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What is Technological Unemployment

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What is Technological Unemployment?*

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Abstract

Will robots or artificial intelligence take our jobs? At the center of the debate about the future of work is "technological unemployment", a term that has a seemingly simple definition but has in fact been used and defined differently by economists. In this paper, we explore how economists have discussed the potential for new techniques to replace workers since Aristotle, and how they have defined and conceived of technological unemployment over the past century. We begin with a detailed analysis of classic texts on this topic, from ancient times to the 20th century. To capture changes in the research frontier, we quantitatively and qualitatively analyze all 153 articles that mention the term "technological unemployment" in twelve major economics journals, including the top five, since their inception. We then use the 19 editions of Paul Samuelson's seminal textbook and a cross-section of 43 economics textbooks from the 2000s and 2010s to observe the state of discourse and changes in economics pedagogy. Our analysis shows that economists have used a range of definitions in their discussions of technological unemployment, and most definitions are brief and imprecise. Economics textbooks notably omit technological unemployment in their discussions of the relationship between technological change and employment, despite the continuing interest in the topic in the academic literature. Nonetheless, we find a surprising consensus in our corpus that technological change may cause unemployment. Over time, the debate around technological unemployment has become narrower and more technical, but also more heated during historical periods of technological anxiety. We suggest that the adoption of a clear definition with specific temporal and scale modifiers could clarify theoretical debates and improve the precision of future empirical research on the topic, which will allow economists to speak directly to public and policy concerns.

JEL Codes: B11, B12, B14, B22, E24, J23, J64, O33

Keywords: technological change, technological unemployment, innovation, labor displacement, text mining

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I. Introduction

The most important labor market impacts of technological change are in outright employment. For centuries the fear of job loss following technological shifts has motivated violence against inventors, attacks on machinery, and an industry of commentary that attempts to predict the risk of future job-replacing technology.[1] The term that sits at the center of this debate is "technological unemployment", a simple but, as we will show, at times elusive concept with resulting difficulties in causal identification. It ascribes responsibility for job loss and any concomitant immiseration to an impersonal force: technology. Despite the seeming simplicity of the term, views on whether it is possible and what form it might take have varied widely in economics. As we show, there has been surprisingly little attention to developing a precise definition, and most uses take for granted that readers will understand its meaning. Sentiments and concerns about the topic have varied greatly, likely related to the perceived threat of labor-replacing technology or due to the occasional use of euphemistic phrases.

To illustrate the recent revival of interest in technological unemployment and potentially competing or overlapping concepts, we web-scrape the 2019 English-language ngram corpus from the Google Books project and search for key relevant expressions (Figure 1). After some early references to the "machinery question", the phrase "technological unemployment" came into frequent use during the turbulent 1920s and the ensuing Great Depression. In the years that followed it was rivalled, but never overtaken, by references to "labor displacement". While this latter term has been used at various times to describe negative employment effects from technology, it can be used to describe job loss from many causes.[2] Finally, over the last twenty years, much research in economics has converged on the concept of "skill-biased technological change". This shift may reflect economists' preference

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[1] Joel Mokyr, Chris Vickers, and Nicolas L. Ziebarth, "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?," *Journal of Economic Perspectives* 29, no. 3 (August 1, 2015): 31–50, https://doi.org/10.1257/jep.29.3.31; Tom Wheeler, *From Gutenberg to Google: The History of Our Future* (Washington, D.C.: Brookings Institution Press, 2019), 18, 47ff., 71, 107, 140, 175, 229f.; Maxine Berg, *The Machinery Question and the Making of Political Economy 1815-1848* (Cambridge: Cambridge University Press, 1980); Carl Benedikt Frey, *The Technology Trap: Capital, Labor, and Power in the Age of Automation* (Princeton: Princeton University Press, 2019).

[2] Christine Evans-Klock et al., *Worker Displacement: Public Policy and Labour-Management Initiatives in Selected OECD Countries* (Geneva: ILO, 1998).

for technical terminology. Despite these trends, technological unemployment remains the term that resonates most clearly in public debates about automation and labor markets, and the term that connects academic and public discussions.

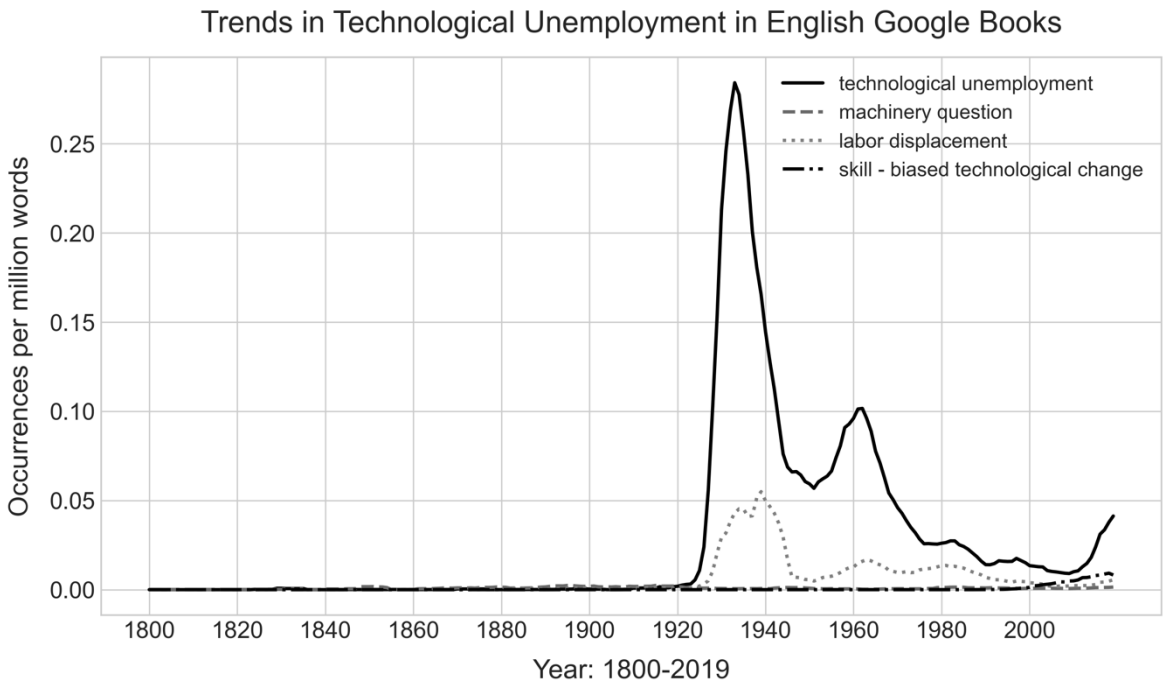

Figure 1: Trends in "technological unemployment" rhetoric in English books. Source: Google Books corpus ("eng_2019").

Given the continued prominence of the term technological unemployment over the past century and its recurring role in the public discourse, one might wonder how this term is conventionally defined. The Oxford Dictionary of Economics uses the following definition:

> Unemployment due to technical progress. This applies to particular types of worker whose skill is made redundant because of changes in methods of production, usually by substituting machines for their services. Technical progress does not necessarily lead to a rise in overall unemployment. New methods of production are economic to adopt only if they lower costs, which allows a larger output to be sold at a lower price. If the elasticity of demand is high enough, overall employment in the industry concerned may rise, as will employment in the industry producing the machines. It is still possible, however, for technological unemployment to afflict workers with old skills, if the new jobs created are either lower-grade operative jobs, or require skills they do not possess.[3]

[3] John Black, Nigar Hashimzade, and Gareth D. Myles, *A Dictionary of Economics*, Fifth edition, Oxford Quick Reference (Oxford New York, NY: Oxford University Press, 2017). The definition is the same in

This seems clear, and could provide a platform for empirical studies, but is such a definition used in economics research? Table 1 presents definitions or descriptions from four of the most-cited articles on Google Scholar that contain substantive discussions of technological unemployment.

Table 1: Definitions or Conceptions of Technological Unemployment in Highly-Cited Articles

Author(s)	**Title**	**Publication Date**	**Definition(s), Description(s), Conceptualization(s)**
Postel-Vinay	The Dynamics of Technological Unemployment	2002	"the influence of the rate of technological change on the level of unemployment"
Feldmann	Technological unemployment in industrial countries	2013	"job losses", "displac[ing] workers", "fall in labor demand"
Mokyr et al	The History of Technological Anxiety and the Future of Economic Growth: Is this time different?	2015	Following "technological progress [that] will cause widespread substitution of machines for labor"
Cords et al	Technological unemployment revisited: automation in a search and matching framework	2022	"automation impacts upon involuntary unemployment"

These authors and the Oxford Dictionary writers agree that the term must refer to a change in unemployment as a result of technological change. But while the Oxford Dictionary states that individuals or occupational groups can be technologically unemployed, Postel-Vinay identifies technological unemployment as an aggregate shift, identifiable only in the overall rate of unemployment. This confusion means that the same empirical finding, e.g. that workers in one occupation lost work following the adoption of technology, can be interpreted as either confirmation or refutation of the hypothesis that technological unemployment has

the 3rd (2009) and 4th (2012) editions. For comparison, the Palgrave Dictionary of Economics (1987) refers readers seeking a definition of "technological unemployment" to "machinery question" and "structural unemployment". The former entry notes that "the machinery question is solely a dispute over whether society benefits from the introduction of machinery, the most pressing social issue being the displacement of labour by machinery and the consequent threat of widespread unemployment." (p. 264). Following a discussion of Wicksell's contribution, it summarizes that "[a] satisfactory treatment of the Machinery Question depends upon modelling the general equilibrium of an economy and of following its transition from an initial equilibrium to the new equilibrium after the introduction of machinery. Even today, such a treatment is by no means easily achieved." (p. 267). The definition of "structural unemployment" includes an extended discussion of "technological unemployment", and notes that it may be long-term in nature and of substantial scale but does not state if such unemployment must be permanent (p. 531–532). John Eatwell et al., eds., *The New Palgrave: A Dictionary of Economics* (London: Macmillan, 1987). The Routledge Dictionary of Economics does not contain an entry for our term of interest. Donald Rutherford, *Routledge Dictionary of Economics*, 2nd ed (London: Routledge, 2002).

followed the adoption of new techniques. The duration of the effects is also unclear: is technological unemployment permanent or transitory? For example, can workers be technologically unemployed for a short time and then re-hired? If it is transitory, is the duration short, like frictional unemployment, or long? As in the case of scale, the very same data, perhaps showing a short-term effect of technology on aggregate unemployment or the disemployment of individuals who later find new work, could be used to confirm or refute the claim that technological unemployment has occurred.

This terminological imprecision makes tracing the intellectual and conceptual history of "technological unemployment" essential for scholarly, public, and policy debates about the effects of technological change and the future of work. Careful study of this scientifically and socially important question requires clearer terminology and integration with the extensive history of economics research and discussion of previous technological waves.[4] Our conceptual and rhetorical study complements empirical research on the consequences of technological change for workers, jobs, and labor markets. We also discuss the related sentiments of economists regarding the probability and potential effects of such displacement.

Before the 20th century, discussions of the employment impacts of innovation did not have a single term that identified the phenomenon of technology replacing workers. Writers referred to employment loss or the disappearance of certain types of jobs and their replacement by machinery, but there was no one shorthand for the phenomenon of job-replacing innovation. The closest terminology was the "machinery question" or clumsier phrases such as "the effect of the use of machinery upon labor".[5] The pithier, former, term only appears rarely in contemporary texts, as shown in Figure 1 above, and is primarily associated with the writings of David Ricardo, which we discuss below. As the debate about the relationship between technological change and employment only crystallized around our term of interest in the 20th century, we focus our study in three areas: first, we provide a survey

[4] Benjamin Schneider and Hillary Vipond, "The Past and Future of Work: How History Can Inform the Age of Automation" (London School of Economics and Political Science, Department of Economic History, May 2023), https://EconPapers.repec.org/RePEc:ehl:wpaper:119282.

[5] We discuss Ricardo's original contribution below in Section II. The "machinery question" is defined in the Palgrave Dictionary (see above) but not the Oxford Dictionary of Economics or the Routledge Dictionary. The latter quotation is taken from the Joint Resolution of the US Congress authorizing the Department of Labor to carry out research that eventually became the Hand and Machine Labor Study. U.S. Congressional Record, Fifty-Third Congress, Session II, Resolution No. 43, August 15, 1894.

of influential thinkers who discussed this relationship since Aristotle. Second, we analyze the research frontier of economics in the age of scholarly journals (1890–present). Third, we explore the most influential economics textbooks since the postwar period. The first element provides us with a long view, while the second and third enable us to focus on our specific expression of interest and its use in research and pedagogy. The classical thinkers are analyzed qualitatively, while the study of journal articles and textbooks uses digital corpora that can be filtered and analyzed using natural language processing (NLP) techniques, allowing for a mixed-methods approach of close and distant reading.[6]

To date, there have been a few attempts to trace the intellectual history of technological unemployment and the related development of technological anxiety or positivity among economists. The most detailed related research on this topic is the work of Woirol, who recounted and analyzed the debate within the economics profession over technological unemployment from the late 1920s and its companion debate on structural unemployment in the 1960s,[7] and that of Bix, who focused on the public and policy debates about technological unemployment in the United States.[8] Woirol provided a detailed examination of the debates and an assessment of theoretical claims and empirical findings. We focus here on how economists have defined the term of interest and the related issue of sentiment among economists regarding the employment implications of technological change.[9]

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[6] Matthew Lee Jockers, *Macroanalysis: Digital Methods and Literary History*, Topics in the Digital Humanities (Urbana: University of Illinois Press, 2013); Franco Moretti, *Distant Reading* (London ; New York: Verso, 2013).

[7] Gregory Ray Woirol, *The Technological Unemployment and Structural Unemployment Debates*, 1. publ, Contributions in Economics and Economic History 173 (Westport, Conn.: Greenwood Press, 1996). Some works have provided a broad narrative arc of schools before shifting to a theoretical discussion of what constitutes technological unemployment or a consideration of empirical aspects. See, e.g.: Guy Standing, "The Notion of Technological Unemployment," *International Labour Review* 123, no. 2 (1984): 127–47. This article provides a synoptic coverage of views up to Marx but does not discuss the 20th century debates in much detail.

[8] Amy Sue Bix, *Inventing Ourselves out of Jobs? America's Debate over Technological Unemployment, 1929 - 1981*, Studies in Industry and Society (Baltimore, Md.: Johns Hopkins University Press, 2002). An automation tax or machinery tax is discussed further in: Gregory R. Woirol, "The Machine Taxers," *History of Political Economy* 50, no. 4 (December 1, 2018): 709–33, https://doi.org/10.1215/00182702-7202536.

[9] This implies that we do not take a position on the empirical question of whether technology has replaced workers over any time horizon, or the theoretical discussion over whether such replacement is possible. When we discuss sentiments, we only consider the reactions of writers and not workers' reactions to technological change, which have been discussed in other historical studies, e.g. Frey, *The Technology Trap*.

The organization of the paper is as follows. In Section II we start with a detailed analysis of classic texts that discuss the potential for innovation to displace workers. To capture changes in the research frontier, we analyze articles which have featured the term "technological unemployment" in twelve leading economics journals, totaling 153 articles, in Section III. We show that economists writing on this topic have shown a surprising consensus that technological unemployment is possible, but also have only defined the term briefly and, in many cases, imprecisely. We then use the 19 editions of Paul Samuelson's seminal textbook and a broader sample of 43 recent economics textbooks to observe trends in the depiction of unemployment and technology in economics pedagogy in Section IV. Section V summarizes the differences in definitions and proposes a matrix of terms and definitions to achieve greater conceptual clarity. Section VI concludes.

II. The Long History of Technological Unemployment and Anxiety in Economics

The intersection of new technology and employment has sparked debate among economists and economic thinkers for millennia. Thinkers have interpreted both the opportunities and the problems of innovation through the lens of their own era and ideological leanings – often maintaining, in contrast to the anxieties of the wider public, that any short-term disruptions would be cancelled out in a more long-run future, which would see the creation of entirely new products and unknown levels of welfare and leisure.[10] This section analyzes and compares the views of Aristotle, Jean-Baptiste Say, David Ricardo, Karl Marx, John Maynard Keynes, Walter Eucken, and Joseph Schumpeter, exploring their divergent perspectives on technological progress, its implications for the labor market, and the underlying conceptual framework that they employed to analyze the employment effects of technology on workers. While we do not consider all historical economists who have discussed this question, our selection captures a representative range of influential thinkers across varying historical contexts. This analysis aligns the long intellectual history of the relationship between technological change and employment with the broad, commonly vague concept of technological unemployment in the journal literature examined in Section III. In so doing, we identify themes that appear in earlier and later writing, recognizing that while only Keynes

[10] Mokyr, Vickers, and Ziebarth, "The History of Technological Anxiety and the Future of Economic Growth."

and Schumpeter explicitly use the term, the ideas and concerns of historical economic thinkers have continued to recur in the era of professional economics analyzed in Sections III and IV.

Aristotle and Ancient Concepts of Automation

Perhaps the first instance of a thinker considering what might now be referred to as technological unemployment is found in the reflections of Aristotle (384–322 BC). In the first book of his *Politics*, he suggests that if machines reached a high enough level of development, they could replace human workers: "if […] the shuttle would weave and the plectrum touch the lyre without a hand to guide them, chief workmen would not want servants, nor masters slaves".[11] His comment comes in the context of a discussion of the order of a household and after the justification of the natural order of enslavement. While this section is commonly cited,[12] Aristotle's view on intelligent devices and automation is often misinterpreted – perhaps because his vision of automatic weaving seemed to predict the fate of weavers during the Industrial Revolution. While he does not directly envision the creation of "intelligent" automated tools, his discussions suggest a vision of a society in which the need for manual labour, especially by slaves, is greatly reduced or eliminated.

There are various possible interpretations of Aristotle's hypothetical scenario. By imagining a world without the need for the labour of slaves and lower-class workers, Bhorat argues, Aristotle indirectly suggests a society in which more individuals could participate in the political process, that is, a potentially freer and more democratic regime.[13] However, his position could also be read more ambiguously: while automation might eliminate the need for slaves, it does not necessarily imply their emancipation or wider political inclusion. For example, there may be an implication of social disorganization if automation overthrows the

[11] Benjamin Jowett, trans., *The Politics of Aristotle Vol. I: Containing the Introduction and Translation* (Oxford: Clarendon Press, 1885), 6.

[12] E.g. Riccardo Campa, "Technological Growth and Unemployment: A Global Scenario Analysis," *Journal of Evolution and Technology* 24, no. 1 (2014): 86f.; Kyle Scott, "Unalienated Labor as Cooperative Self-determination: Aristotle and Marx," *European Journal of Philosophy*, June 11, 2024, 5, https://doi.org/10.1111/ejop.12972; Michael A. Peters, "Technological Unemployment: Educating for the Fourth Industrial Revolution," *Educational Philosophy and Theory* 49, no. 1 (January 2, 2017): 1–6, https://doi.org/10.1080/00131857.2016.1177412. In addition to academic articles, Aristotle's shuttle metaphor is also referenced in popular books on the digital age, such as: Jaron Lanier, *Who Owns the Future?*, Simon&Schuster trade paperback edition (New York: Simon & Schuster Paperback, 2014).

