Firms and Unions*

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Abstract

Is firm growth always positively linked to higher wages? How does technological progress affect the relationship between firms and labor unions? This paper offers the first analysis to explain this interplay, reproducing the empirical patterns observed in the data. We introduce a general equilibrium model showing how firm growth, driven by general–purpose technologies, initially raises both firm size and wages. Beyond a firm–size threshold, firms transition to labor–substituting technologies, like automation, due to their ease of scalability, which, contrary to the predictions of neoclassical growth models, results in stagnating wages despite further firm growth. The progression to automation is delayed in industries with entry barriers. The increased ease of substituting labor diminishes the union–extractable rents, reducing the benefits of unionization. By incorporating automation's impact, we revise the view of unions as rent–seeking entities, offering a novel perspective on how automation reshapes union rents and labor dynamics.

Keywords: Firm Size, Productivity, Wages, Scalability, Industry Dynamics, Automation, Unions

JEL codes: E00, J2, J3, J5, O14, O33

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1 Introduction

In the heart of modern economic discourse lies a contentious debate about the impact of automation on employment and wages. On the one hand, automation, through advancements like AI and industrial robots, is seen as a potential catalyst for unemployment and stagnating wages despite increasing productivity. On the other hand, some argue that automation, similar to past technological revolutions, could increase labor demand and wages. However, this optimism is dampened by the stark reality of wage stagnation since the second half of the 20$^{\text{th}}$ century, contrasting with increased firm size and productivity. Intriguingly, despite larger firms traditionally being fertile grounds for unionization, the trend of union membership has been on a steady decline, even in today's era of 'superstar firms.' This paradox challenges the argument that firm size naturally fosters unionization, pointing towards the transformative role of automation in reshaping the dynamics of workforce expansion and union power in the technology-driven landscape of modern firms.

This paper introduces a productivity and firm growth model that uniquely explains the decline in unionization amid increasing firm size and productivity. This model's distinctive aspect lies in its integration of labor adjustment costs, further accentuating the appeal of automation for firms and its impact on union formation. A key characteristic of our model is its focus on the relative scalability of automation.

We provide a new mechanism to the literature that links trends in firm size, automation, and unionization and offer a fresh perspective on understanding the consequences of automation. Central to our approach is the distinction between two types of technological growth: general-purpose technology growth and labor-substituting technology growth. Our model posits that labor substitution arises from automated technologies, displacing workers from their traditional roles. Conversely, the growth of general-purpose technologies enhances worker productivity, leading to an increase in wages. This dichotomy provides a nuanced understanding of how technological advancements impact the labor market, wage dynamics, and unionization.

We formalize this argument based on a general equilibrium framework that incorporates labor adjustment costs and automation decisions, enabling an analysis of the relationship between firm size and union rents. Our model predicts that when a firm faces labor adjustment costs, growth in general–purpose productivity eventually prompts the adoption of automation. This implies that a larger–scale firm would depend more on automation than a smaller–scale firm, with the efficiency of automation shaping the correlation between automation intensity and firm size.

Our model offers three main theoretical insights. First, as general–purpose productivity grows, firms expand. Initially, this leads to wage increases, but once productivity surpasses a certain threshold, further expansion results in wage stagnation resulting from automation, although firms continue to grow. Second, in a multi–firm industry, firms reach the automation switch threshold earlier than those industries restricting firm entry. Thus, all other factors being equal, industries with restricted entry will likely experience less wage-productivity decoupling. Third, before this productivity threshold is reached, enhanced general-purpose productivity positively influences union formation, alongside growth in firm value–added and equilibrium wages. However, beyond the threshold, the prospect of union formation weakens as the balance of potential union benefits against expected costs tilts unfavorably due to advancing automation. We show that our theoretical findings are robust to alternative model specifications and consistent with stylized empirical evidence.

Related literature. Our paper is the first to connect automation and firm–industry dynamics to shifts in union rents. This connection draws from the studies suggesting that technological changes favoring specific skills have contributed to a decline in union membership since the late 1950s, weakening worker leverage (Acemoglu et al., 2001; Açıkgöz and Kaymak, 2014; Dinlersoz and Greenwood, 2016). To the best of our knowledge, this is the first study to establish a clear link between the expansion of automation–adopting firms and a corresponding decrease in union formation.

