Since one of the problems that prevents workers from being competitive with androids is the existence of a subsistence lower bound for human wage, public policy could allow workers to accept wages below the subsistence level by paying an unconditional basic income to all citizens, both employed and

unemployed.[52] The unconditional basic income is "a cash grant provided to every citizen […] without any other eligibility requirement" (Tanner, 2015, p. 3). When used to counteract full unemployment, it should be high enough to ensure subsistence. Once subsistence is guaranteed, citizens can decide whether to accept a low wage to increase their consumption above the subsistence level or stay unemployed and get only the subsistence basket.[53]

All the above mechanisms operate on relation 1, which is reproduced in Figure 3 below, modifying the different values of relevant magnitudes in the way depicted by arrows (reducing the productivity of androids seems unfeasible, so the first arrow is of little relevance).

Figure 3

$$\frac{\bar{p}\cdot\frac{\partial Q}{\partial A}\downarrow}{w_A\uparrow} > \frac{\bar{p}\cdot\frac{\partial Q}{\partial L}\uparrow}{w_L\downarrow}$$

v. Finally, public policy could impose minimum human employment quotas or maximum android employment quotas on firms. This policy mimics the immediate (Luddite) reaction of authorities to the displacement of workers caused by the First Industrial Revolution, i.e., "limit the use of the machines" (Campa, 2017, p. 3).

To guarantee subsistence for humans (and demand for the goods produced by androids) without employment for human workers, public policy could implement several strategies, the most important of which are as follows:

vi. Public policies could accept unemployment and subsidize humans with an unconditional basic income (UBI) or lifelong unemployment benefits.[54]

vii. Public policies could seek to nationalize firms, assign the ownership of androids (or firms) to citizens, or encourage workers to buy shares of firms. In this way, the surplus derived from goods produced by androids will go to humans displaced by androids, guaranteeing them subsistence.[55]

As said above, even better results could be achieved by implementing a combination of these policies. In particular, a reasonable policy mix could combine the payment of an unconditional basic income to all citizens with the reduction of per-capita working hours and the imposition of mandatory hiring quotas on firms.

In our scheme, the Unconditional Basic Income can play two different roles: counteract unemployment (point iv above), and accept the presence of full unemployment and counteract its income consequences (point vi above). The problem of financial sustainability of this policy tool will be less relevant in a situation of full unemployment compared to its implementation in a situation of low unemployment. In the former case, productivity growth caused by the use of androids will allow firms to pay both the remuneration to android owners and an amount of taxes that suffices for financing the Basic Income since these taxes will be lower than the wages

[52] As proposed, among others, by Hughes (2014), Campa (2014), Colin and Palier (2015), Schiller (2015), Skidelsky (2015), Marchant and Stevens (2017).

[53] For a detailed discussion of this use of the Basic Income see D'Orlando (2022) and (2024).

[54] It is worth noting that the basic income is not an unemployment benefit, as humans receive it whether they are employed or unemployed.

[55] Freeman (2015, p. 1) emphasized 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."

they pay today, and that they no longer have to pay. 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; D'Orlando, 2021).[56] However, basic income seems to present some problems related to well-being: D'Orlando (2022) argues that the payment of an unconditional basic income, in many cases, will reduce well-being compared to alternative policies and increase well-being inequality. However, when the payment of an unconditional basic income is combined with other policies (such as the reduction in per-capita working hours and the imposition of quotas of workers to be hired by firms), it can play a crucial role in counteracting technological unemployment and/or its consequences.

Reducing per capita working hours is another popular measure that economists have proposed (see, e.g., Keynes 1930). Nonetheless, if implemented as the sole policy for counteracting full unemployment caused by AI and/or its consequences, it is useless (and for this reason, this policy is not included in the numbered list above): in the scenario depicted by our thought experiment, unless the lower subsistence bound is removed, even reducing by law per capita working hours, firms will prefer to hire only androids rather than humans to substitute working hours no longer furnished by workers. As a result, this solution per se does not counteract long-period technological unemployment, even if it can be helpful when combined with other measures or in the case of mass and not full unemployment.

The third measure of our ideal policy mix, i.e., imposing on firms mandatory quotas for workers to be hired, mimics Tietenberg's (1990, 2003) traditional tradable permits approach to environmental economics.[57] In the original approach, pollution quotas are allocated among firms, which can either comply with these quotas or sell/buy them. The same theoretical framework and policy tools can be used to deal with technological unemployment problems: governments can decide on the quotas of workers that each firm must hire; once quotas have been allocated (free of charge or based on auctions in which firms pay more for smaller quotas), firms can trade them. In this case, sellers pay for selling quotas, and buyers get paid for buying quotas. Firms or industries for which hiring human workers is less profitable would sell quotas to firms or industries for which the employment of human workers is less disadvantageous. Paraphrasing Tietenberg, quotas will flow toward their lowest-loss use. Those who would suffer a higher loss from being forced to hire humans are incentivized to trade them with someone with lower losses. Such trade benefits both. Furthermore, the government can more reliably achieve its employment goals by imposing quotas rather than relying solely on market forces.