[13] Muhammed Z. Bhorat, "Aristotle on Automation – A Preindustrial Political Theory of Technology" (PhD dissertation, UCLA, 2022), https://escholarship.org/uc/item/7416q0c6.

household order, which was based on enslaved labor.[14] Aristotle's "theory of automation" was highly influential and transmitted through medieval and early Renaissance thinkers.[15]

The Compensation Theories of Say

One of the later modern thinkers who picked up this thread was Jean-Baptiste Say (1767–1832), a prominent economist and social philosopher who sought to make economic concepts accessible to the public. His practical experience in the cotton industry likely influenced his realistic view of machinery. In Chapter VII of his *Treatise on Political Economy* (1803), which was translated into several languages and revised in later editions, Say acknowledges the immediate disruption caused by machines that could displace human labor previously engaged in industrial activities.[16] He notes that the primary function of machines is to increase efficiency by reducing the amount of labor required to produce the same output, or by increasing the output from the same amount of labor.[17] Such an effect generates "painful circumstances", both for a capitalist, "when his funds are unprofitably engaged or in a state of inactivity", but more importantly for the "industrious population deprived of the means of subsistence."[18]

While this displacement of labor may cause temporary hardship for those directly affected ("transient evil"[19]), Say argues that the wider community benefits from the increased output and lower prices provided by machine production. He also sketches several mechanisms that remedy the problems caused by new technologies. First, he argues that the construction and adoption of technology is a slow process, which gives the government time to provide replacement employment through public works – "canals, roads, churches, or the like"[20]. Second, he points out that the design and implementation of new machinery itself

[14] Slaves are also depicted as finding a role in their economic position, without which they may be unable to manifest their human features. The ancient household economy and views of slaves' role therein are discussed by Dotan Leshem, "The Ancient Art of Economics," *The European Journal of the History of Economic Thought* 21, no. 2 (April 2014): 201–29, https://doi.org/10.1080/09672567.2012.683032.
[15] Bhorat, "Aristotle on Automation – A Preindustrial Political Theory of Technology."
[16] Jean Baptiste Say, *A Treatise On Political Economy*, trans. C.R. Prinsep, vol. 1 (London, 1821), 59–71.
[17] *Say, 1:61.*
[18] Say, 1:62–63.
[19] *Say, 1:64.*
[20] *Say, 1:64, footnote.*

creates jobs, as significant labor is required to build, install, and maintain these innovations. Third, he argues that the increased availability of cheaper goods benefits society as a whole, including workers. The second and third mechanisms both stimulate demand and create new employment opportunities in the same and other sectors. Despite the short-term hardship faced by displaced workers ("immediate effect"), Say argues that the long-term benefits of machinery (what he calls "ultimate effect") outweigh the initial challenges.[21]

In a later edition of his work, he asserts that contemporary critics of technological adoption, such as J.-C.-L. Simonde de Sismondi in his *Nouveaux principes d'économie politique* (1819), may have exaggerated the temporary harms and underestimated the permanent benefits of machinery.[22] While acknowledging the painful plight of displaced workers, Say rejects the idea of banning machinery, warning that such restrictions would hinder economic progress. He also incorporates a spatial dimension. Even if machinery is banned in one jurisdiction, it can still be adopted elsewhere and the concomitant lower prices "will run away with the consumption and demand", producing the same unemployment effect without a counterbalancing new demand for workers in the location that blocked new technology.[23]

Ricardo's About-Turn

David Ricardo (1772–1823) remains one of the most influential thinkers on the machinery problem, and as we discuss in Section III, is commonly invoked, along with Keynes, in recent discussions.[24] He remarked that an "enquiry respecting the influence of machinery on the interests of the different classes of society" was a "subject of great importance", but one which "appears never to have been investigated in a manner to lead to any certain or satisfactory results."[25] Ricardo is a particularly interesting case because, unlike

[21] *Say, 1:65.*
[22] *Say, 1:71, footnote.*
[23] Say, 1:64–65.
[24] Other writers who considered the machinery question in the 17th and 18th centuries included J. Cary, *Discourse Concerning the East-India-Trade* (London: E. Baldwin, 1699), https://books.google.de/books?id=xoqPwgEACAAJ; Henry Martin, *Considerations of the East-India Trade* (London: Black Swan, 1701); Charles Louis de Secondat de Montesquieu, *The Spirit of the Laws*, ed. Anne M. Cohler, Basia Carolyn Miller, and Harold Samuel Stone, Cambridge Texts in the History of Political Thought (Cambridge: Cambrigde Univ. Press, 1989).
[25] David Ricardo, *On the Principles of Political Economy and Taxation*, 3rd ed. (London: John Murray, 1821), 466.

the other thinkers examined here, he completely reversed his position on the "influence of machinery" within a few years. Initially, he was a liberal advocate of the belief that innovation was generally beneficial to society. The first edition of his seminal work *On the Principles of Political Economy and Taxation* (1817), which introduced the influential free-trade idea of comparative advantage, notes, in its first chapter "On Value", that the public is "benefited by machinery", as "[t]hrough their [the machines'] influence, an increase in the price of provisions which raises wages, will affect fewer persons."[26] In other words, by making commodities cheaper, machinery would not adversely affect the demand for labor, thereby benefiting all societal classes equally. In a later part of the book, Ricardo argues that opposing the introduction of new machinery is similar to the flawed rationale behind the ban on corn imports, because such opposition overlooks the fact that increased trade or new machinery, although briefly eliminating "a part of the existing capital of farmers and manufacturers", leads to increased production and, by extension, "general happiness" and "abundance".[27] Throughout the *Principles*, he uses the term "improved machinery", emphasizing its role in refining the relative values of commodities and underlining its integral function in optimizing economic efficiency.[28] Ricardo's public statements, including in Parliament, reflect this optimistic view on the machinery question. In 1819, for example, he claimed that "machinery did not lessen the demand for labour."[29]

Subsequently, however, Ricardo was persuaded that technological progress could actually depress wages for the working class and possibly lead to unemployment, at least for the duration of the period when circulating capital was diverted to building machinery. The cause of this shift is disputed. Based on the long friendship and extensive correspondence between Ricardo and Malthus, and certain textual similarities, Hollander posits that "the seeds of Ricardo's case may well have been sown (consciously or not) in the course of reading

[26] David Ricardo, *On the Principles of Political Economy and Taxation*, 1st ed. (London: John Murray, 1817), 40f.
[27] *Ricardo, 375.*
[28] Ricardo, 34–41.
[29] Samuel Hollander, "Retrospectives Ricardo on Machinery," *Journal of Economic Perspectives* 33, no. 2 (May 1, 2019): 230, https://doi.org/10.1257/jep.33.2.229. Hollander further argues that Ricardo's first edition was less clear-cut in its optimism on the machinery question, and that the third edition (discussed below) was not entirely pessimistic.

Malthus' *Principles*".[30] Acemoglu and Johnson suggest that Ricardo changed his thinking on the machinery question not because of new theoretical arguments, such as those put forward by John Barton in *Observations on the Circumstances Influencing the Condition of the Labouring Classes of Society* (1817), but rather because of his membership of Parliament's Select Committee on the Poor Laws, where he was able to witness first-hand the consequences of power looms in the cotton industry.[31] In their intellectual biography of Ricardo, Henderson and Davis summarize that "[t]he mass assemblies of working people in the postwar years, the protests of weavers against the power-loom, and the passage of the infamous Six Acts to halt impending 'revolution' may have inspired him [Ricardo] to take another look at Barton's arguments or other evidence regarding the process of industrialization".[32] Departing from Hollander, and Acemoglu and Johnson, they claim that Barton was arguably the only contemporary economist whose debate with Ricardo produced a genuine shift in the latter's fundamental positions. By April 1821, Ricardo privately acknowledged that Barton's insights had led him to reconsider and revise his views significantly for the forthcoming third edition. Where Malthus argued that machinery led to surplus production and insufficient demand, Ricardo clarified that his concern was rather that machinery could reduce workers' purchasing power, constraining effective demand in a fundamentally different way.[33]

Whatever the reason for this change of perspective, it led Ricardo to include an additional chapter entitled "On Machinery" in the third and final edition of his *Principles*, published in 1821.[34] First, he admits he had long allowed for some transitory difficulties, "that portion of inconvenience which in most cases attends the removal of capital and labour from one employment to another." Then, Ricardo acknowledges a critical oversight in his earlier argument: while the "net income" of a society might increase, the "gross income" – which

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[30] *Hollander, 239f.* In earlier work, Hollander argued that Ricardo's shift was probably not, as previously thought, mainly influenced by John Barton. Samuel Hollander, "The Development of Ricardo's Position on Machinery," *History of Political Economy* 3, no. 1 (March 1, 1971): 105–35, https://doi.org/10.1215/00182702-3-1-105.

[31] Daron Acemoglu and Simon Johnson, "Learning From Ricardo and Thompson: Machinery and Labor in the Early Industrial Revolution and in the Age of Artificial Intelligence," *Annual Review of Economics* (Annual Reviews, 2024), https://doi.org/10.1146/annurev-economics-091823-025129.

[32] John P. Henderson and John B. Davis, *The Life and Economics of David Ricardo*, ed. Warren J. Samuels and Gilbert B. Davis (Boston, MA: Springer US, 1997), 594, https://doi.org/10.1007/978-1-4615-6129-3.

[33] Henderson and Davis, 575–94.

[34] Ricardo, *On the Principles of Political Economy and Taxation*, 1821, 466–82.

supports the working class – might simultaneously decrease. In his "wage-fund"[35] theory, capital spent on machinery was taken out of the funds available to pay workers, so employment could be reduced because of increased investment in machinery. Therefore, he concludes that advances in machinery, while increasing a country's net income, might simultaneously increase unemployment.[36]

Ricardo goes on to illustrate this point with a calculation exercise, showing that the introduction of machinery could lead to a reduction in gross output, which would adversely affect the working class by making the population redundant in relation to the available means of employment.[37] From this finding he draws several conclusions: first, that the use of machinery invariably increases the net product of a country without necessarily increasing its gross value; second, that this net increase can coexist with a gross decrease, thus validating the use of machinery when it increases the net product despite a potential reduction in value; and third, that the fears of the working class regarding machinery are thus not unfounded, but are consistent with the "principles of political economy". Moreover, he posits that only if machinery did not reduce gross output, all social classes would benefit from the resulting abundance and lower commodity prices, thereby improving overall welfare.[38]

Despite his nuanced analysis, which described the relationships between machinery, labor demand, and social welfare in much more detail than in the first edition of his *Principles*, Ricardo continued to argue against discouraging the use of machinery, stressing that capital would otherwise flow abroad, exacerbating the reduction in labor demand at home. He concluded that while the use of machinery could mitigate the growth of labor demand, the prohibition of its use would prove more damaging because of the competitive disadvantages in world trade.[39] This reasoning aligns closely with Say's earlier argument that discouraging technological advancement locally would simply lead capital and investment to relocate geographically, worsening domestic employment outcomes. As in the first edition, Ricardo also articulated this position in public comment before the House of Commons, and in private

[35] Mokyr, Vickers, and Ziebarth, "The History of Technological Anxiety and the Future of Economic Growth," 133.
[36] Ricardo, *On the Principles of Political Economy and Taxation*, 1821, 468f.
[37] *Ricardo, 472.*
[38] *Ricardo, 474f.*
[39] *Ricardo, 480f.*

letters, although this new stance did not lead him to oppose technological adoption in general.[40] While he still maintained that the "qualified" use of machinery was not harmful to labor *per se*, Ricardo's more skeptical view was extremely controversial among contemporaries, and some thought it provided justification for Luddite machine-breaking.[41]

In writing about improved machinery Ricardo did not anticipate fully autonomous agents ("machinery cannot be worked without the assistance of men"), as in today's debate about AI. His temporal analysis implies that employment may return to its previous level after the construction of the new machines, when capital employed in constructing machines could be released back to a circulating capital.[42] Still, echoing today's debate about technology, Ricardo (as Say had before him) recognizes the geopolitical competition between countries, which precludes any attempts to ban new machinery, as capitalists can simply move to another country to build their machinery. Ricardo's work is likely the most debated and re-analyzed writing on this topic and has been the subject of a number of later studies attempting to model his example and propositions.[43]

Marx and the Reserve Army

Karl Marx's (1818–1883) analysis of technological development within a capitalist framework posits that significant and persistent unemployment results primarily from the dynamics of technological innovation.[44] Central to Marx's influential critique of capitalism is

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[40] Hollander, "Retrospectives Ricardo on Machinery," 230–31; Miguel D. Ramirez, "Marx and Ricardo on Machinery: A Critical Note," *The European Journal of the History of Economic Thought* 26, no. 1 (January 2, 2019): 86, https://doi.org/10.1080/09672567.2018.1523208.

[41] Hollander, "Retrospectives Ricardo on Machinery," 236–37; Ramirez, "Marx and Ricardo on Machinery," 83.

[42] Berg, *The Machinery Question and the Making of Political Economy 1815-1848*, 66ff.

[43] See e.g. Takashi Uchiyama, "Ricardo on Machinery: A Dynamic Analysis," *The European Journal of the History of Economic Thought* 7, no. 2 (June 2000): 208–27, https://doi.org/10.1080/096725600361780; Haim Barkai, "Ricardo's Volte-Face on Machinery," *Journal of Political Economy* 94, no. 3, Part 1 (June 1986): 595–613, https://doi.org/10.1086/261391; Giuseppe Freni and Neri Salvadori, "Ricardo on Machinery: An Analysis of Ricardo's Examples," *The European Journal of the History of Economic Thought* 26, no. 3 (May 4, 2019): 537–53, https://doi.org/10.1080/09672567.2019.1622756. Paul A. Samuelson, "Mathematical Vindication of Ricardo on Machinery," *Journal of Political Economy* 96, no. 2 (1988): 274–82.

[44] D. Furth, A. Heertje, and R. J. Van Der Veen, "On Marx's Theory of Unemployment," *Oxford Economic Papers* 30, no. 2 (July 1978): 263–76, https://doi.org/10.1093/oxfordjournals.oep.a041412; Heinz D. Kurz, "Marx on Technological Change: The Ricardian Heritage," in *Marxian Economics: A*

his theory of the nature of technological change, which he believed would inevitably favor an increasing "organic composition of capital", a term he used to describe the ratio of capital invested in machinery and equipment to that invested in labor. This particular trajectory of technological progress, Marx argued, was naturally consistent with the capitalist mode of production but would eventually produce – and depend on – a so-called reserve army of labor.[45] Moreover, he asserted that as the organic composition of capital escalated, it would lead to a sustained decline in the general rate of profit, a phenomenon he saw as indicative of the inherently unstable nature of capitalism itself. Marx's focus on the direction of technological change is in line with his broader critique of capitalist society.

Much of Marx's examination of the interplay between machinery and labor under capitalism is found in Chapter XV of Volume I of *Capital*, which describes at length the systemic conditions that produce technological unemployment. In this chapter, Marx recognizes machinery as a central element in the capitalist endeavor to maximize surplus value – a notion encapsulated in his discussion of machinery as the "means of producing surplus value".[46] He details how machines, by consolidating various labor processes into a single automated operation, not only increased the efficiency of production but also fundamentally transformed the labor landscape. The example of the envelope machine, capable of performing several tasks previously performed by separate workers, illustrates this shift towards displacement of labor by mechanization.[47] Industrialization had necessitated, as Marx correctly saw, a profound transformation in the modes of production in both industry and agriculture, and required revolutionary changes in the means of communication and transport.[48] For him, the self-reinforcement of machines – machines making machines – emerged as a technical hallmark of this phase of industrial development.[49]

Reappraisal, ed. Riccardo Bellofiore (London: Palgrave Macmillan UK, 1998), 119–38, https://doi.org/10.1007/978-1-349-26121-5_9.

[45] Deepankar Basu, "The Reserve Army of Labor in the Postwar U. S. Economy," *Science & Society* 77, no. 2 (2013): 179–201.

[46] Karl Marx, *Capital: A Critique of Political Economy. Volume I: The Process of Capitalist Production* (Chicago: Charles H. Kerr and Company, 1867), 405.

[47] *Marx, 413.*

[48] *Marx, 419.*

[49] *Marx, 420.*

In this context, Marx argues that the introduction of machines, while raising the productivity of labor to unprecedented levels, did not clearly translate into a reduction in labor input. Instead, the use of machinery, as part of constant capital, does not in itself create new value, but transfers its value to the product, complicating the calculus of capitalist investment in technology.[50] The impact of machinery on labor is therefore manifold. For instance, Marx details how the introduction of machinery led to the employment of women and children, exploiting their labor under conditions of reduced physical demands but increased exploitation.[51] Moreover, machinery facilitated the lengthening of the working day, the intensification of labor, and the eventual reduction of the workforce as machines took over tasks previously performed by humans.[52]

For the debate about the relationship between new technology and employment, a critical aspect of Marx's analysis centers on the distinction between the productive potential of machines and their capitalist application. He argues that the misery inflicted on the working class by technological progress is not an inherent feature of technology, but a result of its capitalist mode of implementation, which prioritizes profit over human and social well-being.[53] Tellingly, the chapter's narrative extends to the struggle between workers and machinery, identifying a period of Luddite resistance in which workers initially targeted machinery as the source of their plight before recognizing the underlying capitalist dynamics at play.[54] In this way, Marx described labor-replacing machinery not as an accidental by-product but as a structural result of capitalism's reliance on machinery for capital's self-expansion.[55] The optimism of many of Marx's contemporaries, as well as today's liberal economists, about the eventual ability of machinery to compensate for displaced labor in the medium to long term is criticized by Marx, who questions the notion that machinery inherently creates employment opportunities in other sectors. Instead, he highlights the

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[50] *Marx, 422f.*

[51] *Marx, 431f.* See also: Jane Humphries, "The Lure of Aggregates and the Pitfalls of the Patriarchal Perspective: A Critique of the High Wage Economy Interpretation of the British Industrial Revolution," *The Economic History Review* 66, no. 3 (2013): 693–714, https://doi.org/doi:10.1111/j.1468-0289.2012.00663.x.

[52] Marx, *Capital: A Critique of Political Economy. Volume I: The Process of Capitalist Production*, 440, 447, 450, 455.

[53] *Marx, 461f.*

[54] *Marx, 468.*

[55] *Marx, 470.*

precarious conditions faced by displaced workers, who, stripped of opportunities to apply their specialized skills, are thrust into a saturated labor market and thus highly vulnerable.[56]

Overall, Marx's examination of machinery under capitalism emphasizes the systemic nature of worker displacement rooted in the capitalist exploitation of technological progress. A noteworthy aspect is that his writings implicitly assume that technologies are in some sense inherently political, because, as Winner observes in her important essay on "Do Artifacts Have Politics?", "the conditions that will eventually dissolve the capitalist division of labor and facilitate proletarian revolution" are, in Marx's view, "conditions latent in industrial technology itself".[57] With this emphasis on systematic and political aspects of technological innovation, Marx's analysis may have influenced the thinking of later economists about the interplay between capitalism, innovation, and the labor market, such as Joseph Alois Schumpeter and Emil Hans Lederer.[58]

Beyond his critique of capitalism, as Spencer emphasizes, Marx offers a positive vision for the use of technology.[59] He believed that in the transition from capitalism to communism, technology could be used to reduce the amount of time required to work, thereby increasing leisure time. This shift would allow individuals to engage in creative and fulfilling activities of their own choosing, transforming work into a non-alienating, self-realizing endeavor – a notion not entirely unlike Keynes's vision.

Keynes and Post-Work

Marx's skeptical view of technological progress under capitalism contrasts sharply with John Maynard Keynes's (1883–1946) widely cited optimistic essay, "Economic Possibilities for Our Grandchildren" (1930). Whereas Marx argued that technology under capitalism primarily serves the interests of profit-making, enslaving rather than liberating workers, Keynes envisioned that technological progress would eventually reduce the burden

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[56] *Marx, 481f.*

[57] Langdon Winner, "Do Artifacts Have Politics?," *Daedalus* 109, no. 1 (1980): 129f.

[58] Harald Hagemann, "Capitalist Development, Innovations, Business Cycles and Unemployment: Joseph Alois Schumpeter and Emil Hans Lederer," *Journal of Evolutionary Economics* 25, no. 1 (January 2015): 117–31, https://doi.org/10.1007/s00191-014-0358-4.

[59] David A. Spencer, "Fear and Hope in an Age of Mass Automation: Debating the Future of Work," *New Technology, Work and Employment* 33, no. 1 (March 2018): 3, https://doi.org/10.1111/ntwe.12105.

of work and create a leisure-oriented society within the capitalist framework itself.[60] Written during the most significant economic downturn of the 20th century,[61] Keynes's reflections offer both an analysis of contemporary economic challenges and a prophetic view of long-term possibilities. This well-known essay is worth examining for its broad perspective on the relationship between technological change and employment, which – as we show below – differs from how the terminology and discussions became narrower and more technical in the mid-20th century with the professionalization of economics. "Economic Possibilities" is also commonly cited as the first usage of the term "technological unemployment", although Sumner Slichter probably coined it earlier in the same year, first in an article for the *New Republic* and then in the title of a conference paper at the 1928 American Economic Association annual meeting.[62]

Keynes' essay was an "attempt to see what life would be like if peace, prosperity and techno-scientific developments were increasingly part of humanity's future"[63] – soon counteracted by the onset of the Great Depression and, later, World War II. With the benefit of hindsight, however, some of Keynes' predictions have been borne out by events, such as rising living standards, and others have either not been achieved, or only to a lesser extent

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[60] Spencer, 4.

[61] Keynes first discussed these ideas in 1928 in front of learned meetings, including at Winchester College and the Cambridge Political Economy Club. In the summer of 1930, he expanded his notes into a lecture that he gave in Madrid. Finally, the lecture was published in two instalments in the *Nation and Athenaeum* in mid-October 1930. As only one version appeared in print, it is not clear whether or how Keynes' ideas developed over this period, and if they were influenced by the Great Crash in the United States and the onset of the Depression.

[62] Slichter's paper was never printed, but is listed in the program: Anonymous, "Notes," *The American Economic Review* 18, no. 4 (1928): 816–28. His *New Republic* article may predate Keynes' first usage of the term, as it appeared in February 1928. Slichter began the article by noting substantial decreases in factory and railroad employment in data from the US Bureau of Labor Statistics, and argued that that "[t]he present unemployment appears to be due to two principal causes, one cyclical and the other technological". He went on to downplay the importance of the former, cyclical factors, stating that "we are confronted with what appears to be a new kind of unemployment problem—the problem of unemployment created by technical progress." While he noted that unemployment had been caused by technological change before, "its presence has been obscured by the violent cyclical fluctuations of the business cycle". Since business cycles were, in his view, under greater control than previously, "the problem of 'technological' unemployment will be with us permanently." He went on to consider methods to create employment via deflation of wages or prices, or loose credit conditions, but found all such methods unsatisfactory. Sumner Slichter, "The Price of Industrial Progress," *The New Republic* 53, no. 688 (February 8, 1928): 316–18.