Recent research has begun to unravel the macroeconomic implications of unionization. Holmes (1998), utilizing state–border data, demonstrates the detrimental impact of pro–union policies on postwar manufacturing productivity. Further, Taschereau-Dumouchel (2020) highlight how even the potential threat of unionization can shape the strategies of non–unionized firms to prevent union formation. Bridgman (2015) suggests that unions might favor less efficient production methods in environments with minimal competition. Finally, Alder et al. (2023) posit a significant role of unionization in the decline of the Rust Belt. Our paper enhances this field of research by exploring a novel aspect: it examines how the adoption of automation technologies diminishes the economic benefits previously leveraged by unions.

Our paper adds to the burgeoning field of automation adoption by examining how large firms unevenly adopt automation technologies. Critical studies in this area include Acemoglu et al. (2022), which find that the largest firms within specific industries are significantly more likely to use these technologies than their mid–sized counterparts. Dinlersoz and Wolf (2023) observe a similar pattern in US manufacturing, where automation adoption escalates with firm size. Hubmer and Restrepo (2022) note a disparity where larger firms tend to automate more tasks, in contrast to the median firm's reliance on labor–intensive technologies. A growing body of work, including studies by Koch et al. (2021), Humlum (2019), Bonfiglioli et al. (2020), Acemoglu et al. (2020), Wang (2021), and Dixon et al. (2020), supports these findings, especially in the context of industrial robot use in manufacturing firms across the US, Canada, and Europe, highlighting a correlation between robot usage and firm size. Our research extends these insights by demonstrating that firms opt for automation technologies, particularly after surpassing a certain size threshold in the context of general–purpose technology growth.

Finally, our paper contributes to the discussion on union behavior by incorporating the emergence of labor-substituting technologies as a significant factor in labor negotiations. Traditional bargaining frameworks, which generally split between wage-centric and both wage-and-employment discussions, did not fully account for the long-term implications of technological progress on labor dynamics (Dunlop et al., 1944; Oswald, 1982; McDonald and Solow, 1981; Card et al., 2017). Drawing from Hirsch's critiques of traditional models and the introduction of the rent-seeking models, we highlight that labor-substituting technologies can shift union targets. Hirsch (1990b, 1991) showed how union demands could deter investment in innovation and capital by acting akin to a capital tax. We underscore that labor-substituting technologies reduce potential union rents, making such firms less attractive to unions and, thus, redefining the strategic interplay between unions and firms in the context of modern technological advancements.

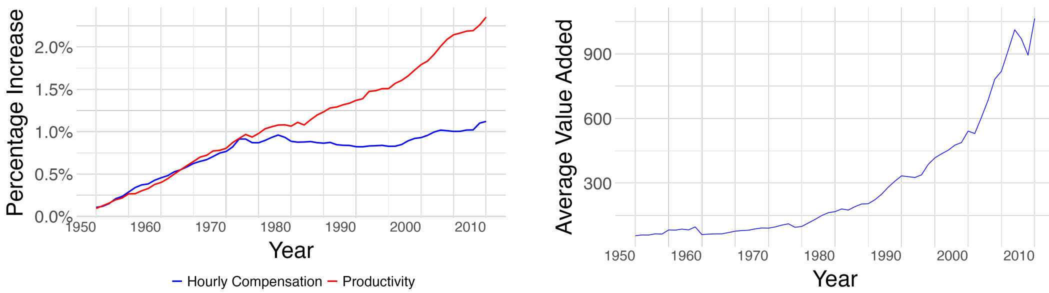
2 Stylized Facts and Background

The underlying motivation for this paper stems from a striking paradox: while recent decades have seen a pronounced disconnect between productivity and wages, alongside substantial growth of firms, these trends have not precipitated the expected rise in unionization. We propose that this phenomenon can be attributed to the distinct nature of firm expansion during this period, a hypothesis grounded in a series of stylized facts that we explore in depth.