The main disadvantage of this latter solution is identical to those concerning environmental protection policies and can be overcome similarly. Firms lose competitiveness since they are forced to pay for hiring humans more than they would have paid for hiring androids, or they will be forced to pay for selling their quotas. And opportunistic behaviors by some countries that gain competitiveness by not implementing quotas are possible. However, the possibility remains to negotiate international treaties that commit countries to enforcing quotas, as in the case of the Kyoto Protocol. Furthermore, the international trade of quotas can be planned.

[56] The debate on the basic income dates 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).

[57] On the tradable-permits approach, see Baumol and Oates (1971), Montgomery (1972), and Tietenberg (1990, 2003).

In any case, a reasonable policy mix could overcome the peculiar weaknesses of each policy by combining the three measures discussed in this section: (i) a basic income (which could allow wages to fall below the subsistence level so that firms can profitably hire workers); (ii) a reduction in per capita working hours (which could guarantee close to full employment); (iii) imposing quotas and allowing their trade (which could help the system not to lose economic efficiency excessively and to achieve with greater certainty the employment objectives).

6. Conclusions: Does full unemployment deserve theoretical interest?

The actual relevance of the whole analysis developed in the above sections crucially depends upon the likelihood of the circumstance that AI or AGI (and/or machines endowed with AI or AGI) will be able to substitute for human workers in all (or at least in most) jobs and tasks at a lower remuneration-to-productivity ratio: if such a substitution has a positive, even if small, probability of occurring in the foreseeable future, the concept of full unemployment undoubtedly deserves theoretical interest; on the contrary, if there is no possibility at all that this substitution will occur, full unemployment is deprived of theoretical interest. So, we should answer a simple question: How realistic is a future substitution rate among human workers and humanoid machines equal to one?

The problem is that we cannot answer this (unanswerable) question. As of today, AI and machines endowed with AI seem capable of substituting for human workers in most or all productive processes, irrespectively of workers' skill endowment and/or the circumstance that they perform routine or non-routine tasks, a scenario that was simply impossible (and unpredictable) in the past. We cannot know if this process of substitution of AI, machines endowed with AI, and/or androids endowed with AGI for human workers will go so far as to create mass or even full technological unemployment. What we know is that economic theory developed for studying the past Industrial Revolutions, as well as today's empirical data, are useless for forecasting future economic outcomes: We are in the presence of a completely different and more pervasive kind of technological progress, a real paradigm shift, so that what happened in the past cannot be used to extrapolate what will happen in the future. Everything will depend upon how AI will develop in the immediate future and how it will impact unemployment in the less immediate future. And, last but certainly not least, on the public policies that might be implemented to counteract the possible rise of technological unemployment and/or its consequences.

Therefore, the real question we should answer is slightly different: is it legitimate to undertake ex-ante theoretical analysis of economic processes that might or might not occur in the future, or must we wait for these processes to come about and study them only ex-post? I argue that undertaking these analyses is entirely legitimate and somehow unavoidable. Indeed, even if we cannot know the future, we must admit that today's fast and seemingly unstoppable diffusion of AI suggests that the possibility of a future rate of substitution equal to one exists. And if such a possibility exists, so that technological progress might generate full (or at least mass) unemployment, it is reasonable to imagine that *adequate counteracting policies will, in that case, be implemented*. The last statement is crucial since if we believe that in the case of a heavy impact of technological progress on employment, public authorities will implement adequate policies to counteract the process, or its consequences, we will need a theoretical economic framework capable of suggesting how these measures should be designed, as well as their likelihood impact on employment, productivity, and well-being. Say it another way: we will need a theoretical analysis of the phenomenon. And it would be better to develop such a theoretical analysis *before* full (or mass) technological unemployment occurs; or, but ultimately they are the same thing, before we know if it will ever occur or not.

So, while it is impossible to state today whether a full unemployment scenario will occur in the foreseeable future, it is undoubtedly that full (and mass) technological unemployment caused by the diffusion of AI does deserve theoretical interest.

This theoretical interest could take the form of thought experiments similar to the android experiment proposed by Brynjolfsson and McAfee (2014, pp. 180-182). Orthodox (i.e., neoclassical) economic theory may indeed encounter some theoretical problems in discussing a world of full unemployment. Still, this circumstance reinforces the conclusion that it is better to analyze the phenomenon ex-ante before it occurs, modifying the theory if necessary, rather than studying it ex-post if it comes about, leaving policy design and implementation to the creativity of the policy maker.

However, economists might also conclude that the phenomenon does not deserve theoretical interest since it will never occur. But to reach such a conclusion, they should prove that the phenomenon will never happen. In other words, they should put full unemployment at the center stage of their studies and propose a theoretical analysis showing that technological progress cannot generate full unemployment. So, once again, it would be confirmed that (mass and) full unemployment does deserve theoretical interest.

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