[63] Luciano Floridi, "Technological Unemployment, Leisure Occupation, and the Human Project," *Philosophy & Technology* 27, no. 2 (June 2014): 143–50, https://doi.org/10.1007/s13347-014-0166-7.

than he predicted, such as consumer satiation and a shorter working week.[64] Keynes identifies the root of the economic malaise of his time not as a symptom of an ageing economy, but as the growing pains associated with rapid technological advances and the consequent adjustments required between different economic epochs. He attributes the prevailing distress to an imbalance in which the rate of technological progress, which economizes on the use of labor, outstrips the creation of new employment opportunities – a condition he calls "technological unemployment".[65] Importantly, and in contrast to Marx, Keynes takes an optimistic view of the long run, describing technological unemployment as "a temporary phase of maladjustment". Rapid technological advance, even with dislocating consequences in the short- or medium-term, is evidence for Keynes "that mankind is solving its economic problem".[66] He thereby suggests that the immediate adversities are a transitional phase rather than a permanent structural flaw. This perspective is based on his distinction between absolute and relative needs: he posits that the satisfaction of absolute human needs, aided by technological advances, could lead to a reorientation of effort towards non-economic pursuits. In this future, humans would *choose to work less* because productivity has risen rapidly and our demand for goods and services has been satisfied. However, and presciently, he does concede that relative needs "may indeed be insatiable".[67]

It is noteworthy that Keynes's discussion goes beyond the economic implications of technological progress to consider the socio-psychological effects of a world in which technological progress has yielded sufficiently high labor productivity that humans only need to work little, perhaps 15 hours per week, to achieve a good standard of living. In particular, Keynes considers the profound adjustments that individuals and societies may have to make in response to these changes, including the potential for a "general 'nervous breakdown'" as traditional roles and activities become obsolete.[68]

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[64] Lorenzo Pecchi and Gustavo Piga, eds., *Revisiting Keynes: Economic Possibilities for Our Grandchildren* (The MIT Press, 2008), https://doi.org/10.7551/mitpress/9780262162494.001.0001; Nicholas Crafts, "The 15-Hour Week: Keynes's Prediction Revisited," *Economica* 89, no. 356 (October 2022): 815–29, https://doi.org/10.1111/ecca.12439.

[65] John Maynard Keynes, "Economic Possibilities for Our Grandchildren (1930)," in *Essays in Persuasion*, by John Maynard Keynes (London: Palgrave Macmillan UK, 2010), 325, https://doi.org/10.1007/978-1-349-59072-8_25.

[66] Keynes describes the "economic problem" as ensuring that everyone has a basic standard of living.

[67] Keynes, "Economic Possibilities for Our Grandchildren (1930)," 326.

[68] *Keynes, 327.*

The preoccupation with hectic life and nervousness was certainly prominent in the writings of intellectuals of the time, who increasingly observed – and expressed concern about – how the earlier philosophical notion of "labor power" was gradually being transformed, under the influence of the Industrial Revolution and thermodynamics, into a "human motor". This new conception treated labor as a system of muscles and nerves that could be measured, controlled, and integrated into planned, mechanized work processes.[69] Similarly, Keynes's reflection on the biological basis of economic behavior – describing the "economic problem" as historically the primary concern of both human beings and the wider biological kingdom – implies that a potential existential void could arise once the economic problem is supposedly solved.[70]

While technological unemployment may have been seen as an immediate problem in Keynes's time, his high-productivity future a century hence (2030) is a "post-work" society. As noted above, in such a world, individuals may no longer seek employment to meet basic needs, but instead face the challenge of finding meaning and purpose in activities outside of work. His intuition about this broader existential purpose and the reconfiguration of absolute and relative needs in a post-work age resonates with recent research on the relationship between technological progress, meaningful work, and overall quality of life.[71] The difference between Keynes' description of the immediate situation in 1928–1930, which featured what he termed technological unemployment, and his prediction of a possible post-work future is a subject of frequent confusion by many of the authors who invoke his name in their discussions of technological unemployment, as we discuss further below.

Eucken: Technological Unemployment through the Lens of German Ordoliberalism

Walter Eucken (1891–1950), a central figure in German economics and a founding father of the so-called Freiburg School, shaped economic thought in post-war Germany and

[69] Jürgen Osterhammel, *Die Verwandlung der Welt: eine Geschichte des 19. Jahrhunderts*, 3rd ed., Historische Bibliothek der Gerda-Henkel-Stiftung (München: C.H. Beck, 2020), 930.
[70] Keynes, "Economic Possibilities for Our Grandchildren (1930)," 326f.
[71] Leandro Prados de la Escosura, *Human Development and the Path to Freedom: 1870 to the Present* (Cambridge, United Kingdom: Cambridge University Press, 2022); Andrea Veltman, *Meaningful Work* (Oxford University Press, 2016), https://doi.org/10.1093/acprof:oso/9780190618179.001.0001; Milena Nikolova and Femke Cnossen, "What Makes Work Meaningful and Why Economists Should Care about It," *Labour Economics* 65 (August 2020): 101847, https://doi.org/10.1016/j.labeco.2020.101847.

beyond.[72] In stark contrast to the writings of both Marx and Keynes, whom he criticized in his early research,[73] Eucken was an ardent proponent of a circumscribed set of policy principles that emphasized a strong legal framework and competitive markets, later known as ordoliberalism. Unlike Marx, who saw capitalism as a system doomed to collapse under its contradictions, Eucken argued for a social market economy regulated by a "strong state" to prevent monopolies and ensure social welfare.[74] In contrast to Keynes, who prescribed state intervention to manage demand and alleviate unemployment, Eucken believed in the power of competitive markets to address economic and societal challenges.[75] His insistence on the need for a legal and institutional framework to maintain a competitive order shaped the economic policies of post-war Germany and, later, the European Union.[76] Eucken's work thus provides an alternative to both Marxist and Keynesian concepts and offers a crucial historical perspective on the debate about the relationship between technology and employment in the German discourse at the time. This approach is illuminating, given that German economics is often seen – not least due to the alleged ordoliberal influences – as an "oddity".[77]

While the literature typically focuses on Eucken's two seminal monographs, his earlier work *Kapitaltheoretische Untersuchungen* provides a critical examination of the "machinery problem" (*Maschinenproblem*), that is, the economic implications of technological progress and unemployment. Although Eucken does not explicitly use the term "technological unemployment", he clearly recognizes structural unemployment resulting from changes in production methods. He illustrates this with historical examples, such as the displacement of hand weaving by mechanical looms in the nineteenth century and the contemporary

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[72] For his biography and impact, see: Wendula von Klinckowstroem, *Walter Eucken: ein Leben für Menschenwürde und Wettbewerb* (Tübingen: Mohr Siebeck, 2023).

[73] See his early writings collected in: Walter Eucken, *Freiheit, Staat und Sozialismus*, ed. Viktor Vanberg, Daniel Nientiedt, and Uwe Dathe, Gesammelte Schriften / Walter Eucken ; herausgegeben von Viktor J. Vanberg, Daniel Nientiedt und Uwe Dathe, Band 2,3 (Tübingen: Mohr Siebeck, 2023), https://doi.org/10.1628/978-3-16-162024-9.

[74] Walter Eucken, "Staatliche Strukturwandlungen und die Krisis des Kapitalismus," *Weltwirtschaftliches Archiv* 36 (1932): 297–321.

[75] Walter Eucken, "Technik, Konzentration Und Ordnung Der Wirtschaft," *ORDO: Jahrbuch Für Die Ordnung von Wirtschaft Und Gesellschaft* 3 (1950): 3–17.

[76] Werner Abelshauser, *Deutsche Wirtschaftsgeschichte seit 1945*, 2nd ed. (München: Beck, 2011); Jan-Otmar Hesse, *Wirtschaft als Wissenschaft: die Volkswirtschaftslehre in der frühen Bundesrepublik*, Campus Forschung 947 (Frankfurt am Main: Campus, 2010).

[77] Thorsten Beck and Hans-Helmut Kotz, eds., *Ordoliberalism: A German Oddity?* (London: CEPR Press, 2017).

competition between railroads and automobiles.[78] Although these cases imply technological unemployment, Eucken avoids explicitly labeling them as such. As we explain below, his analysis remains rooted in broader economic theory rather than focusing directly on automation or innovation-driven job losses.

In his analysis, Eucken confronts the perennial debate between proponents of the so-called compensation theory – who argue that technological progress, while displacing workers in the short term, ultimately leads to greater employment opportunities through increased demand and new industries – and its critics, who emphasize the immediate and often prolonged hardship faced by displaced workers. Eucken begins by acknowledging the persistent division between these schools of thought and attributes the lack of consensus to several factors. First, he points to the inherent difficulties of the problem, which exceed the analytical capabilities of many scholars (though apparently not his own). Second, he emphasizes its relevance in the socio-political sphere and the multidimensional consequences – economic, psychological, and political – of introducing machinery. Finally, he notes the intermittent attention the issue received from leading economists, especially during the Industrial Revolution, characterized by workers' resistance to mechanization.[79]

To contribute to this debate, Eucken advocates for the "variation method", similar to ceteris paribus or natural experiments in modern economics, to analyze the nuanced effects of technological innovation on economic systems.[80] Moreover, he criticizes contemporary literature for failing to distinguish between "technical knowledge" and "applied technology", and emphasizes the economic and historical importance of this distinction, particularly in understanding the origins of the Industrial Revolution.[81] Through a thought experiment with Robinson Crusoe, the hero of Defoe's fable[82] and also used, for instance, by Marx in *Das Kapital* and by Chicago School economist Frank Knight,[83] Eucken aims to illustrate the universal nature of the machine problem by showing how the invention of a more efficient loom

[78] Walter Eucken, *Kapitaltheoretische Untersuchungen* (Jena: Gustav Fischer, 1934), 37.
[79] Eucken, 161.
[80] *Eucken, 163.*
[81] *Eucken, 164.*
[82] Joshua Rahtz, *The Politics of Order: Ordo-Liberalism from the Inter-War Period through the Long 1970s*, PhD Dissertation, UCLA (Los Angeles: UCLA Electronic Theses and Dissertations, 2017), 69.
[83] David Cowan, *Frank H. Knight: Prophet of Freedom*, Great Thinkers in Economics Series (London: Palgrave Macmillan, 2016), 44.

disrupts and reconfigures the allocation of productive resources in different economic systems.[84] He criticizes classical economics for narrowly linking the machinery problem to Say's theorem – that supply creates its own demand – and argues that this oversimplifies the real dynamics at play, especially in economies characterized by monopolies, state intervention, and non-competitive market structures.[85] Here, Eucken highlights – in the tradition of Ricardo – the overlooked problem of capital theory: the source of capital for technological innovation and the expansion of compensating sectors. He points to the significant barriers to the reallocation of displaced labor, such as skill mismatches and mobility constraints, and the far-reaching influences of the existence of durable capital goods.[86]

In response to the contemporary fear of general overproduction and the arguments for rationalization, Eucken finds both perspectives lacking and suggests that the real problem lies in the impact of technological change on the average maturation period of investments and, consequently, on the labor market.[87] From this, he concludes that while technological progress may initially lead to wage reductions and layoffs, the overall condition of workers could improve in a free competitive market. However, this improvement depends on several factors, including the temporal dynamics of the supply of consumer goods to the labor force and the distribution of these benefits among workers, which may not necessarily favor those displaced by new technologies.[88] Overall, Eucken's analysis calls for a comprehensive, step-by-step understanding of adjustment processes in different market conditions, and is typical for theoretical explorations in German economics at the time.

Schumpeter: Cyclical Unemployment as Technological Unemployment

Finally, we turn to Joseph A. Schumpeter's (1883–1950) well-known concept of "creative destruction", as articulated in his seminal work *Capitalism, Socialism and Democracy*, as this offers a characteristically dynamic perspective on technological unemployment. Schumpeter's analysis differs from other economic theories by emphasizing the inherent,

[84] Eucken, *Kapitaltheoretische Untersuchungen*, 166f.
[85] *Eucken, 169f.*
[86] Eucken, 170–72.
[87] *Eucken, 173ff., 186.*
[88] Eucken, 186–88.

perpetual cycle of innovation that drives capitalist economies forward. While this cycle generates growth and improves living standards, it also involves significant disruptions, including periods of unemployment. Consequently, Schumpeter is often labelled a staunch liquidationist because of his bold statements in favor of minimal government intervention. While some scholars have pointed out that this is an oversimplified interpretation and that Schumpeter's stance on economic matters was actually far more complex, it is interesting to note that his academic perspective on this issue was not substantially altered by the Great Depression, unlike many others.[89]

Schumpeter first directly addresses the topic of technological unemployment in *Business Cycles* (1939). He begins with a pithy if imprecise conventional definition, namely "displacement of workmen by machinery", which he states was of long use.[90] He then insists that a broader framing is required:

> "We make it cover a much wider range and include not only the effects on employment of every kind of change in industry and commerce—organizational change, for instance—but also the effects which changes have on employment in firms of industries that are competed with by the firms of industries that have new production functions."[91]

He then provides several examples of workers replaced by technological change: coachmen replaced by automobiles, bookkeepers replaced by calculators, and cotton pickers replaced because other textile fibers claimed market share from cotton. In some cases, it may not be possible to ask workers whether they were substituted by technological improvements, but Schumpeter claims the effect is the same and all such results should be considered under the same heading. Perhaps controversially, Schumpeter goes on to claim that "cyclical unemployment *is* technological unemployment" because it is the business cycles and gales of creative destruction through technological change that generate unemployment. Because it is cyclical, "technological unemployment is ephemeral" at least for individuals, even if it is

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[89] Muriel Dal Pont Legrand and Harald Hagemann, "Business Cycles, Growth, and Economic Policy: Schumpeter and the Great Depression," *Journal of the History of Economic Thought* 39, no. 1 (March 2017): 19–33, https://doi.org/10.1017/S1053837216001048.

[90] As discussed above the first use of this term we have identified was in 1928, only 11 years before the publication of *Business Cycles*.

[91] Joseph A. Schumpeter, *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*, *Business Cycles : A Theoretical, Historical, and Statistical Analysis of the Capitalist Process* (New York: McGraw-Hill, 1939), 514.

constantly present in different parts of the economy. As to the general effects on workers, Schumpeter asserts that "the long run interest of the working class is in the effects of innovation on the total real wage bill and not in the incident variation of employment".

In a later section of *Business Cycles*, Schumpeter discusses the deleterious individual impacts of technological unemployment and the difficulties of its causal identification. First, he implies that technological unemployment can be created as a gross effect—consistent with his earlier comments: "during that period [1920–1929 in the United States] the system as a whole 'absorbed' much more than the technological unemployment it 'created'". He continues, describing the individual difficulty, "for many workmen what looks like statistically to be temporary loss of employment often is permanent, that reemployment is often secured after delay spelling much hardship, that even when secured the new job may be transitory, less skilled, or otherwise less desirable".[92] In a topic of continuing interest today, Schumpeter even goes so far to say that "[n]o unemployment ever can [be exclusively described as technological], except in the shortest of runs" but that technological change may nonetheless play a role in longer-term employment shifts associated with Kondratieff waves.[93]

Later, in *Capitalism, Socialism and Democracy*, Schumpeter argues that capitalist economies are inherently characterized by continuous innovation, leading to the creation of new commodities, methods of production, forms of organization, and markets. This follows on from his earlier articulation that technological shifts are continuously creating new unemployment, even if many workers may eventually find new work. These innovations not only create prosperity through increased spending but also lead to depression as they displace obsolete elements of the industrial structure. This process, according to Schumpeter, ultimately raises the standard of living for the masses, albeit through a series of economic upheavals.[94] On the question of unemployment, in this text, Schumpeter downplays its importance in the long-term assessment of capitalism. He argues that, unlike poverty, capitalist development cannot be expected to eradicate unemployment completely. But he also disputes the notion that unemployment rates tend to rise over time. Instead, Schumpeter emphasizes the transient and variable nature of unemployment and suggests that the real

[92] Schumpeter, 805–6, fn. 3.
[93] *Schumpeter, 806, 839.*
[94] Joseph A. Schumpeter, *Capitalism, Socialism and Democracy* (London: Routledge, 1943), 68.

challenge is not unemployment itself but the difficulty of providing adequate provision for the unemployed without impeding economic progress.[95]

At the heart of Schumpeter's thesis, as in *Business Cycles*, is the process of creative destruction, which he defines as the fundamental mechanism by which capitalism continually generates economic change. This process involves introducing innovative products, production methods, and organizational structures that revolutionize the economic landscape, simultaneously creating new opportunities and rendering existing paradigms obsolete. Schumpeter argues that this constant overhaul is not merely a response to external social or natural changes, but the essence of the capitalist enterprise itself,[96] mirroring Marx's claims about the essence of capitalism. Remarkably, just like Keynes, he uses biological metaphors to describe economic adjustments – in his case, however, to underline the organic and evolutionary nature of capitalism.[97] Finally, Schumpeter advocates a long-term perspective on economic processes, warning of the limitations of short-term evaluations or isolated case studies.[98]

To conceptualize Schumpeter's predictions regarding the impact of technological progress on labor markets, economists have developed a basic model of frictional unemployment to illustrate how the creative destruction aspect of technology can adversely affect employment.[99] It can be shown that over time, rapid technological progress leads to faster job turnover, which reduces stable employment levels. However, the model also identifies positive and significant short-term employment effects of technological innovation. As the author notes, this provides a theoretical bridge between the "Schumpeterian" perspective on technological change in labor markets and historical observations, such as the rise in unemployment rates in most OECD countries following the productivity slowdown of the 1970s.

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[95] *Schumpeter, 69f.*
[96] *Schumpeter, 82f.*
[97] He likens change within capitalism to biological mutation, a constant cycle of birth and death within the economic structure that is crucial to its vitality and progress. *Schumpeter, 83.*
[98] *Schumpeter, 83.*
[99] Fabien Postel-Vinay, "The Dynamics of Technological Unemployment," *International Economic Review* 43, no. 3 (2002): 737–60.

Synthesis

These seven classical thinkers – Aristotle, Say, Ricardo, Marx, Keynes, Eucken, and Schumpeter – present a diverse set of definitions, prognoses, and key concepts regarding the interplay between technological progress and labor markets (Table 2). While each theorist acknowledges that technological innovation may disrupt employment, their views on the consequences of and solutions for this phenomenon vary considerably, reflecting their broader economic ideologies and the historical contexts in which they wrote. Understanding these nuanced differences matters because their names and explicit arguments are invoked in current debates, sometimes incorrectly, and thereby continue to shape modern economic research and policy. Moreover, their *implicit* assumptions frequently underpin contemporary debates, influencing perceptions, biases, and ultimately the policy trajectories we adopt when confronting technological disruption.

Table 2: Technology-Employment Relationship and Concepts of Key Thinkers

Theorist	**Conception of Technology-Employment Relationship**	**Outlook on Technology-Employment Relationship**	**Key Concepts**
Aristotle	Technology may substitute for human work with artificial tools capable of acting themselves to complete a task	Ambiguous: could be optimistic as technological development enables emancipation, or pessimistic as it upsets the social order	Automation, servants as instruments
Say	Disemployment as a result of technological progress that substitutes machines for human labor, temporarily displacing workers	Mixed: short-term negative impact on workers, but long-term benefits to society through larger output and new employment opportunities	Labor and machines as complex tools; immediate versus ultimate effects; compensation
Ricardo	"Wage-fund" theory in which capital spent on building machinery is taken out of the funds available to pay for workers	At first optimistic about the effects of machinery; later changes to express concern over technology affecting not only wages but also employment for the working class	Malthusian ideas, permanent unemployment, wage-fund
Marx	Disemployment from technological change as a structural result of capital's reliance on machinery for self-expansion	Critical, emphasizing the negative (economic and social) impacts on workers	Surplus value, alienation, reserve army
Keynes	One of the earliest users of the term TU, presents it as a "temporary […] maladjustment", but suggests a long-term future of post-work prosperity	Short-run: concern over immediate disruption; Long-run: mixed; optimistic about technology freeing humans from poverty, but unknown socio-psychological effects, possible post-work ennui	TU as transitional; absolute versus relative needs; post-work world

Eucken	Technological-employment relationship as a complex phenomenon, dependent on interlinked choices of technology and policy	Analytical, emphasizes optimal technology selection and real-world barriers to reallocation of displaced workers (e.g. monopoly)	Variation method, technical knowledge vs applied technology
Schumpeter	TU as integral part of "creative destruction", driving evolution and long-term progress, cyclical unemployment as TU because technological change drives business cycles, as ephemeral for individuals but as constantly present in the economy	Accepting of disruption as necessary for progress, but notes potentially severe individual consequences for workers	Creative destruction, organic/evolutionary nature of capitalism; cyclical unemployment as TU

Aristotle's economic framework is based on the household economy of a slave society, with labor-replacing technology either a liberating or socially disruptive force. Ricardo initially held an optimistic view of machinery, believing that technological progress would generally benefit society; however, he later revised his perspective, expressing concern that investment in machinery financed from the wage fund might negatively affect workers' wages and job security, potentially leading to persistent unemployment. Marx sees unemployment following technological change as an inherent feature of capitalist economies, where machinery is used primarily to increase surplus value, often at the expense of the working class. Keynes, on the other hand, regards technological unemployment as a temporary maladjustment in the transition to a new economic era in which humanity's "economic problem" – providing for basic needs – will eventually be solved. Say offers a similar but more nuanced temporal differentiation that remains relevant today, acknowledging the short-term disruption caused by machines displacing workers, but emphasizing the long-term benefits of increased productivity, lower costs, and new employment opportunities. Eucken introduces a capital-based view that distinguishes between "technical knowledge" and "applied technology", and emphasizes the complex dynamics of technological change, including real-world barriers to reallocation of labor and the impact of different economic systems. Finally, Schumpeter conceptualizes the phenomenon as an ongoing part of the process of "creative destruction", a fundamental and perpetual cycle within capitalism that drives innovation. While Marx focuses on the exploitative aspects of technological progress within capitalism, (initially) Ricardo, Keynes, Eucken, and Schumpeter offer more optimistic perspectives on its potential benefits.

III. Technological Unemployment in Economics Research

Ricardo, Keynes, Marx, and Schumpeter are still often cited in discussions of technological unemployment and the coming waves of automation. Since the mid-20th century, however, economics as an academic discipline has undergone a significant professionalization. This development has shifted the focus from the classical, qualitative approaches of early economic thought to more sophisticated, often mathematical, methods of analysis. This professionalization has been accompanied by a narrowing of the conceptual approach, as the field increasingly prioritizes specific analytical or applied frameworks over broader theoretical exploration.[100] As we show, despite the increasing professionalization of economics as a discipline, technological unemployment has yet to receive a consistent and rigorous definition. This conceptual ambiguity persists even as economists employ increasingly precise analytical tools and debates continue about the relationship between technological change and employment.

To capture evolving views in academic economics, we searched for uses of the term "technological unemployment" in the full text of twelve leading economics journals since their inception—the "top five" (the *American Economic Review*, the *Journal of Political Economy*, the *Quarterly Journal of Economics*, the *Review of Economic Studies*, and *Econometrica*), plus five highly-ranked general interest journals (the *Economic Journal*, the *Review of Economics and Statistics*, the *Annual Review of Economics*, the *Journal of Economic Perspectives*, and the *Journal of Economic Surveys*) as well as two relevant and highly-ranked field journals (*Labour Economics* and *Economics of Innovation and New Technology*).[101] We selected these journals because they have been influential indicators of the frontier of research on economics and have a long time coverage (since 1891 in the case of the *Economic Journal*) that matches several waves of

[100] Roger E. Backhouse and Béatrice Cherrier, "The Age of the Applied Economist," *History of Political Economy* 49, no. Supplement (2017): 1–33; Angela Ambrosino et al., "What Topic Modeling Could Reveal about the Evolution of Economics," *Journal of Economic Methodology* 25, no. 4 (October 2, 2018): 329–48.

[101] We also searched the *Journal of Labor Economics* and the *Journal of Economic Literature*, but did not find any relevant articles in these publications. *Industry & Innovation* and *Work, Employment, and Society* are indexed with economics in Journal Citation Reports, but we excluded them because the articles with our search term were not authored by economists. We analyze journals rather than books as this approach allows us to construct a more consistent text corpus. While books were more influential in early 20th century economics than they have been since the 1950s, book databases are less consistent in structure than journal back catalogs.

technological anxiety found in previous historical studies. We also tested several related search terms in the *American Economic Review* (e.g. "labor displacement", "labor replacing") but found far fewer results and narrowed our terms accordingly.[102]

Our initial collection identified 153 articles from these 12 journals, excluding sources labeled as book reviews and front and back matter, and forthcoming papers for which there is no accepted version available.[103] We then hand-reviewed these articles and removed 20 that were not substantive, not original research, or where our term of interest only appeared in the title of a citation and not in the text (e.g. conference programs for the American Economic Association Annual Meeting, book reviews not labelled as such in journal databases), which left us with a final corpus of 133 articles (Appendix I).[104] Our first observation concerns the timing of publication of these articles (Figure 2): there was a spike, as we expect, in the 1930s with a long tail into the 1950s, and another small rise in the 1960s and 1970s, related to fears of automation and rising structural unemployment in high-income countries. A number of recent contributions (since 2010) have also featured the term. This corresponds well to the contemporaneous waves of technological anxiety discussed in the literature and to the ngram data of Figure 1. We do not observe any uses of the term before the 1930s, which fits with Woirol's discussion of the technology and employment debates by economists and our examination of key thinkers in Section II.[105]

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[102] See: "technological unemployment" – 120; "labor displacement" – 26; "labor replacing" or "labor replacement" – 5; "skill-biased technical change" or "skill-biased technological change" – 50; "routine-biased technical change" or "routine-biased technological change" – 6.

[103] For context, before screening, there were 120 results from the *American Economic Review* in Jstor for the search term "technological unemployment", 125 for "structural unemployment" and 100 for "cyclical unemployment". While the frequency of these terms varies with time, this comparison suggests that our term of interest has been a salient point of discussion in this leading outlet for economics research.

[104] We exclude book reviews for consistency as we also do not include books in this part of our analysis, and we only present the views of the authors of works. In the same vein, there are several discussant comments from early AEA meetings that we do include in the analysis. We only code our dimensions for the definitions used and views expressed by the discussants, and not their summaries of the papers.

[105] Woirol, *The Technological Unemployment and Structural Unemployment Debates*, 25–27.

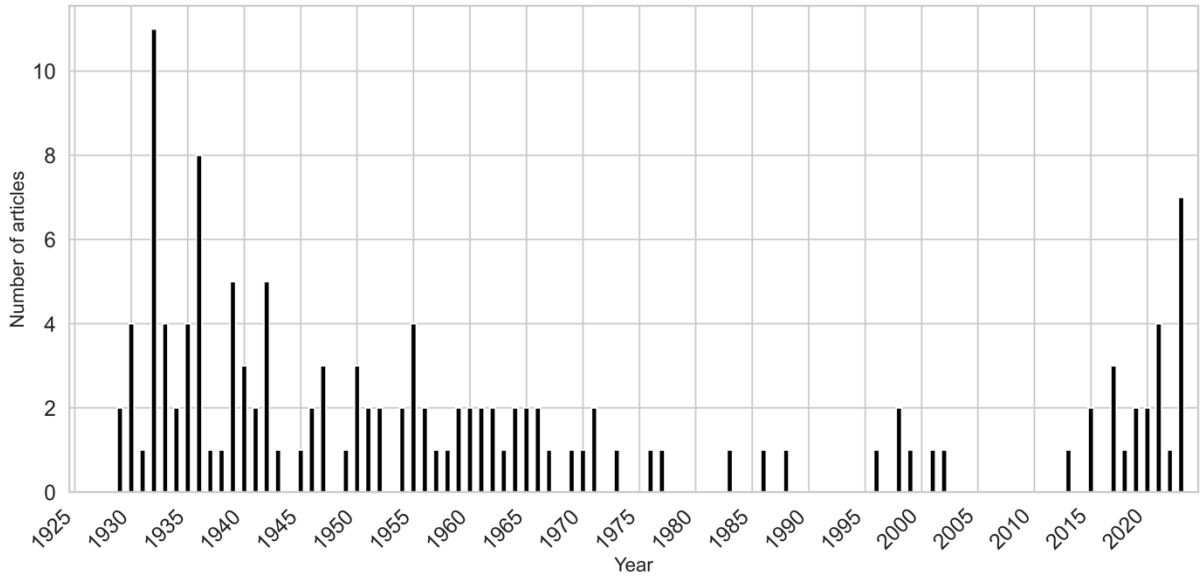

Figure 2: Temporal distribution of our "technological unemployment" journal corpus. Sources: see main text.

Before proceeding with our manual classification and close reading of the articles, we look for several key terms within the full text of the articles to better understand the thematic focus of the literature over time. The terms analyzed include "unemployment", "automation", "computer", "machinery", "displacement" and "robots" (Figure 3). First, the term "unemployment" has consistently appeared with the highest frequency, particularly in the 1930s and 1940s, coinciding with the economic hardships of the Great Depression and its aftermath. While its prominence declined in subsequent decades, notable spikes reappear in the 1990s and early 2020s, indicating renewed concern about labor market challenges. In contrast, the classic Ricardian term "machinery" shows an irregular pattern of occurrence, with notable peaks in the mid-20th century and the late 2010s. Meanwhile, "automation" gained significant attention in the 1960s and reappears prominently in the late 2010s and early 2020s, reflecting ongoing debates about, first, the introduction of early industrial automation techniques, and its ongoing impacts on workforce transformation. Similarly, "displacement" has experienced episodic spikes, particularly in the 1930s, 1960s, and in recent years, signaling recurring concerns about job losses due to technological advances. The term "computer" began to emerge in the 1960s with the advent of the digital revolution, but its frequency remained relatively modest compared to other terms until the 21st century. A spike in its use after 2020 suggests a growing interest in the intersection of computing and automation technologies. Likewise, the term "robots," which was virtually absent in earlier periods,

experiences a dramatic increase in usage after 2010, coinciding with the rapid development of AI. By 2020, references to robots dominate the discourse. The frequency analysis underlines that ideas and arguments related to technological unemployment have evolved over time, necessitating a close reading of the articles before proceeding with our more detailed quantitative analysis. The frequency analysis also sketches how the specific technologies that have generated concern about the effects of innovations on labor have developed across our near-century sample of articles.

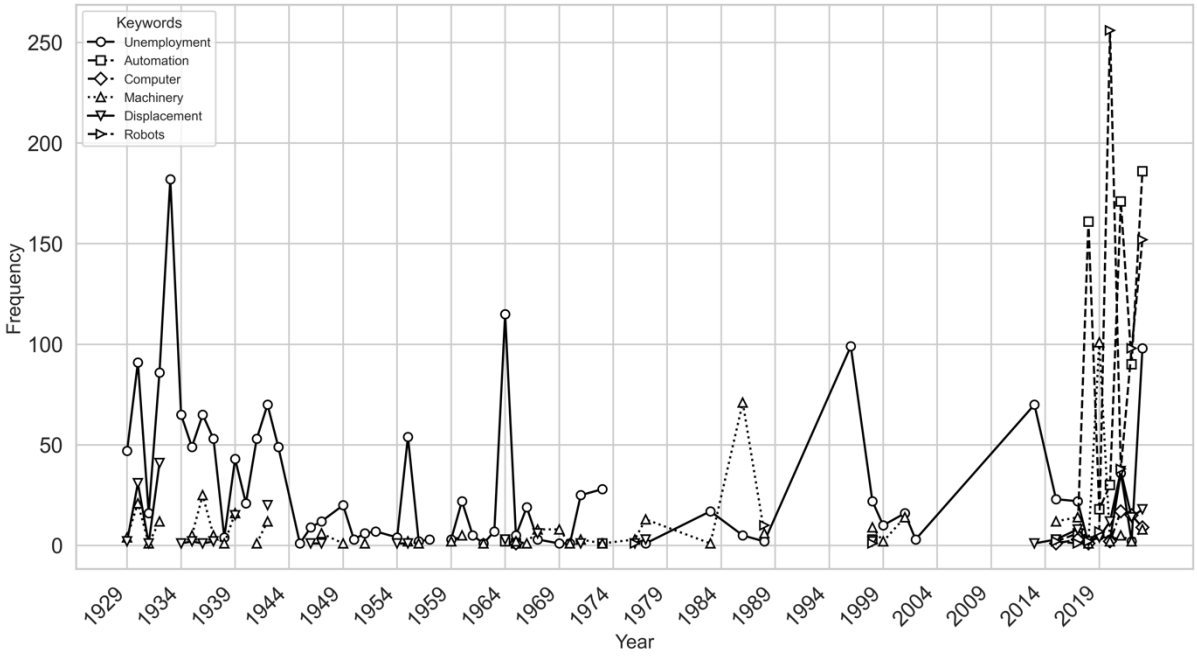

Figure 3: Absolute frequency of technology keywords in our "technological unemployment" journal corpus.

Close Reading: Conceptualization, Possibility, and Dimensions of Technological Unemployment

In the first stage of our close reading, we manually reviewed and categorized the articles by the main type of contribution (Theoretical, Empirical, and Survey/Review; see Appendix II.1 for criteria). A surprisingly large share (56 of 133 relevant articles) was mainly theoretical, and a similar number (57) were empirical contributions. The remaining 20 relevant articles were surveys or reviews of the literature. Consequently, we evaluated the use of our term of interest in these articles and categorized the articles in a tripartite system: "In Passing", or articles that only mentioned our term incidentally; "Brief Discussion", which contained some consideration of the concept and/or term; and "Main Topic", articles in which technological unemployment or technologically-caused structural unemployment was one of the core points. We identified 76 articles as "In Passing", 33 articles as "Brief Discussion", and 24

articles as "Main Topic". If the article provided a definition or conceptualization of "technological unemployment" this was recorded as written in the text. The conceptualizations and definitions are provided in Appendix II.1.

Our close reading confirms that economists have only defined or conceptualized technological unemployment briefly and vaguely. As shown in Appendix I, 85 articles (64% of relevant articles) provided no definition or conceptualization at all. Even in the early years of the term's use (the 1920s and 1930s), there was no debate in the journal literature we analyzed about the term itself, only about topics such as possible groups (e.g. older workers) who might be most susceptible to it. Most of the definitions that were provided were brief, and many were general: scale and duration were rarely mentioned. For the 48 articles that did provide a conceptualization or definition, these descriptions are almost invariably short, generally a few words or a phrase. A composite, short version might be synthesized as "the effects of technological change upon employment", although there is considerable variation, in part as authors who only discuss the topic in passing provide definitions that may be more suited to their main interest. This vagueness may raise concerns, as noted in the introduction, about empirical tests of hypotheses related to technological unemployment.

In turn, we hand-coded the texts on five other dimensions: whether the article suggested that technologically-induced job loss was possible in theory (Possible/Not Possible/No Indication); whether the author(s) suggested that it had occurred in practice (Did Occur/Did Not Occur/No Indication); and we noted any examples that the authors cited for the occurrence of technologically-caused job loss. We also categorized the temporal (Impermanent, Permanent, No Indication) and scale (Aggregate, Sectoral/Occupational, Individual, No Indication) dimensions of technological unemployment discussed in the articles. The full listing of articles and criteria for categorization is provided again in Appendix II.1.

Surprisingly in light of the long debate over this topic, we find that a large majority of the articles (97 of the 133 relevant articles) state or imply that technological unemployment is theoretically possible. Only four articles state that technological unemployment is not possible, while 32 make no indication. One might expect that scholars disputing its possibility would have been at least as likely to discuss the term, and therefore to appear in our results, as those positing it as a genuine phenomenon.

However, the empirical evidence is scarce: 36 articles state or imply that technological unemployment has occurred, and of these, 26 provide examples. The examples themselves vary widely, from national-level historical examples to specific occupations that were familiar or contemporaneous for the writers, such as midwives and obstetricians because of the rise of birth control in the second part of the 20th century, and performing artists in the early 20th century United States. The most commonly mentioned example, ahead even of the early Industrial Revolution in Britain, is the United States in the 1920s or 1930s, which was a contemporaneous example in many, but not all, cases.

Given the extensive recent public debates over the risk of permanent technological unemployment,[106] it is perhaps surprising that only three articles discuss technological unemployment exclusively as a permanent phenomenon; a further five articles discuss it alongside impermanent technological unemployment. Many more articles (30) only discuss technological unemployment as an impermanent shift, in which workers may be re-employed. A further 95 articles make no indication of the expected or possible duration of technological unemployment.

The scale of analysis is a further salient consideration, and one that is particularly relevant for identifying technological unemployment in empirical research. Again, a majority of articles (67 of 133 relevant articles) make no indication of the scale. Of the remainder, 35 discuss or imply technological unemployment as an aggregate phenomenon, 31 as a sectoral or occupational development, and 10 articles state that individual workers may be technologically unemployed. Note that in this categorization, multiple codes were possible (authors could refer to technological unemployment as an aggregate problem and an occupational or sectoral concern).

As the density of discussion in our sample varies greatly over time, we do not examine categorization of subsamples by period, except to note that the most detailed discussions of

[106] Inter alia: David Rotman, "People Are Worried That AI Will Take Everyone's Jobs. We've Been Here before.," *MIT Technology Review*, January 27, 2024, https://www.technologyreview.com/2024/01/27/1087041/technological-unemployment-elon-musk-jobs-ai/; Brian Merchant, *Blood in the Machine: The Origins of the Rebellion against Big Tech*, First edition (New York: Little, Brown and Company, 2023); Robert Skidelsky, *The Machine Age: An Idea, a History, a Warning* (Milton Keynes: Allen Lane, 2023); Mokyr, Vickers, and Ziebarth, "The History of Technological Anxiety and the Future of Economic Growth."

technological unemployment occurred in the 1930s and 1940s, fitting the heightened interest of the period.

Perhaps the most important complication of our findings from this element of the study is that because economists have only briefly defined technological unemployment, then the apparent consensus regarding its possibility—at least among those writers who mention the term directly—may be based on a mutual misunderstanding. If scholars have not agreed on a detailed definition, then there is scope for *prima facie* agreement but more fine-grained substantive differences.

Close Reading: Factors, Impacts, and Solutions

While our focus is on the conceptual aspects of the debate, as in our discussion of the classic thinkers above, we briefly survey perspectives of academic economists regarding (1) the factors that may lead to technological unemployment, (2) their views on groups which might be most seriously affected, and (3) potential remedies. For example, there may be substantial differences of opinion in the role and parameters of different factors related to the first point, which were succinctly outlined by Hans Staehle in 1940. He outlined four relevant attributes of an invention or sector:

> (i) the rate at which labor requirements are reduced by the labor-saving device; (2) the rate at which the reduction in labor requirements expresses itself in lower production costs; (3) the rate at which the lower costs of production entail lower prices; and (4) the rate of response of demand to price reductions.[107]

In turn, Staehle also discussed attributes of the contemporary economy which could shape technological adoption, wage flexibility, and the mobility of workers. Alvin Hansen, in an earlier contribution, argued forcefully that sufficiently flexible wages would make technological unemployment impossible, and that "[t]echnological unemployment is thus seen to be the result of the time lag required to adjust the earnings of the factors to the changes in productivity."[108] During the same heated 1930s debates, Harry Jerome proposed a different set of factors to predict how production would be rationalized following technological shifts:

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[107] H. Staehle, "Employment in Relation to Technical Progress" *Review of Economics and Statistics* 22 (1940): 94. A number of others also highlighted the key role of the price elasticity of demand following technological change in determining its effects on employment. C. Emery Troxel, "Economic Influences of Obsolescence," *The American Economic Review* 26, no. 2 (1936): 289.

[108] Alvin H. Hansen, "The Theory of Technological Progress and the Dislocation of Employment," *The American Economic Review* 22, no. 1 (1932): 27.

one must project the technologies that would emerge, their effects on productivity, how that productivity increase turns into labor displacement, and how much of the displacement becomes technological unemployment.[109] A number of thinkers pushed back against Keynes' claim that the limitation of human wants would lead to a world of leisure, contending that (as Keynes admitted was a possibility) ever-increasing wants would generate new employment.[110]

In debates about technological unemployment, older workers were commonly depicted as those most likely to suffer.[111] Echoing Schumpeter, Norman James Simler pointed out that the individual effects of technological displacement are much more severe than cyclical or seasonal job loss. While a cyclically unemployed worker can find a new position without retraining, "the technologically displaced worker must seek a new position. He is likely to be unemployed for an extended period of time and may often be forced to take a job at substantially lower pay."[112]

While Jean-Baptiste Say advocated for public works as one solution to labor displacement caused by technological change, Sumner Slichter proposed a dismissal wage—a fee that firms would have to pay when releasing a worker replaced by new technology.[113] Other economists in the 1930s similarly pointed out that without some kind of recompense for dismissed workers, firms would not take account of the social cost of adopting technology.[114] On the other hand, Hansen claimed that if business cycles were eliminated through stabilizing monetary policies or public works, technological unemployment would become a more serious problem as booms provide the new jobs for technologically displaced workers.[115] While not a recommended solution, so-called featherbedding was also noted as

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[109] Harry Jerome, "The Measurement of Productivity Changes and the Displacement of Labor," *The American Economic Review* 22, no. 1 (1932): 33.
[110] T. E. Gregory, "Rationalisation and Technological Unemployment," *The Economic Journal* 40, no. 160 (1930): 554, 563, https://doi.org/10.2307/2224241.
[111] Sumner H. Slichter, "Lines of Action, Adaptation, and Control," *The American Economic Review* 22, no. 1 (1932): 43.
[112] N. J. Simler, "Long-Term Unemployment, the Structural Hypothesis, and Public Policy," *The American Economic Review* 54, no. 6 (1964): 998n9.
[113] Slichter, "Lines of Action, Adaptation, and Control," 46.
[114] Harold M. Groves and Elizabeth Brandeis, "Economic Bases of the Wisconsin Unemployment Reserves Act," *The American Economic Review* 24, no. 1 (1934): 42.Paul Studenski, "Toward a Theory of Business Taxation," *Journal of Political Economy* 48, no. 5 (1940): 631–632.
[115] Hansen, "The Theory of Technological Progress and the Dislocation of Employment," 30–31.

one ameliorative course, albeit one most commonly found in oligopolistic or monopolistic sectors.[116] The public works avenue also appeared in the early years of World War II, with rearmament in the United States presented as a route out of technological unemployment.[117]

Various of these topics have been examined by subsequent economics research, but perhaps less well integrated into theories and remedies for technological unemployment as interest in the topic has been less concerted since the 1940s. We will return to some approaches that may help to bridge the divides in research on this topic in the penultimate section.

Close Reading: Locations of Mentions

The final part of our close reading analysis concerns the placement of references to our term of interest. While reading through the corpus, we developed the hypothesis that in the last few decades, the term "technological unemployment" has typically appeared in the motivation and discussion sections of articles (we will empirically test and confirm this hypothesis below). In these articles, the empirical analysis is implied as speaking to the broader question of technological unemployment and its broad public and policy relevance noted in the Introduction, albeit without clarity about how the outcome indicators chosen might contribute to the debate, because the overall concept is not defined. In this way, the *invocation* of technological unemployment as a public, policy, or scholarly concern has begged the question of how to conceptualize or define the term in a way that enables a clear empirical analysis of its occurrence or prevalence. Regrettably, we also identified a number of cases in which this invocation was paired with a misunderstanding or misinterpretation of the classic literature discussed above in our Section II. While ascribing the origin of the term to Keynes is understandable given that Slichter's first contribution was not presented in scholarly journals but the *New Republic*, some writers have erroneously claimed that Keynes was *predicting* future developments rather than commenting upon problems of his own time. The discontinuous debate over technological unemployment and the lack of clarity in both

[116] Paul A. Weinstein, "The Featherbedding Problem," *The American Economic Review* 54, no. 3 (1964): 145–146. Featherbedding refers to labor union practices that artificially preserve or create jobs to counteract job losses caused by technological advancements, such as rules requiring employers to hire more workers than needed, retain redundant employees, or adopt workflows that slow productivity.
[117] Oskar Morgenstern, "Unemployment: Analysis of Factors," *The American Economic Review* 30, no. 5 (1941): 289.

empirical and conceptual literature may be related to similar issues in economics pedagogy, which we consider in the next section (IV).

Quantitative Analysis: Positions

Based on the previous qualitative analysis, we now turn to a corpus-linguistic analysis of the articles, which consists of four steps: using NLP, we begin by analyzing where our term of interest, "technological unemployment", appears in these articles (positional analysis) to examine some of the hypotheses described above. This is followed by a quantitative analysis of the role of the classical thinkers whom we introduced in section II above. Thirdly, we turn to adjectives, as our close reading revealed an important role for "modifiers" and changing contexts. Finally, we conduct a sentiment analysis based on a language model to investigate the tonality accompanying the academic discourse on technological unemployment.

To investigate how the term "technological unemployment" is deployed in academic articles – in particular, whether it appears predominantly at the beginning as a motivational element, as just discussed – we conducted a positional analysis of the term's occurrence in our corpus of academic texts. To refine our analysis, we divided the corpus into two temporal subsets: articles published before 1980 and those published in 1980 and after. This division was informed by our hypothesis that the incentive to introduce the term early in articles has increased in recent decades, possibly reflecting shifts in academic priorities or broader public debates. After identifying all sentences containing the phrase "technological unemployment", we recorded their positions relative to the total number of sentences in the article. The relative position was calculated by dividing the index of each sentence by the total number of sentences, resulting in a normalized value between 0 and 1, where 0 represents the beginning of the article and 1 represents the end. By aggregating these relative positions, we constructed a distribution that reflects where within the articles the term is most frequently mentioned (Figure 4). A higher concentration of occurrences near the beginning suggests that "technological unemployment" is primarily introduced as a foundational concept or to provide context, framing, or motivation. Alternatively, a more even distribution or peaks in other sections would indicate that it is discussed in analytical or concluding parts.

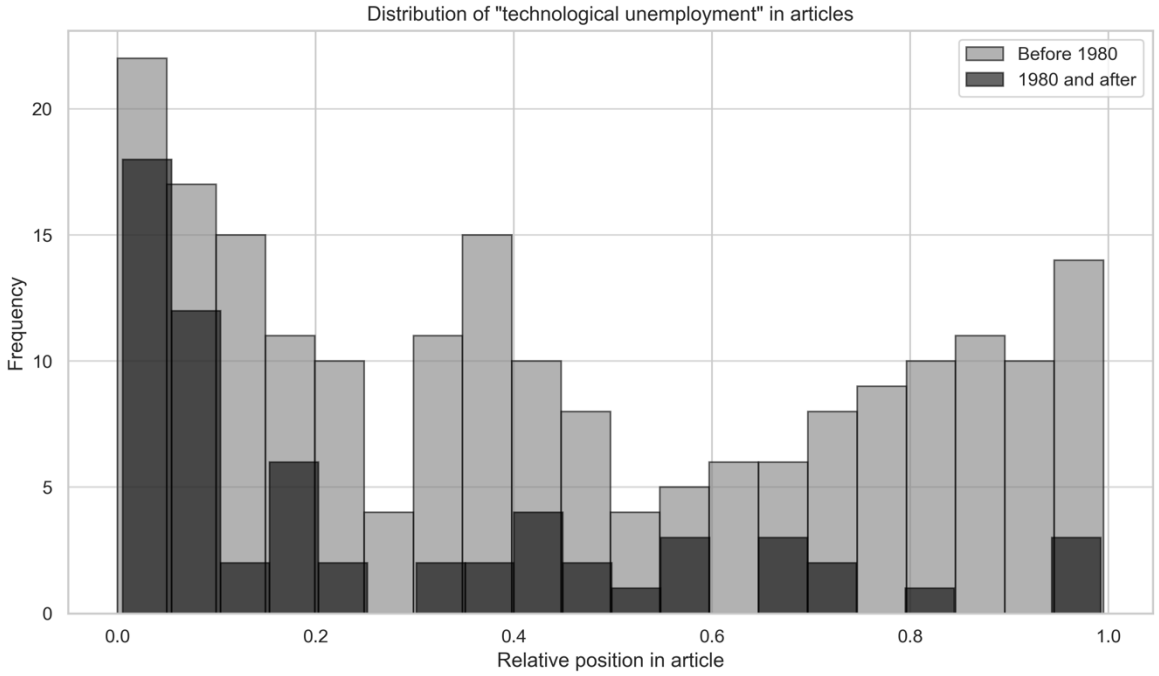

Figure 4: Positional distribution of references to "technological unemployment" in journal corpus.

The distribution plotted in Figure 4 indeed shows a concentration of occurrences early in article texts. For articles published before 1980, there is a pronounced peak at the very beginning of the articles (relative position 0.00-0.05), with 22 mentions, followed by a gradual decline. The peak at the beginning suggests that authors during this period often used "technological unemployment" to frame their research question or to emphasize the importance of the topic. However, the mentions are relatively dispersed throughout the rest of the article, with secondary peaks in the middle (0.35-0.45) and toward the end (0.95-1.00). While our term of interest was used as motivation, it also frequently received comment in the body of the article.

For articles published in 1980 and later, the trend diverges notably. While the initial peak remains strong (18 mentions in the 0.00-0.05 range), subsequent bins show a sharper decline, particularly in the 0.10-0.25 range, with mentions dropping to as few as two in some intervals. This pattern indicates a more concentrated effort to position "technological unemployment" as a framing concept early in recent papers.[118] Since the middle intervals

[118] Although the current style in economics is to mention results at the beginning of articles as well as framing or motivation, close reading of the articles ruled out this explanation for the placement of our term of interest.

(0.40-0.60) have far fewer mentions than the earlier period, recent authors may be less inclined to articulate a detailed conceptualization, investigate the theoretical possibility of technological unemployment, or articulate and implement empirical methodologies by which its occurrence may be analyzed. Towards the end of the articles, mentions increase slightly again, probably through discussions of policy implications or citations of the term in the reference section. Overall, the distribution highlights the dual role of "technological unemployment" in academic articles: It is often initially positioned as a foundational or framing concept, while occasional later occurrences reflect broader narrative or policy conclusions, suggesting that economists understand the salience of the term for the public and policymakers. As both a conceptual anchor and a lens through which to contextualize findings, the term deserves a thorough definition and more systematic exploration.

Quantitative Analysis: Classical Thinkers

Next, using case-insensitive matching with regular expressions, we systematically search for occurrences of classical thinkers such as Aristotle, Say, Ricardo, Marx, Keynes, Eucken, and Schumpeter, as well as important economic concepts such as Say's Law and "creative destruction". To capture the full range of references, we group synonymous and related terms under common categories – for example, mentions of "Marx", "reserve army" and "reserve army of labor" are grouped under the single heading of "Marx". The resulting temporal distribution, shown in Figure 5, shows that some figures have pronounced peaks in certain years, suggesting bursts of scholarly or social interest. Marx has notable peaks in the mid-20th century, coinciding with heightened discourse on socialism and economic inequality. Schumpeter's influence rises sharply in the late 20th century, likely driven by growing academic and policy interest in innovation-driven economic growth and the concept of "creative destruction". Ricardo experiences a pronounced surge in the 1980s, as a pair of articles (Barkai 1986 and Samuelson 1988) revived his work to discuss contemporary concerns about technological change. Interestingly, mentions of Keynes, a foundational figure in modern macroeconomics, remain at a moderate but sustained level throughout the time series, underscoring his enduring relevance, partly as the oft-claimed originator of our term of interest. In contrast, thinkers such as Aristotle and Eucken (whose primary works were published in German) show sporadic mentions with no clear temporal clustering.

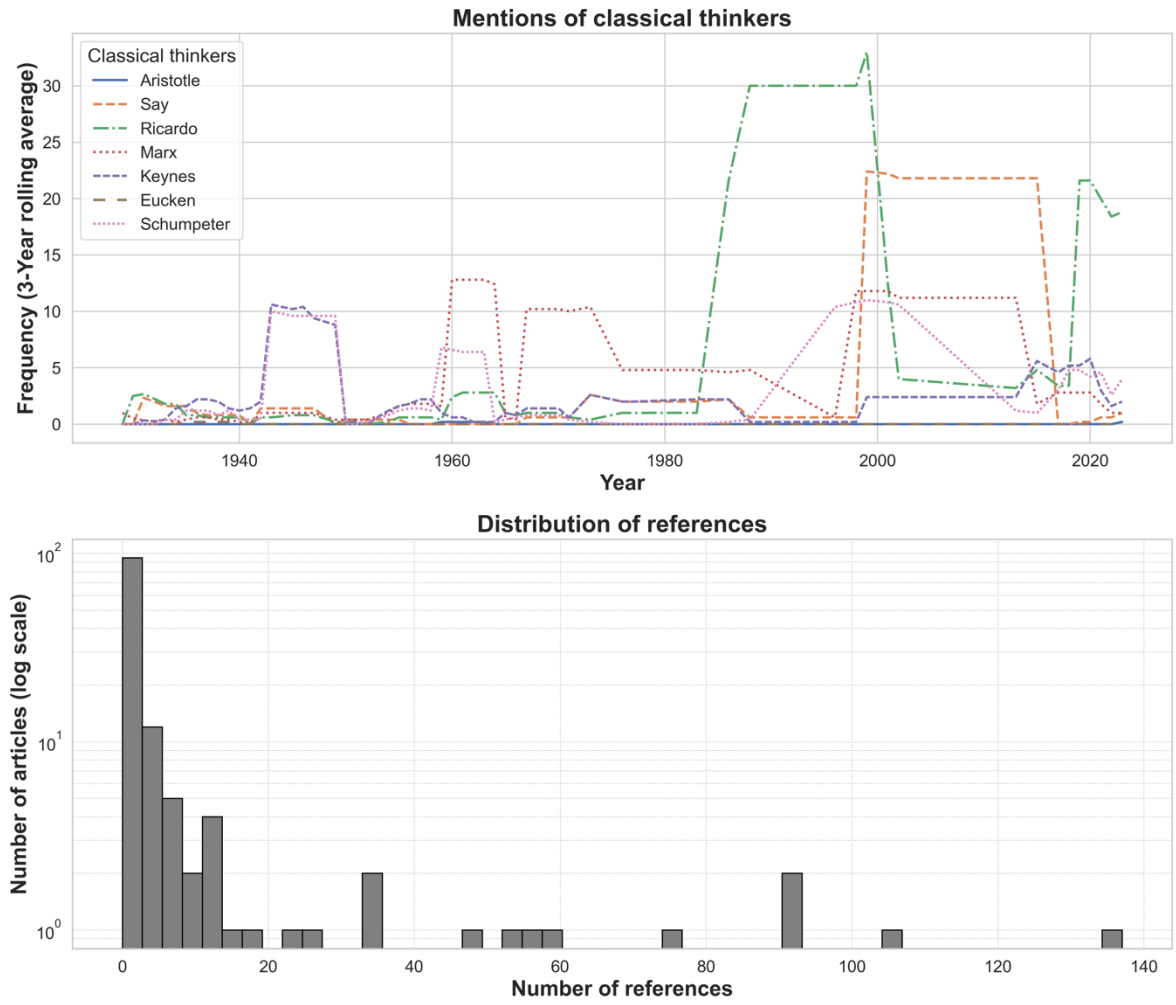

Figure 5: Frequency and positional distribution of references to classical thinkers in modern articles.

Moreover, Figure 5 underscores a declining trend in references to these classical thinkers after 2000. We posit that this trend may reflect a broader shift in economics towards contemporary issues and quantitative methods. This pattern is supported by the distribution of citations per article. While the mean number of references per article is 7.91, the median is only 1, indicating that references to these classical thinkers are often concentrated in a few scholarly works rather than being widely distributed. This finding is at least partly driven by the fact that our corpus includes three articles specifically on Ricardo (Barkai 1986, Samuelson 1988, and Hollander 2019). The histogram (bottom panel of Figure 5) confirms this with a skewed distribution: the majority of articles contain only a handful of references, while a small number of articles have a disproportionately high frequency of mentions, with a maximum of 137 references in a single work.

Quantitative Analysis: Modifiers

Our next quantitative analysis examines the use of key modifiers. Their changing frequency in our dataset reflects, we argue, broader shifts in economic theory, policy, and global events, underlining the shifting understanding and conceptualization of "technological unemployment" over time. To test our argument, we separate articles mentioning technological unemployment by decade and group relevant modifiers into categories, namely "temporal", "type", "characteristics", and "scale", to highlight trends and facilitate better visibility (Figure 6).[119] The specific counts for each modifier can be found in Appendix III. We find that the 1930s saw the highest frequency of "temporal" modifiers (137 occurrences), such as "cyclical", which was particularly prominent during this period (57 occurrences). This reflects the significant economic upheaval of the Great Depression. Similarly, "type" modifiers were relatively common in the 1930s (88 occurrences), indicating a focus on differentiating forms of unemployment. In contrast, the 1940s showed a slightly lower frequency in most categories, with a notable presence of "theoretical" modifiers in the 1940s (36 occurrences). The empirical debates of the 1930s had largely petered out and the question of whether technological unemployment had or could occur only continued in theoretical research, perhaps because scholars had largely exhausted the limits of contemporary data and methods.

[119] The modifiers are categorized as follows: (1) "Temporal" captures time-related aspects of unemployment and includes: temporary, permanent, seasonal, cyclical, mid-term, long-run, depressionary; (2) "Type" reflects the nature or theoretical framing of unemployment and includes: structural, systemic, chronic, theoretical, frictional; (3) "Characteristics" pertains to workforce-related attributes and includes: skilled, unskilled, low-skilled, high-skilled, male, female, urban, rural; (4) "Scale" addresses the level at which unemployment is analyzed and includes aggregate, sectoral, occupational, individual. These modifier categories are informed by the terminology used in labor economics to describe types of unemployment and our close reading of the text corpus in Sections II and III.

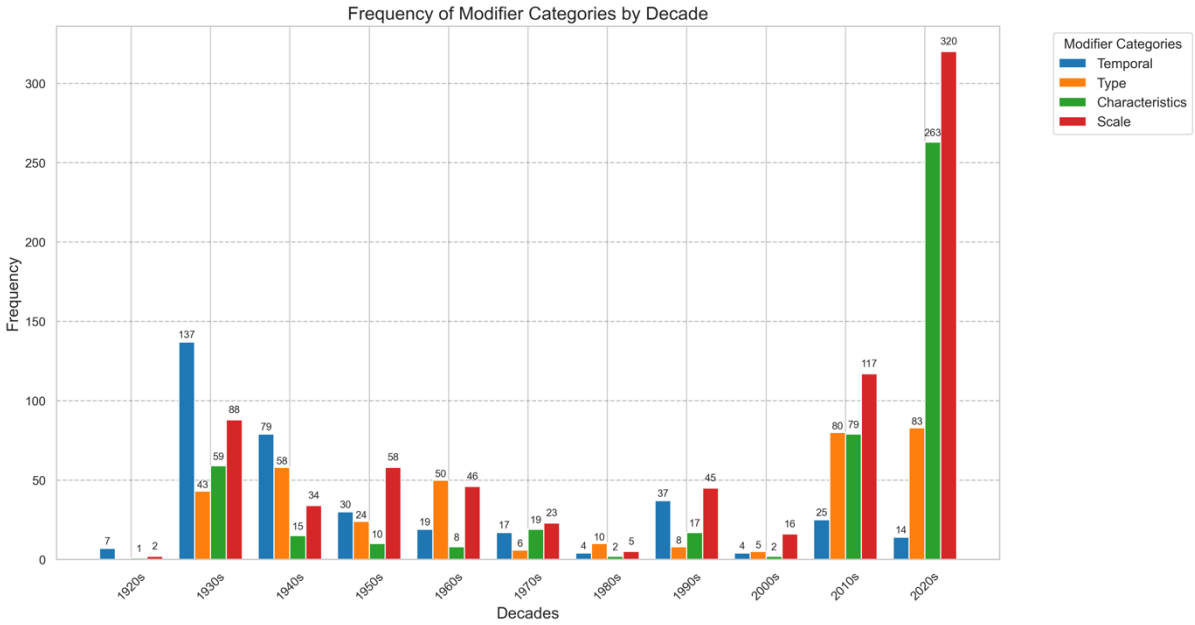

Figure 6: Frequency of modifier categories in articles by decade. Note: For definitions of the modifiers, see main text.

In the 1950s and 1960s, we observe a shift toward "scale" modifiers (e.g., 58 occurrences in the 1950s and 50 in the 1960s), indicating a growing interest in long-term structural economic patterns, such as "structural" unemployment. The "temporal" and "type" modifiers both saw significant declines during these decades, likely reflecting the relative economic stability of the postwar boom (with a brief resurgence of "temporal" modifiers in the 1990s). In the 2010s and 2020s, however, there is a clear shift toward "scale" and "characteristics" modifiers, with significant increases in these categories. For example, "skilled" appears 50 times in the 2010s and 203 times in the 2020s, while "aggregate" rises from 48 occurrences in the 2010s to 96 in the 2020s. This reflects a growing focus on workforce characteristics, the prominence of skill-biased technical change, and broader macroeconomic trends rather than short-term cycles. Interestingly, "systemic" remains largely absent (3 occurrences in the 2020s), highlighting a gap in the integration of systemic risk concepts, e.g. from the literature on macroprudential regulation, into the discourse on technological unemployment. Overall, the significant decline in the use of temporal modifiers in TU-related articles supports our argument that, over time, economists have used the expression in a more impressionistic way, without specifying a definition, potentially leading to ambiguity and reduced analytical clarity.

However, when we contrast this aggregate analysis of the overall corpus with the immediate linguistic context surrounding the phrase "technological unemployment", we find

a stark difference (Figure 7). Specifically, we focus on identifying and analyzing adjectives that directly modify the noun "unemployment" within sentences containing the phrase "technological unemployment". Our first step is to extract the sentences that contain the phrase "technological unemployment" from our dataset of economics journal articles, totaling 269 sentences. Within these filtered sentences, we apply an NLP method called dependency parsing via the *SpaCy* library in Python to identify adjectives that directly modify the noun "unemployment", excluding "technological", which is present in every sentence by default (details in Appendix II.3).

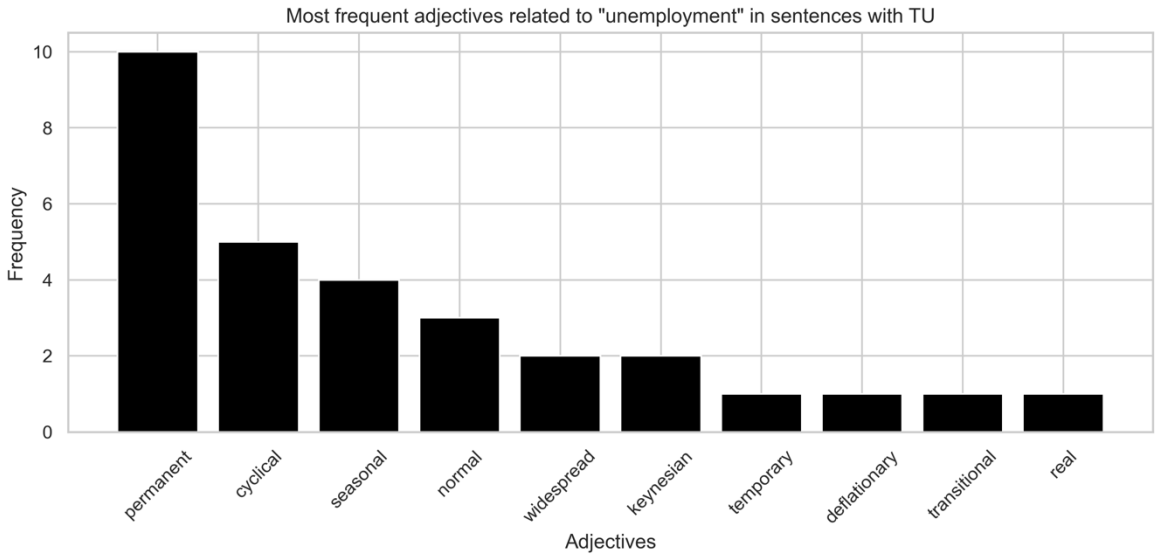

Figure 7: Frequently used adjectives in journal sentences about "technological unemployment".

The word "permanent" is again a significant term with the highest frequency. Other recurring terms include "cyclical", "seasonal", and "normal", albeit at lower frequencies. Several other descriptors, such as "widespread", "Keynesian", and "temporary", appear infrequently, with a frequency of only one or two instances. Our analysis thus shows that while economists often use a wide range of descriptors in their articles analyzing technological unemployment in general, the same modifiers are rarely applied directly to the term "technological unemployment". This lack of specific adjectives may lead to ambiguity and inconsistency in the literature, making it difficult to clearly distinguish between different conceptions of technological unemployment. In the final section, we therefore suggest that economists adopt a more precise and consistent use of modifiers when discussing technological unemployment in order to improve clarity and ensure a more accurate understanding of the phenomenon.

Quantitative Analysis: Sentiment

Our final quantitative analysis of the journal article corpus examines sentiment in all full sentences containing the phrase "technological unemployment" to examine the overall tone of the discourse over time. Using the RoBERTa sentiment analyzer, which is based on a large language model (LLM), we processed the sentences and classified them into categories of positive, neutral, or negative sentiment (ranging from +1 to -1).[120] Simplified pre-processing was used in this part of the analysis, as language models are very sensitive to missing words or characters, which could inadvertently alter sentiment detection.[121] To illustrate the method, the three-sentence window surrounding the sentence from 1932, "It [technological unemployment] is an element in industrial instability […] and in the waste involved in the dislocations of capital and labor", received a sentiment score of -0.68, reflecting a highly negative perspective on the economic consequences of technological unemployment. In contrast, a sentence from 1947, "Far from causing unemployment, larger, faster planes have created jobs for pilots […] and possibilities for further fare reductions", received a positive score of 0.63, emphasizing the potential for technology to create new job opportunities and spur growth. More recently, in 2023, a sentence expressed cautious optimism: "Identifying inclusive institutions and technological capabilities can mitigate technological unemployment", achieving a positive polarity score of 0.60. Further details of the measurement method can be found in Appendix II.4; the highest ranked negative and positive examples (single sentences and three-sentence windows) are given in Appendix IV.

Most sentences explicitly referring to the concept of "technological unemployment" were classified as neutral, consistent with our close reading of the literature, which shows that much of the discourse is descriptive or analytical in nature without expressing strong opinions. The use of technological unemployment as framing also contributes somewhat to

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[120] Francesco Barbieri et al., "TweetEval: Unified Benchmark and Comparative Evaluation for Tweet Classification," in *Findings of the Association for Computational Linguistics: EMNLP 2020* (Findings of the Association for Computational Linguistics: EMNLP 2020, Online: Association for Computational Linguistics, 2020), 1644–50, https://doi.org/10.18653/v1/2020.findings-emnlp.148.

[121] Care was taken to exclude sentences, or their surrounding contextual sentences, that were not genuine statements about technological unemployment. For example, we removed footnote acknowledgments, references to other articles that simply mentioned the phrase, or quotations that did not directly contribute to the discourse on the topic.

the number of neutral sentences. A total of 139 occurrences were neutral, while negative sentiments appeared 51 times, reflecting periods of heightened concern or pessimistic views about technological unemployment. Positive sentiments were rare (7), and closer inspection revealed that some of these instances were "false positives", as they did not reflect genuine optimism about the concept itself, but rather positive remarks about related topics, such as broader economic development following technological change. The sentiment scores for the three-sentence windows were similar: 142 were neutral, 53 were negative, and only 2 were positive. This consistency across contexts underscores the predominantly analytical tone of the discourse, punctuated by occasional negativity during times of economic stress or technological disruption.

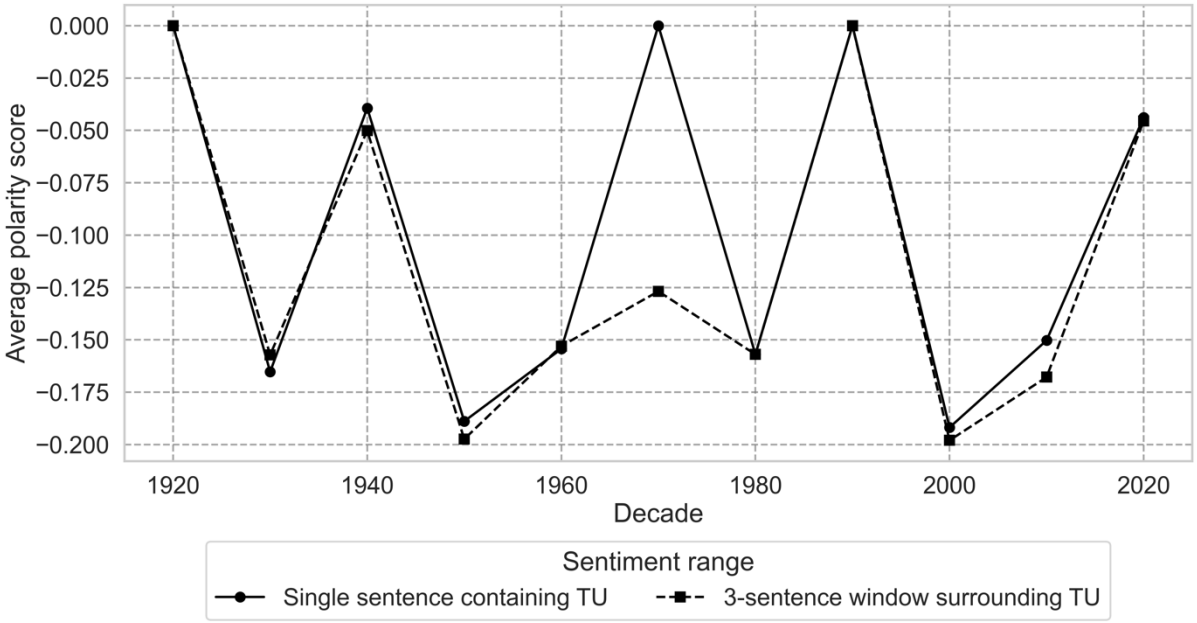

Figure 8: Sentiment scores for journal articles about "technological unemployment". Note: The sentiment scores are calculated via the roBERTa algorithm, for details see main text and the Appendix.

Sentiment scores for individual sentences containing the phrase "technological unemployment" reveal fluctuations in tone across decades, as shown in Figure 8. In the 1920s, the discourse was relatively neutral (polarity ~0), likely reflecting the limited number of articles during this time. In the 1930s (-0.165), however, sentiment shifted sharply into negative territory, correlating with the Great Depression and tied to the same debates during the Depression over whether unemployment was caused by technological change or a lack of demand. In the 1950s (-0.189), sentiment was again strongly negative, and the polarity improved only very slightly in the 1960s, which saw much debate about structural

unemployment. In contrast, the 1970s marked a period of relative optimism, driven by post-war economic growth and stabilization. Negative sentiment resurfaced in the 1980s (-0.157), coinciding with concerns about automation and industrial restructuring, and again in the 2000s (-0.192) and 2010s (-0.150), as the spread of digital technologies and automation raised new fears of labor market disruption.[122] In the 2020s, sentiment improved slightly (-0.044), possibly reflecting a more nuanced discourse or optimism about policy interventions. When analyzed in the context of surrounding sentences, i.e. the three-sentence windows, sentiment trends are broadly consistent with single-sentence results, but show greater variation. For example, negative sentiment reached deeper lows in the 1930s (-0.157), 1950s (-0.197), and 2000s (-0.198). The diverse sentiment scores highlight the challenges of framing technological unemployment as a cohesive concept.

In summary, our sentiment analysis reveals a predominantly neutral tone around technological unemployment, punctuated by periods of negativity during times of economic stress or major technological transitions. The increasing spread over time between the different sentiments associated with technological unemployment is consistent with the idea that the concept has never been specified and unified, and may have become less central to academic economics discourse over time, a point supported by the treatment of this concept in economics education, which we turn to next.

IV. The Technology-Employment Relationship in Economics Education

This section examines how discussions of unemployment in economics pedagogy have evolved and how economics education has presented the relationship between technology and employment by focusing on economics textbooks, which routinely cite both classical thinkers and academic articles. Textbooks, as important vehicles for the transmission of economic ideas, simplify and popularize complex theories, making them more accessible to students and practitioners. Unlike specialized academic papers, textbooks often reflect the prevailing economic orthodoxy, which can narrow the conceptual scope and influence how key concepts are understood. This process shapes the broader perception of technological unemployment within the economics community.

[122] Wheeler, *From Gutenberg to Google*, 230.

For our quantitative analysis of this often-underrepresented aspect of economic knowledge dissemination, we rely on two specialized datasets. The first is a novel dataset covering the 19 editions of Paul Samuelson's seminal textbook "Economics",[123] which influenced generations of economists and has been investigated, qualitatively, by a long line of research in the history of economic thought. After selling more than 100,000 copies of its first edition in 1948, the textbook was soon adopted by most leading US universities and eventually became a global success, selling more than 4 million copies by the end of the century and being translated into 41 languages.[124] This first dataset was created by digitizing physical copies of the 19 issues and using specially trained optical character recognition (OCR) software to convert the scanned images into machine-processable text, with only marginal errors.[125] In addition to this longitudinal perspective, we also provide a horizontal perspective based on the "econspeak" dataset assembled by Fix, a sample of 43 recent economics textbooks published in the period 2004–2014.[126] This section utilizes several NLP methods to trace changes in the depiction of unemployment and technology in economics pedagogy in these data sources, and also provides a brief discussion of our close reading of the discussions of the impact of technology on employment in these textbooks.

Samuelson's Textbook: A Long View of Technology and Unemployment in Economics Pedagogy

Since its first edition, Samuelson's textbook has treated the concept of unemployment as central to understanding economic dynamics. Samuelson introduces unemployment in the opening chapter, underscoring its importance with analogies and explaining, perhaps to attract a student's attention, that no one is immune to the economic shifts that lead to

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[123] *P. Samuelson*, Economics: An Introductory Analysis, Toronto 1948.

[124] Yann Giraud, "Addressing the Audience: Paul Samuelson, Radical Economics and Textbook Making, 1967-1973," *Journal of the History of Economic Thought* 42, no. 2 (June 2020): 180, https://doi.org/10.1017/S1053837219000257; Mark Skousen, "The Perseverance of Paul Samuelson's *Economics*," *Journal of Economic Perspectives* 11, no. 2 (May 1, 1997): 138, https://doi.org/10.1257/jep.11.2.137.

[125] Originally, this dataset was created for another project, entitled: "Shifts in Canonized Economic Knowledge: A Quantitative Assessment of Economics à la Paul Samuelson and William Nordhaus (1948-2010)", joint work with Rainer Klump, Marius Liebald and Ingo Sauer. The accuracy of this conversion process was assessed using test data, which showed an error rate of around 0.5 per cent. As these errors occur randomly, there is no underlying systematic bias. More details on this dataset can be found in the accompanying paper.

[126] Blair Fix, "Deconstructing Econospeak" (OSF, January 2023), osf.io/afz3p.

unemployment.[127] This early focus establishes a theme that echoes throughout the book: economic systems, especially with their propensity to develop new technology, are inherently susceptible to fluctuations that can render entire populations unemployed, regardless of their skills or diligence.

Samuelson's discussion of unemployment begins with traditional unemployment but soon, in the second chapter, explicitly addresses "technological unemployment", contextually linking it to the Great Depression and the wider economic consequences of technological progress.[128] He criticizes the overly optimistic belief of writers of the time that technological progress could sustain economic growth indefinitely without a corresponding increase in unemployment. This skepticism is rooted in the observed effects of technological progress, which, while increasing the productive capacity of an economy, often reduce the need for human labor, leading to job losses. Although he questions the notion of a linear progression from technological innovation to general prosperity, he ends on an optimistic note for the long run, essentially saying that there will always be work for people to do: "There can be no shortage of useful work to be done. An infinite number of tunes are still to be written. If ever consumption needs should be sated – which is unlikely – there would always remain the alternative of leisure, recreation, and the other elements that go to make up the good life."[129] Unlike Keynes, who imagines abundant leisure as the defining outcome of technological progress in *Economic Possibilities*, Samuelson sees continuous human engagement in new forms of productive or creative activity – two eminent thinkers in strong contrast.

In his much later discussion of the intersection of international trade policy and technological unemployment, Samuelson acknowledges the potential of tariffs to alleviate unemployment, a key argument in tariff debates.[130] While the primary focus of his analysis is on the broader context of a nation's potential income at full employment, Samuelson does not dismiss the relevance of tariffs in addressing unemployment. Rather, he argues that international trade, like technological innovation, can paradoxically increase a country's potential economic output while reducing the level of actual production, consumption, and

[127] First edition, page 3.
[128] First edition, page 16.
[129] First edition, page 17.
[130] First edition, pages 566f.

employment. This mismatch can lead to "technological unemployment", where advances that could increase productivity instead lead to job losses and economic inefficiency due to overcapacity and underutilization. Samuelson is critical of beggar-my-neighbor policies that use tariffs solely as a tool for short-term employment gains at the expense of long-term international economic stability. He stresses that while tariffs can play a role in dealing with technological unemployment, they must be part of a broader, more considered approach to trade policy that avoids the pitfalls of protectionism.

Interestingly for our purposes, the treatment of technological unemployment in Samuelson's textbook series extends to discussions of the historical effects of industrialization. In a historical section on the handloom, he quotes extensively from a contemporary source to illustrate that prior to technological progress, which saw the mechanization of weaving through the invention and adoption of the power loom, living standards were very low.[131] Significantly, by the 19th edition, this reference to the handloom has been replaced by discussions of computers and their transformative effects on the workplace and education.[132] Besides indicating authors' view of history, this shift shows that while the specific technologies that cause anxiety may change over time, the underlying concerns about the displacement of traditional skills and types of employment remain essentially the same.

[131] First edition, pages 68f.
[132] See, for instance, 19th edition, page 7.

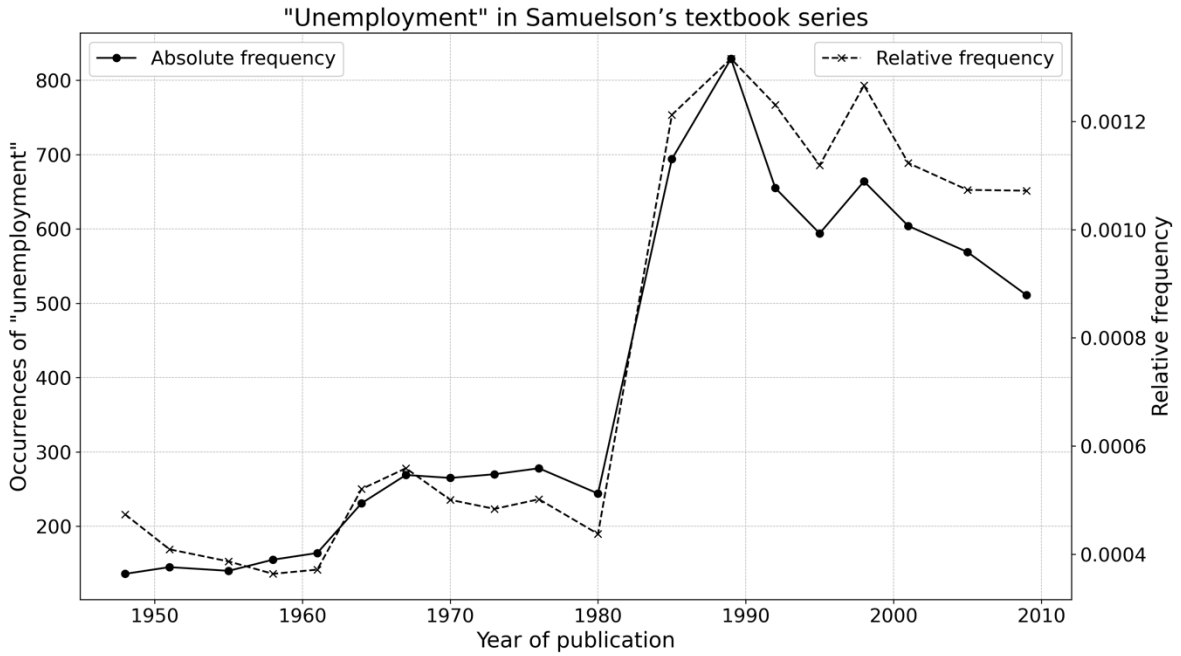

Figure 9: Frequency of "unemployment" in Samuelson's "Economics" textbook series. Source: see main text.

The revision of the textbook structure following William Nordhaus's collaboration with Samuelson for the 12th edition in 1985 significantly changed how unemployment was treated, which was also reflected in the sharp increase in the number of references to the concept at that time (Figure 9). In particular, this edition included extensive sections and chapters dealing specifically with unemployment and inflation, phenomena which are closely linked to the wider business cycle. The main methodological change associated with this was the introduction of the Aggregate Supply and Demand (AS-AD) model, which provided a robust framework for understanding the dynamics of unemployment, inflation, and business cycles. Despite the changes, Samuelson's understanding of technological unemployment as something best addressed without restrictionist or protectionist measures remained the same: "Fear of unemployment often leads to acceptance of the 'lump-of-labor' fallacy. This belief, that there is only a fixed amount of useful work to be done, may arise from experiencing technological unemployment or depression. It lies behind much of the agitation for a shorter work week and featherbedding work rules. But excessively high unemployment calls for macroeconomic policies to furnish adequate overall job opportunities, not for defeatist restrictionism."[133] This section has been a staple of the textbook since the second edition.

[133] 12th edition, page 630.

Throughout the book, Samuelson's discussion of unemployment, both general and technological, emphasizes the need for proactive economic policies. He notes that while free trade and technological progress are generally positive, they must be carefully managed to avoid undesirable economic outcomes such as persistent unemployment or underemployment. The thread running through all editions of Samuelson's textbook series, in line with his classical synthesis of Keynesian thinking, is the assertion that full employment remains a primary goal of economic policy, essential for both economic stability and equitable growth. Overall, this conceptualization of technological unemployment not only goes beyond the economic principles at play, but also actively engages in policy design to mitigate the adverse effects on the labor force.

Next, we examine which words are most frequently mentioned in Samuelson's textbook in connection with discussions of unemployment to determine whether technology plays a significant role as a factor over time. To do this, we calculate, after some standard pre-processing removing common stop words (see Appendix II.2), the raw word frequencies in all paragraphs containing the term "unemployment" across the different editions (Figure 10). In the earliest editions (1948–1958), the most frequent words accompanying unemployment are "employment", "full", "income", "economic", "investment", "system", and "social". In the 1948 edition, words such as "social" (34 occurrences), "full" (33), and "economic" (31) suggest a strong emphasis on achieving full employment and addressing the social consequences of unemployment, in keeping with the immediate post-World War II demands as economies transitioned from wartime production to peacetime growth. As we move into the 1960s, there is a noticeable shift in vocabulary. Words such as "growth", "demand", "labor", "policy", and "price" become more prominent. For instance, in the 1964 edition, "growth" appears 50 times, "demand" 44 times and "policy" 37 times alongside unemployment. This change reflects the growing importance of Keynesian economic policies aimed at stimulating demand to promote economic growth and thus to reduce unemployment. The most dramatic change occurs from the 1970s onwards, when terms such as "inflation", "rate", "natural", "high", "percent", "wages", "output", and "policy" dominate discussions of unemployment. In the 1976 edition, "inflation" is mentioned 72 times, "rate" 64 times and "price" 55 times in the context of unemployment – clearly reflecting the stagflation era of the 1970s, which challenged existing Keynesian models. The prominence of

inflation alongside unemployment indicates Samuelson's preoccupation with the Phillips curve and the trade-offs between inflation and unemployment as economists sought to understand and combat stagflation.

Figure 10: Word clouds for Samuelson's textbook series. The word clouds visualize the words that are most frequently mentioned in Samuelson's textbook in connection with discussions of unemployment.

In the 1980s and 1990s, the term "natural" appears significantly more often, 140 times in 1985, and 168 times in 1989. This reflects the inclusion of the concept of the "natural rate of unemployment" or NAIRU (Non-Accelerating Inflation Rate of Unemployment) in Samuelson's textbook from the 13th edition onwards. At the time, mainstream economic thought was beginning to emphasize that there is a level of unemployment that the economy cannot reduce without causing accelerating inflation. The frequent appearance of "policy", "wages" and "output" during this period illustrates the continued focus on supply-side economics and the increasing focus on monetary policy and wage restraint in managing unemployment and inflation. In the editions from the late 1990s to 2009, while "inflation", "rate" and "NAIRU" remain prevalent, there is an increased emphasis on "labour", "output", and "economy". The reappearance of words such as "workers", "wages" and "market" suggests a renewed interest in labor market dynamics, influenced by globalization, advances in IT and automation, and changing industrial relations during this period.

Throughout the 19 editions, it is noticeable that the term "technology" does not appear among the most common words associated with "unemployment". While Samuelson acknowledges technological unemployment, it is not the primary focus of the textbook's discussion of unemployment. Instead, the evolving macroeconomic context, shaped by events such as postwar reconstruction, oil crises, stagflation, globalization, and the rise of information technology, shifted the focus to issues such as inflation and natural rates of unemployment.

Economics Pedagogy in Cross-Section: Recent Textbooks

Building on this longitudinal analysis of *Economics*, we analyze the second corpus, which consists of 43 economics textbooks published between 2004 and 2014 (for the full list, see Appendix V). While this 7.7-million-word dataset covers a wide range of economics education – from general "Principles of Economics" to specialized macro- and microeconomics – it also includes several editions of the same title by the same author(s). For example, some authors such as Arnold published separate volumes on general, macro- and micro-economics in the same or different years. Others such as Nicholson & Snyder published successive editions of the same textbook (in their case, *Microeconomic Theory*). Consequently, the corpus includes situations where an author or team of authors contributes three or more articles, as well as instances where a single title appears in several consecutive editions (e.g., 2004, 2007, 2011). By capturing both horizontal breadth across different subfields of economics and vertical depth through multiple editions, our corpus allows for a richer analysis of how unemployment and technological change are presented.

Analogous to our approach for Samuelson's editions, Figure 11 traces the frequency and relative prominence of the term "unemployment" in textbooks by different authors. Authors such as Krugman and Hubbard have some of the highest raw frequencies of the term, reflecting the focus of their textbooks on unemployment as a central economic challenge. Miller's exceptionally high relative frequency of "unemployment" indicates his targeted focus. Conversely, textbooks such as Varian's show a lower relative frequency, in line with his prioritization of microeconomic analysis. In addition, the group averages in Figure 11 show that macro-oriented textbooks tend to have the highest average relative frequency of "unemployment", followed by general textbooks and then micro texts. This pattern is quite

intuitive, given that micro textbooks tend to focus on individual markets and incentives rather than broader labor market issues. Our key finding is the heterogeneity in the contextualization of unemployment. A brief qualitative check confirms that, similar to the case of Samuelson, discussions of unemployment are more likely to address inflation, wages, and labor markets in aggregate terms rather than going into the nuances of technological change. One plausible interpretation might be that introductory economics textbooks typically portray technology as a positive driver of productivity and growth, exemplified by the framing of technological progress within Solow-type growth models. In these models, technological innovation is predominantly portrayed as increasing output and facilitating growth rather than displacing labor. As a result, introductory economics courses often omit explicit links between technological progress and unemployment, deferring a more nuanced exploration of this critical relationship to advanced or specialized economics courses.[134]

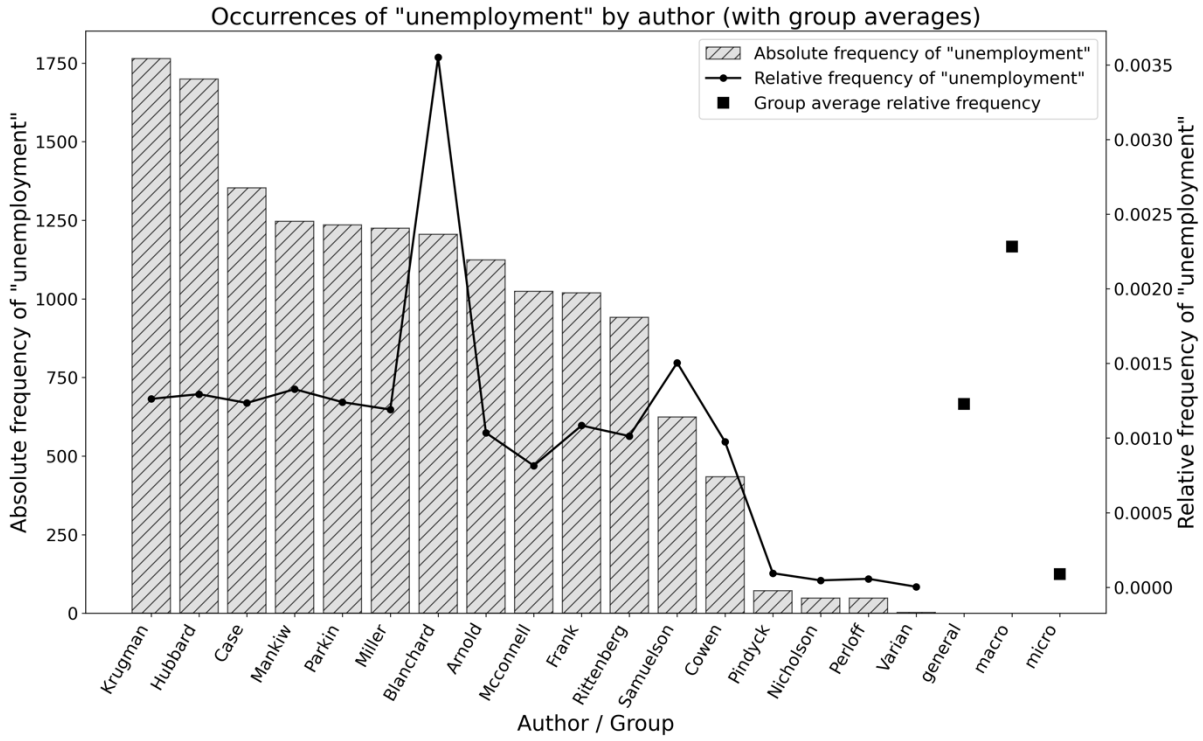

Figure 11: Absolute and relative frequencies of "unemployment" in economics textbooks. Source: "econspeak" dataset assembled by Fix, a sample of 43 recent economics textbooks published in the period 2004–2014.

[134] We are grateful to Milena Nikolova for pointing out this interpretation. We also note that one source identified in our journal corpus, an article by Hans Neisser, stated that "most American textbooks prefer not to mention the problem itself [technological unemployment]". Hans P. Neisser, "'Permanent' Technological Unemployment: 'Demand for Commodities Is Not Demand for Labor,'" *The American Economic Review* 32, no. 1 (1942): 50.

Next, the word cloud visualizations in Figure 12 again provide additional context by highlighting the lexicon associated with unemployment in textbooks. Common terms include "rate", "inflation", "labour", and "market", suggesting a preoccupation with macroeconomic dimensions such as the Phillips curve and the NAIRU. However, despite the long-term importance of technology in reshaping labor markets, terms such as "automation" are conspicuously absent from the dominant word clusters. This is consistent with findings from the Samuelson dataset, where technological unemployment was acknowledged but not a dominant thematic focus. Interestingly, some authors, such as Krugman, incorporate labor dynamics and wage discussions more prominently, reflecting a sensitivity to global shifts in labor markets. Nevertheless, the focus remains firmly on traditional macroeconomic frameworks, leaving technological factors underexplored, at least in this sample. While the journal literature is increasingly addressing the impact of automation, AI, and digitalization, textbooks in recent years only included some discussions of technological change, its potential to disrupt labor markets, and the policy tools needed to address these challenges. Interestingly, despite the prominence of Routine-Biased Technological Change (RBTC) in recent academic literature,[135] this concept does not appear prominently (or explicitly) in the textbooks reviewed here. This raises broader questions about the time lag between academic debates and their integration into educational resources, an issue worthy of further research.

[135] Starting with: D. H. Autor, F. Levy, and R. J. Murnane, "The Skill Content of Recent Technological Change: An Empirical Exploration," *The Quarterly Journal of Economics* 118, no. 4 (November 1, 2003): 1279–1333, https://doi.org/10.1162/003355303322552801. For a recent example, see: Brad Hershbein and Lisa B. Kahn, "Do Recessions Accelerate Routine-Biased Technological Change? Evidence from Vacancy Postings," *American Economic Review* 108, no. 7 (July 2018): 1737–72, https://doi.org/10.1257/aer.20161570.

Figure 12: Word clouds for the economics textbook corpus. The word clouds visualize the words that are most frequently mentioned in the textbooks in connection with discussions of unemployment. Source: "econspeak" dataset by Fix.

Similar to our analysis of the role of classical thinkers in journal articles on technological unemployment, we also examined the frequency of mentions of key classical thinkers and concepts in our sample of economic textbooks over time, using the same normalization and pre-processing of the text as described in section III above. The temporal variance in Figure 13 is less pronounced in this case, as all the textbooks are from the 21st century, but it still highlights the varying prominence of the classical thinkers as well as some specific peaks. Keynes, for example, shows a notable spike around 2008, reflecting increased interest in his demand-side theories during the global financial crisis.[136] Similarly, the resurgence of Marxian concepts over the same period could be linked to growing concerns about inequality and labor issues. In general, Keynes is a much more prominent presence in the textbook literature compared to the specialized journal literature discussed in the previous section. In addition, the distribution of references per article in the textbooks reveals strong variability in how extensively different textbooks engage with classical thinkers and concepts.

[136] Robert Jacob Alexander Skidelsky, *Keynes: The Return of the Master*, 1. publ (London: Allen Lane, 2009).

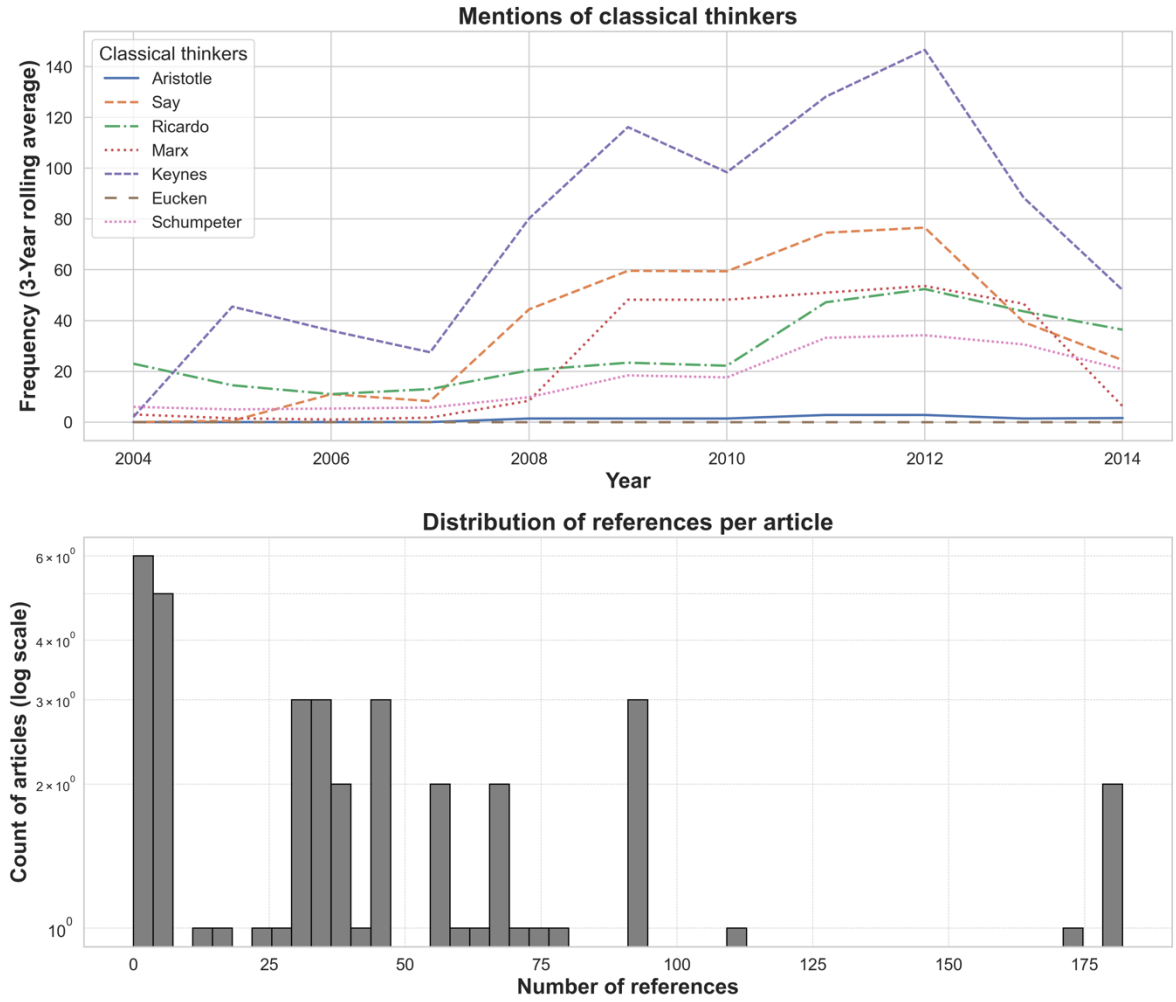

Figure 13: Frequency and positional distribution of references to classical thinkers in modern economics textbooks. Source: "econspeak" dataset by Fix.

In addition to the quantitative analysis, we qualitatively examined the textbook corpus for discussions of our term of interest and related concepts. Notably, the term "technological unemployment" was not mentioned in any of the textbooks. About a third of the textbooks included some discussion of the conceptualization we synthesized from the articles in Section III (technology replacing or displacing workers), commonly using examples that would be familiar to students, some of which are historical. However, these discussions were usually brief and fell within (1) general discussions of unemployment, in descriptions or definitions of structural unemployment or (2) discourses on the effects of technological change. A few textbooks mentioned policy options for addressing these effects and were uniform in their recommendation for retraining support. None of the textbooks expressed any concern about the possibility of a permanent shift in labor demand following technological change.

We thus conclude that the lack of emphasis on technological unemployment in Samuelson's *Economics* is indicative of the wider field of introductory textbooks. Although the concept and term appear in the history of economic thought and in the frontier academic literature, as we have seen above, the term has barely been used in mainstream economic education even as the concept of a relationship between technological change and employment has received frequent attention. Therefore, it is perhaps unsurprising that debates about technological unemployment have not become much clearer over the past century: while the term is still used regularly to motivate research, and its usage broadly follows the rise and fall of public concern about the effects of technological shifts, economics pedagogy has not incorporated a firm conceptualization or definition of technological unemployment. Of course, there is a dialectical relationship between pedagogy and the research frontier, which itself has not advanced at all in how to construct a definition that can be implemented in empirical tests since the 1930s and 1940s.

V. Conceptual synthesis

We now use the foregoing analysis to outline main points of ambiguity in the definition and concept of "technological unemployment", to propose possible resolutions to these areas, and to specify situations in which there is particular concern about the effects of technology on workers. To improve conceptual clarity and empirical analysis of the labor market impacts of technology, we suggest that scholars should first build a cohesive general definition for technological unemployment, and then use temporal and scale modifiers for specific discussions and analysis of potential job-replacing technology. These may help by focusing the debate on tractable, identifiable indicators. More precise terminology can enable clearer empirical analysis and theoretical debates regarding this concept and its potential risks for the future of employment. We also follow our analysis of classic thinkers and research literature by discussing several areas in which there is concern about the labor-replacing effects of technology. Public, policy, and research community attention to specific potential instances of technological impacts on labor explain and justify the heightened atmosphere of debate in this area and its continuing relevance.

Our first proposal is to build a semantically-founded definition for technological unemployment (Table 3). There is a consensus that technological unemployment requires

both some technology and some unemployment—so far, so obvious. However, we have shown here that there is vagueness in how both terms have been used and combined in a definition. Part of the confusion may come from the varying uses of "technology" in the English language: as a specific invention, as a group of related inventions, and as the general state of applied knowledge.[137] In turn, each of these uses could be related to the scale categorization we provided in Section III. For example, a term such as "aggregate" could be prepended to describe a rise in the overall unemployment rate which is shown to be related to a change in Arthur's highest level of "technology", that of a general state of applied knowledge. In turn, "sectoral" or "occupational" could be used to describe unemployment for workers in one or more such subsets of the economy that follows some identifiable technical change or group of related shifts, even if *other* workers find new jobs following the adoption of new technology. Finally, "individual technological unemployment" may be used in longitudinal research identifying specific persons who lost work when their employers adopted techniques, if such workers were not immediately re-employed.[138]

Next, the ILO's definition of unemployment allows us to draw a distinction, noted above in our discussion of Keynes, between a world of technological unemployment and a "post-work" world. In the latter, humans have no need to work, perhaps because there is a universal basic income, and therefore no one seeks paid employment. The ILO definition requires that workers not only be without paid employment in the survey period, but also that they have been seeking work over the same interval. Therefore, "technological unemployment" should only be used when people are *aiming to find new work*. Section III above shows further that few scholars have claimed that technological unemployment implies a permanent reduction in labor demand. We argue that this supports the use of "permanent technological unemployment" as a standalone term to describe a situation in which technological change consistently displaces more workers than it reinstates, and that it does so without creating a "post-work" world.[139] In a world of "permanent technological unemployment", there is some

[137] W. Brian Arthur, *The Nature of Technology: What It Is and How It Evolves* (London: Allen Lane, 2009).
[138] This clarification is required to separate *displaced* workers (using the ILO definition of labor displacement, see note 2 above) from technologically unemployed workers. A displaced worker may also become technologically unemployed, but only if they are not immediately re-employed.
[139] This situation is in contrast to the "post-work" world we discussed in Section II, in which people *choose* not to work because technological change has provided abundance without the need for human labor.

number of workers who are seeking employment but cannot be re-absorbed into the paid labor force. Therefore, if AI causes a permanent reduction in overall labor demand, this could be referred to as "permanent aggregate technological unemployment". Evidence of unemployment over shorter time horizons in which workers eventually find new work might be described as "impermanent technological unemployment", or more specific temporal modifiers could be appended (e.g. "medium-term") based on empirical evidence of the typical duration between separation and re-hiring. To further illustrate the use of our definitions, consider the article by Postel-Vinay mentioned in the introduction. He considers the term in aggregate, focusing on how technological change affects the overall level of unemployment, but does not specify whether this change is permanent or temporary. This study may thus be understood as an exploration of *aggregate technological unemployment*.[140]

Table 3: Proposed Definitions and Modifiers

Term	*Definition*
technological unemployment (umbrella term)	labor displacement without immediate re-employment caused by the adoption of different technology, methods, or techniques
aggregate technological unemployment	an increase in the overall (e.g. national) unemployment rate as a result of an advance in the general state of technological development over the same area
sectoral or occupational technological unemployment	labor displacement without immediate re-employment experienced by workers in a particular sector or occupation, caused by the adoption of different technology, methods, or techniques
individual technological unemployment	labor displacement without immediate re-employment for a worker caused by the adoption of one or more different technologies, methods, or techniques
permanent aggregate technological unemployment	a reduction in the overall demand for labor without any subsequent compensation effects
impermanent occupational technological unemployment	a period of unemployment for workers previously employed in a specific occupation, after which the said workers find new employment or choose to exit the labor force
post-work world	a situation in which the labor force participation rate falls or individuals reduce their working hours because of increased incomes following the adoption of different technologies, methods, or techniques

[140] In contrast, the other authors noted in the introduction are more opaque (Feldmann) or vary in their treatment of technological unemployment (Mokyr et al), so they are more difficult to classify along the different dimensions. For example, Mokyr et al. state that technological unemployment follows the "widespread substitution of machines for labor" (p. 32) but later imply that workers who are temporarily unemployed because machinery is introduced are technologically unemployed. Even so, they doubt that even this impermanent technological unemployment occurred at a "large scale" in the British Industrial Revolution (p. 34).

A semantically-founded definition, particularly when used with scale and duration modifiers, opens up the potential for much clearer theoretical exploration and empirical research on technological unemployment. Such studies could take the form of new original research on the adoption of specific technologies, groups of technologies, or the progress of the technological frontier, and systematic reviews or meta-analyses. Research could aim to establish whether there is evidence for technological unemployment, where, when, and for what scale or time horizon.

Table 4

Dimension	**Area of Concern**
Skill	blue-collar versus white-collar jobs, high-skill versus low-skill, task-based versus skill-based framework
Geography	Urban, rural, regional versus country level, economies of agglomeration, regional skills intelligence
Gender	Gender bias of machinery, household composition
Societal embedding/Social/Psychological	Inequality, work and life satisfaction, psychosocial risks, such as fear of losing one's job or human autonomy, adaptability

Following the long-run historical literature surveyed in Section II, we highlight several categories of worker that may be particularly susceptible to job loss following technological change (Table 4). First, as is well known and of particular recent concern, technological change may disproportionately affect employment opportunities by skill level, depending on the type and features of the technology. For example, it may particularly affect opportunities for low-skilled workers whose jobs require minimal training or education, or high-skilled workers, especially those in fields susceptible to automation by advanced technologies such as impending AI (deskilling). In other words, using a definition of technological unemployment at the occupation level, one could investigate whether it has occurred, and if so, the effects on workers' long-term career trajectories and incomes, as a function of the skill level affected. For instance, early research into the impact of generative AI technology on productivity suggests that it might act as a skill equalizer: people with below-average skills are leveled up by interacting with AI chatbots.[141]

[141] Tyna Eloundou et al., "GPTs Are GPTs: Labor Market Impact Potential of LLMs," *Science* 384, no. 6702 (June 21, 2024): 1306–8, https://doi.org/10.1126/science.adj0998; Fabrizio Dell'Acqua et al., "Navigating the Jagged Technological Frontier: Field Experimental Evidence of the Effects of AI on

The employment effects of new technology may differ by institutional settings and geography, mediated for example by politics shaping the adoption of technology. Rosenberg and Curci empirically show that during the Industrial Revolution, workers in some English cities, notably those with strong self-governing institutions, were able to resist the adoption of labor-saving technologies due to fears of technological unemployment.[142] Outside of politics, economic geography may shape technological adoption and thereby disemployment effects. For instance, recent research has shown that the widespread adoption of technologies across entire countries is a very slow process.[143] Therefore, rural areas may experience slower adoption rates and different impacts on different sectors, particularly between occupations where workers may be on the technological frontier regardless of physical location (e.g. those for which remote working is possible) and occupations without such competitive pressures.

Technology may also have differential impacts when there is high gender segregation of occupations. Historical technological developments such as in textile production disproportionately affected women, leading to job loss and a sustained fall in female labor force participation in Britain from the beginning of the 19th century.[144] Notably, studies focusing on occupational displacement or technological unemployment in widely varying contexts have found such gendered effects.[145] While historical research has only begun to systematically explore labor displacement following technological change and technological unemployment, the absence of socially-acceptable alternative work may be one explanation for these findings.

Knowledge Worker Productivity and Quality," *SSRN Electronic Journal*, 2023, https://doi.org/10.2139/ssrn.4573321; Shakked Noy and Whitney Zhang, "Experimental Evidence on the Productivity Effects of Generative Artificial Intelligence," *Science* 381, no. 6654 (July 14, 2023): 187–92, https://doi.org/10.1126/science.adh2586.

[142] Michele Rosenberg and Federico Curci, "Factory Location: Resistance to Technology Adoption and Local Institutions," *SSRN Electronic Journal*, 2023, https://doi.org/10.2139/ssrn.4428398.

[143] Aakash Kalyani et al., "The Diffusion of New Technologies," *The Quarterly Journal of Economics*, January 17, 2025, qjaf002, https://doi.org/10.1093/qje/qjaf002.

[144] Jane Humphries and Benjamin Schneider, "Gender Equality, Growth, and How a Technological Trap Destroyed Female Work," *Economic History of Developing Regions* 36, no. 3 (2021): 428–38, https://doi.org/10.1080/20780389.2021.1929606; Benjamin Schneider, "Technological Unemployment in the British Industrial Revolution: The Destruction of Hand Spinning," *Past & Present*, 2025.

[145] James Feigenbaum and Daniel P Gross, "Answering the Call of Automation: How the Labor Market Adjusted to Mechanizing Telephone Operation," *The Quarterly Journal of Economics* 139, no. 3 (July 5, 2024): 1879–1939, https://doi.org/10.1093/qje/qjae005.

While we have focused above, particularly in Sections III and IV, on the conceptualization of the technology-employment relationship by economists, understanding the reception and effects of technology may also benefit from a broader perspective. The economic framework tends to focus on factors such as relative prices and reduced demand for labor. However, a broader approach includes examining inequality, job satisfaction, fear of job loss, and the psychological adaptability of the workforce, nowadays sometimes labelled "resilience". As discussed in Section II, thinkers such as Marx and Keynes provide a much broader understanding of the implications of technological change, emphasizing the wider social context in which new machinery was embedded. As noted by Hobsbawm in a classic article, workers who faced new machinery during the Industrial Revolution were concerned "with the practical twin problems of preventing unemployment and maintaining the customary standard of life, which included non-monetary factors such as freedom and dignity, as well as wages".[146] This latter dimension is likely to become more critical in the age of AI-induced technological unemployment, which has revived questions about the social and political embeddedness of machines and issues such as surveillance and job quality that were debated by the Luddites.[147]

To summarize our discussion, we suggest that economists use a definition of technological unemployment grounded in its two constituent words, and apply modifiers when carrying out empirical studies to enable a clearer research agenda on the employment effects of technology. We highlight the scale and temporal dimensions as particularly useful in this regard. Overall, the use of a comprehensive terminology and typology allows researchers to more accurately describe and analyze the multi-dimensional nature of technological unemployment, thereby facilitating clearer communication and, perhaps, more effective policy recommendations in the future. The work of classic economists also highlights the potential inequalities that may be produced by technological change, and the social and psychological impacts of the threat of job loss or occupational change.

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[146] E. J. Hobsbawm, "The Machine Breakers," *Past and Present* 1, no. 1 (1952): 62, https://doi.org/10.1093/past/1.1.57.

[147] Merchant, *Blood in the Machine*. Janine Berg et al., "Risks to Job Quality from Digital Technologies: Are Industrial Relations in Europe Ready for the Challenge?," *European Journal of Industrial Relations*, 2023, 09596801231178904, https://doi.org/10.1177/09596801231178904.

VI. Conclusion

Economic writers have been concerned about the potential for technological change to replace the demand for human labor for more than 2,000 years. We have shown here that while technological anxiety has been a common feature of economics for centuries, the frame of analysis for the employment implications of innovation has varied widely, and opinions about whether disemployment effects are meaningful in scale and duration have been both diverse and opaque. The debate has been complicated by the fact that many scholars who have used the term have only briefly and vaguely defined it. Differing conceptions of the employment effects of technological change, perhaps related to variation in implicit conceptualizations, temporal and scale frames of analysis, and above all the lack of a generally-agreed definition may explain the long-running debate over whether the possibility for new techniques to replace workers is a genuine empirical phenomenon. Any empirical strategy requires a clear and specific definition of the underlying concept of interest.

The research frontier of academic economics over the past 130 years has seen three waves of interest in this topic: in the 1930s and 1940s, in the 1960s, and since the 2010s. These three waves fit well with existing research on the development of technological anxiety among the public over the same period. As we have shown, during these periods of heightened technological anxiety, there has been a significant increase in the number of journal articles and in the sentiment (polarity score) of debates about technological unemployment – perhaps reflecting broader societal anxieties, even as academic discussions in general have become narrower and more technical in their focus. If current technological projections are accurate, we are likely to see a continuing intense debate over the next decade.

The evolution of economic thought on technological unemployment is reflected in Samuelson's textbook series, which initially linked technological unemployment to historical events such as industrialization and the Great Depression. Over time, Samuelson's discussions shifted from social concerns and full employment to managing trade-offs between inflation and unemployment, eventually adopting formal analytical frameworks such as Aggregate Supply and Demand (AS-AD). While Samuelson consistently acknowledged technological unemployment and advocated proactive policies rather than protectionism, this remained a secondary theme within his broader macroeconomic discussions. Similarly, our wider analysis of economics textbooks reveals that, although the disemployment effects of

technology are occasionally recognized – particularly in the context of labor-replacing technologies – the topic is rarely emphasized. Instead, textbooks typically encourage an optimistic view, stressing long-term benefits of technological change, while sometimes briefly acknowledging short-term displacement and challenges faced by workers in specific occupations.

We suggest that future research would benefit from, first, an agreed definition for the base concept of technological unemployment, and second, adopting more precise and consistent modifiers when discussing technological unemployment, such as "permanent" or "sectoral" technological unemployment, to specify the scope of analysis. A specific, clear definition is an essential basis for empirical research. Economists understand, from their continued use of the term in motivation and framing, that the public and policymakers are concerned about a phenomenon that fits our proposed definition of technological unemployment. Research that directly tackles its occurrence and prevalence could improve or even resolve such broad debates without resorting to more opaque terminology, some of which we have used here out of necessity, such as "the relationship between technological change and employment". We have also highlighted a variety of additional dimensions through which technological shifts may produce unequal impacts, such as skill level, geography, and the social implications of labor-replacing technology.

Adopting a clearer definition for technological unemployment while refraining from euphemisms would improve conceptual clarity and thus enhance empirical analysis of this question. In turn, empirical research can improve the quality of public debates and the formulation of policy responses in an era where the impact of artificial intelligence and automation is increasingly significant. By unpacking this concept through the classical history of economic thought, the academic journal literature, and economics textbooks, we hope to have demonstrated that precise definitions are important not only as an academic exercise, but also as a means of bridging the gap between public anxiety about job displacement and the scholarly analyses that inform policy responses. Avoiding an open discussion of technological unemployment and resort to euphemisms risks both scientific inaccuracy and disconnection from societal concerns. Future research should adopt clearer language, engage more directly with empirical evidence, including historical technological shifts, and openly

confront the challenges posed by technological unemployment rather than retreating into conceptual and terminological ambiguity.

APPENDIX

I. Access to corpus articles, including classifications

The final spreadsheet is available to download from Zenodo: Schneider, B., & Küsters, A. (2025). Dataset: Technological Unemployment in Leading Economics Journals [Data set]. Zenodo. https://doi.org/10.5281/zenodo.15011373.

II. Methodological documentation

1. **Coding instructions for classifying the journal articles that mention "technological unemployment"**:
    a. Type of Article
        i. *Theoretical:* The article is primarily concerned with advancing (a) new theory/theories or concept(s), or with analyzing or critiquing the theory or concepts of a small number of other writers or specific points of view.
        ii. *Empirical:* The article primarily presents empirical findings produced by analyzing or re-analyzing primary or secondary data; there may be a theoretical framework used or mentioned and a presentation of related literature, but this is not its main contribution. The empirical findings may be new, or a re-evaluation of previous work, so long as any re-analysis is focused on a small number of articles rather than a wider literature, as in a Survey/Review.
        iii. *Survey/Review:* The article primarily summarizes, discusses, synthesizes, or evaluates previous research (theoretical or empirical). Survey/Review articles consider a range of different research outputs rather than responding to or critiquing only a few works, or the views of a specific school of thought.
        iv. *NB:* Articles that recount the proceedings of conference discussions (commonly published in the early decades of the *American Economic Review*) are coded based on the content of the discussant comments.
    b. Level of Discussion:

i. *Not Relevant*: "technological unemployment" appears in the article, but the article is (1) a conference program, front or end matter, or book review mis-categorized in the repository as a research article; (2) the term only appears in the references, and not in the text or substantive footnotes.

ii. *In Passing*: "technological unemployment" appears but is not discussed in any substance.

iii. *Brief Discussion*: "technological unemployment" is considered by the author(s), but only in a few sentences up to 1–3 paragraphs.

iv. *Main Topic*: "technological unemployment" is one of the most important themes of the article; it may appear in the title and/or, with at least one mention of the term, be considered in depth for more than one page.

c. Definition or Conceptualization of "technological unemployment": A direct quotation from the article in which the authors define the term or describe the concept in their own words, if one is provided.

d. Indication of Possibility in Theory:

i. *Possible*: The article states or implies that "technological unemployment" may occur. No definition is imposed, the author(s) may or may not provide a definition.

ii. *Not Possible*: The article states or implies that "technological unemployment" cannot occur. No definition is imposed, the author(s) may or may not provide a definition.

iii. *No Indication*: The articles does not state or imply whether "technological unemployment" can occur.

e. Indication of Occurrence in Practice:

i. *Did occur*: The article states that "technological unemployment" has occurred. No definition is imposed, the author(s) may or may not provide a definition.

ii. *Did not occur*: The article states that "technological unemployment" has not occurred. No definition is imposed, the author(s) may or may not provide a definition.

iii. *No Indication*: The article does not state whether "technological unemployment" has occurred.

f. Examples Given:

i. *Listing of examples*: A summary of any places, times, sectors, or occupations in which the author(s) state or imply that technological unemployment has occurred.

ii. *Not applicable*: The article states that "technological unemployment" has not occurred (see "Indication of Occurrence in Practice" above), therefore no examples are given.

iii. *No Examples*: No such examples are given.

g. Temporal Dimension (multiple codes possible):

i. *Impermanent*: the article states that "technological unemployment" may occur, or has occurred, but that workers may be reabsorbed.

ii. *Permanent*: The article states that "technological unemployment" may result, or has resulted in, a permanent shift, using the authors' temporal descriptors.

iii. *No Indication*: The article does not provide any temporal description for "technological unemployment".

h. Scale Dimension (multiple codes possible):

i. *Aggregate*: The article states that "technological unemployment" is observed or can be observed as a change in the overall unemployment rate, or a change in aggregate demand for labor.

ii. *Sectoral/Occupational*: The article states that "technological unemployment" is or can be observed as changes in employment within a sector or for specific occupations.

iii. *Individual*: The article states that "technological unemployment" is or can be observed as changes in employment for individual workers.

iv. *No Indication*: The articles does not provide any description of the scale or level at which "technological unemployment" is or can be observed.

2. **Pre-processing steps for NLP analysis**: In our NLP analysis of journal articles related to "technological unemployment", we implemented an extensive, manually coded pre-processing pipeline to ensure the integrity of the textual data. First, we extracted raw text from the PDF documents using the *PyMuPDF* library. Recognising that scientific articles often contain repetitive headers, footers, and boilerplate text that can distort analysis, we wrote code to remove such content. This was achieved by identifying and eliminating lines and patterns that match specific heuristics and regular expressions, targeting elements such as page numbers, author names, article titles, copyright notices, and other repetitive or irrelevant content. We also addressed common problems in digitised text, such as hyphenation at line breaks, by merging split words to restore correct word forms. Line breaks within paragraphs were replaced with spaces to maintain sentence continuity and ensure that sentences were not incorrectly segmented. Further cleanup included removing unwanted patterns such as URLs, email addresses, figure and table captions, and acknowledgments. Non-standard characters were removed to ensure textual consistency. We carefully filtered out orphaned numbers, preserving four-digit years to maintain temporal references critical to our analysis. Finally, we normalised the text by converting it to lowercase and removing stopwords, including both standard English stopwords from the *NLTK* library and custom stopwords tailored to our corpus. For our analysis of Paul Samuelson's economics textbooks, the pre-processing differed in that we specifically extracted paragraphs related to "unemployment". In this case, we adjusted the stopword list to include the term "unemployment" itself, allowing us to focus on related terms. Additional cleaning steps included removing free-standing numbers and refining the text to create word clouds.
3. **Dependency parsing**: Dependency parsing is a common NLP technique used to analyse the grammatical structure of sentences by identifying relationships between words, such as subject-object relationships and modifiers. In our study, we used dependency parsing to look specifically at the adjectives modifying the term "unemployment" within sentences that also mention "technological unemployment".

Using the Python *spaCy* library, the process involved loading a pre-trained model, *en_core_web_sm*, which provides extensive linguistic annotations. For each sentence in our dataset, the text was tokenised and parsed to identify dependency relationships. We focused on adjectives (adjectival modifiers, or "amod" in dependency terms) directly related to the lemma "unemployment". In order to refine our analysis, we excluded common stop words and the specific adjective "technological", which was central to our study topic but by definition present in all filtered sentences. This allowed us to create a frequency distribution, highlighting how different descriptors are used in the context of technological unemployment.

4. **Sentiment analysis**: Sentiment analysis was performed to assess the emotional tone of sentences mentioning "technological unemployment" within our corpus. For this analysis, we used a RoBERTa-based sentiment analysis model specifically tuned for sentiment detection in short text snippets such as social media contributions (*cardiffnlp/twitter-roberta-base-sentiment*). After pre-processing, each sentence was run through the RoBERTa sentiment analyzer, which assigned a sentiment label (positive, neutral or negative) along with a confidence score for that label. To quantify the overall emotional tone, we calculated a polarity score for each sentence, reflecting its position on a spectrum from negative to positive sentiment. This was done by applying a weighted sum of the sentiment scores, followed by a scaling transformation to ensure that the polarity values remained within a bounded range.

III. Counts for each modifier

Modifier	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	2020s
aggregate	0	15	7	37	28	5	1	22	4	48	96
chronic	0	4	6	1	0	0	0	1	0	0	0
cyclical	1	57	29	14	6	0	2	29	0	3	1
depressionary	0	0	0	1	0	0	0	0	0	0	0
female	0	0	0	0	0	5	0	0	1	0	21
frictional	0	0	11	1	6	0	0	1	1	0	0
high-skilled	0	0	0	0	0	0	0	0	0	0	0
individual	2	70	26	18	16	13	3	16	5	16	77
long-run	0	0	0	0	0	0	0	0	0	0	0
low-skilled	0	0	0	0	0	0	0	0	0	0	0
male	0	1	0	0	0	6	0	4	1	1	10
mid-term	0	0	0	0	0	0	0	0	0	0	0
occupational	0	3	1	3	1	0	0	3	1	7	82
permanent	2	29	29	2	2	10	0	1	1	15	7
rural	0	2	1	3	0	5	0	2	0	2	5

seasonal	2	36	1	3	4	5	0	0	0	1	1
sectoral	0	0	0	0	1	5	1	4	6	46	65
skilled	1	40	10	2	6	1	1	6	0	50	203
structural	0	9	5	12	39	0	6	6	0	41	27
systemic	0	0	0	0	0	0	0	0	0	0	3
temporary	2	15	20	10	7	2	2	7	3	6	5
theoretical	0	30	36	10	5	6	4	0	4	39	53
unskilled	0	12	1	0	2	0	0	1	0	23	18
urban	0	4	3	5	0	2	1	4	0	3	6

IV. Examples sentiment analysis

Top 3 Positive Single Sentences:

- Year: 1947

  Sentence: As for technological unemployment, we have already noted that far from causing unemployment, larger, faster planes have created jobs for pilots by making air transport a more attractive method of travel, by opening up previously inaccessible areas to the industry, and by creating possibilities for further fare reductions.

  Polarity Score: 0.6297244429588318

- Year: 2023

  Sentence: An interesting way to build further on this would be to identify the exact inclusive institutions and technological capabilities that can have a mitigating effect on technological unemployment.

  Polarity Score: 0.6008230447769165

- Year: 1960

  Sentence: Only the resulting increase in productive facilities may eventually help the demand for labor to […] the extent of a small fraction of the technological unemployment created by the increase in productivity.

  Polarity Score: 0.5465844869613647

Top 3 Negative Single Sentences:

- Year: 1940

  Sentence: Among such damages are listed: deforestation, erosion, pollution of rivers, blighting of formerly good residential districts, overcrowding of urban areas, industrial accidents, occupational diseases, and technological unemployment.

Polarity Score: -0.7024879455566406

- Year: 1932

  Sentence: It is an element in industrial instability, in technological unemployment, in the constant need for junking equipment, and in the waste involved in the dislocations of capital and labor.

  Polarity Score: -0.6798681020736694

- Year: 1966

  Sentence: They obviously would not be able to deal, though, with the problems created by the existence of depressed areas or technological unemployment.

  Polarity Score: -0.6729291677474976

Top 3 Positive 3-Sentence Windows:

- Year: 2023

  3-Sentence Window: An interesting way to build further on this would be to identify the exact inclusive institutions and technological capabilities that can have a mitigating effect on technological unemployment. [… page break] On the one hand , according to Say's law, technological unemployment is not permanent because, if technological progress reduces the prices of commodities, it will also increase their demand.

  Polarity Score: 0.5536041855812073

- Year: 2023

  3-Sentence Window: Recent studies aiming to configure the contribution of technological advancements on labour market outcomes, have revived the debate and concerns about technological unemployment. An interesting way to build further on this would be to identify the exact inclusive institutions and technological capabilities that can have a mitigating effect on technological unemployment. [… page break]

  Polarity Score: 0.5330367684364319

- Year: 1929

  3-Sentence Window: Even the notion, however fallacious, of technological unemployment is not of great moment in itself, for doubtless prices would be lower, more goods would be bought, or purchasing power […] would be released and

directed to other commodities, which would increase the demand for labor and hasten its reabsorption. Whether the unemployment of 1927 or of 1924 was technological unemployment, due to the displacement of men by machines, or the that accompanies mild business recession, or the prolongation of the ordinary periods of seasonal unemployment are questions that will be answered only with the accumulation of more and better statistical materials than we now have.

Polarity Score: 0.0

Top 3 Negative 3-Sentence Windows:

- Year: 1962

  3-Sentence Window: It is not technological unemployment and depression which are the threats to the continuity of production and income, but rather physical environment, plant disease. […]

  Polarity Score: -0.6543626189231873
- Year: 1950

  3-Sentence Window: The literature concerning technological unemployment is full of confusion on this point. Technological unemployment and low pay to workers in the past contributed to the development of slums which remain an unsolved economic problem today.

  Polarity Score: -0.648226261138916
- Year: 1988
- 3-Sentence Window: So it is a twist that critics, who found unpalatable his chapter 31 conclusion that machines can hurt workers and wages, commonly had to discount his new chapter with the accusation that he needs to depend on technological unemployment and other fleeting frictions for his pessimistic results.
- Polarity Score: -0.6277214884757996

Note: Some sentences may appear slightly truncated due to the pre-processing steps applied during text extraction. This was necessary to remove boilerplate content such as recurring headings or phrases, particularly those containing the term "technological unemployment", which might otherwise interfere with the analysis (see methodological documentation below).

V. Cross-sectional corpus of economics textbooks

Author	Title	Year	Start page
Arnold	Economics	2008	35
Arnold	Macroeconomics	2008	26
Arnold	Microeconomics	2011	39
Blanchard & Johnson	Macroeconomics	2012	26
Case, Fair & Oster	Principles of Microeconomics	2008	1
Case, Fair & Oster	Principles of Macroeconomics	2011	35
Case, Fair & Oster	Principles of Economics	2012	34
Cowen & Tabarrok	Modern Principles of Economics	2011	55
Frank & Bernanke	Principles of Economics	2008	49
Frank & Bernanke	Principles of Macroeconomics	2008	33
Frank & Bernanke	Principles of Microeconomics	2008	33
Hubbard & O'Brien	Economics	2009	62
Hubbard & O'Brien	Macroeconomics	2011	35
Hubbard & O'Brien	Microeconomics	2013	48
Krugman & Wells	Macroeconomics	2005	35
Krugman & Wells	Economics	2009	49
Krugman & Wells	Microeconomics	2012	34
LeRoy Miller	Economics Today: The Macro View	2011	32
LeRoy Miller	Economics Today: The Micro View	2011	32
LeRoy Miller	Economics Today	2011	32
Mankiw	Principles of Economics	2008	1
Mankiw	Principles of Macroeconomics	2011	27
Mankiw	Principles of Microeconomics	2011	27
McConnell, Brue & Flynn	Macroeconomics	2006	31
McConnell, Brue & Flynn	Economics	2008	32
McConnell, Brue & Flynn	Microeconomics	2011	39
Nicholson & Snyder	Microeconomic Theory	2004	1
Nicholson & Snyder	Microeconomic Theory	2007	24
Nicholson & Snyder	Microeconomic Theory	2011	25
Parkin	Microeconomics	2011	41
Parkin	Macroeconomics	2011	33
Parkin, Powell & Matthews	Economics	2005	44

Perloff	Microeconomics	2011	25
Perloff	Microeconomics	2014	26
Pindyck & Rubinfeld	Microeconomics	2012	26
Pindyck & Rubinfeld	Microeconomics	2014	25
Rittenberg & Tregarthen	Principles of Economics	2009	
Rittenberg & Tregarthen	Principles of Microeconomics	2009	
Rittenberg & Tregarthen	Principles of Macroeconomics	2009	
Samuelson & Nordhaus	Economics	2009	26
Varian	Intermediate Microeconomics	2005	20
Varian	Intermediate Microeconomics	2010	27
Varian	Intermediate Microeconomics	2014	28

Source: Blair Fix, "Deconstructing Econospeak" (OSF, January 2023), osf.io/afz3p.

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