2.1 Firm Growth and Productivity–Wage Decoupling

The debate over the impact of automation on employment and wages is multifaceted. While some perceive the rise of automation, exemplified by technologies like industrial robots and artificial intelligence, as a precursor to widespread unemployment, others contend that akin to previous technological evolutions, the current wave of automation will ultimately stimulate labor demand, culminating in increased employment and higher wage rates (Autor, 2015; Acemoglu and Restrepo, 2018, 2020; Acemoglu et al., 2022). However, Acemoglu and Restrepo (2022) show that technological advancements in automation are displacing less skilled workers by taking over tasks they traditionally performed, leading to significant shifts in the U.S. wage structure and contributing to inequality. The authors estimate that automation accounts for over 50% of wage structure changes in the past four decades, notably diminishing wages for workers engaged in routine tasks susceptible to automation,

Figure 1. Productivity-Wage Decoupling and Value Added: 1950–2010



(a) Productivity–Wage Decoupling **(b)** Average Value Added

Note: The left panel graphically represents the decoupling of productivity and wages in the United States from 1950 to 2010, utilizing data from the BLS Labor Productivity and Costs program, Current Employment Statistics, Employer Costs for Employee Compensation, and BEA National Income and Product Accounts. The right panel plots the rise in average firm value added over the same period, drawing on data from Compustat Fundamentals.

such as manufacturing and clerical jobs. Conversely, groups whose tasks have not been automated have seen wage increases. Acemoglu and Restrepo (2022) show that while technological progress can enhance the productivity of certain groups and capital, automation specifically reallocates tasks to machines, thereby displacing workers and impacting wages and increasing inequality.

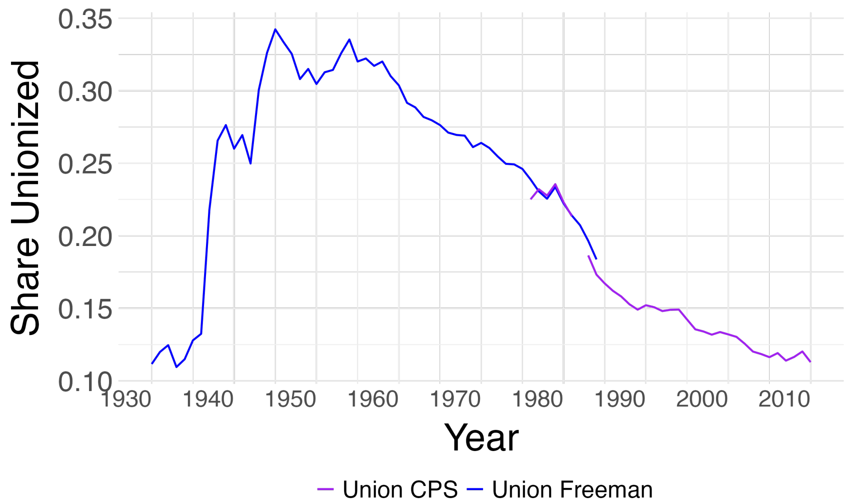
Therefore, the role of automation as a labor-saving innovation may constrain wage growth. This is reflected in the trend that, since the 1970s, wages for most workers have largely stagnated, even as their productivity has surged, as shown in Figure 1a.[1] Additionally, this period has seen consistent growth in firm size, as shown in Figure 1b, adding a complex dimension to this debate.

2.2 Decline in Unionization

It might be anticipated that in response to stagnating wages, workers would increasingly resort to unionization to boost their bargaining power. Yet, contrary to these expectations, the proportion of unionized workers has steadily

[1] The Online Appendix Figure C1 demonstrates that the decoupling between productivity and wages initially observed in Figure 1a also persist across individual industries.

Figure 2. Decline in the Share of Unionized Workers: 1930–2010



Note: The figure presents the proportion of unionized workers from 1930 to 2010, detailing union density as a fraction of the non–agricultural workforce, using data from Historical Statistics of the United States, and individual union density among civilian workers aged 16 to 65 from the Current Population Survey (Farber et al., 2021).

decreased since the latter half of the 20$^{\text{th}}$ century, as evidenced in Figure 2.

During the past decades, the influence of labor unions and the manufacturing sector's role in the U.S. economy notably diminished, coinciding with a significant reduction in overall wage and productivity growth. Unions mainly declined following the onset of productivity-wage decoupling in the mid to late 1970s. However, Figure 2 shows that the decline in unions started as early as the late 1950s. This trend of declining unionization is largely attributed to structural shifts within the U.S. economy, such as the transition away from traditionally union-dense manufacturing jobs towards less unionized roles in the service sector, compounded by factors like rising international competition affecting goods-producing sectors, deregulation in industries like transportation and communication, faster job creation in areas of the country with low union presence, an influx of women into predominantly nonunion sectors, and a shift in attitudes against unions among management, workers, and regulatory bodies.

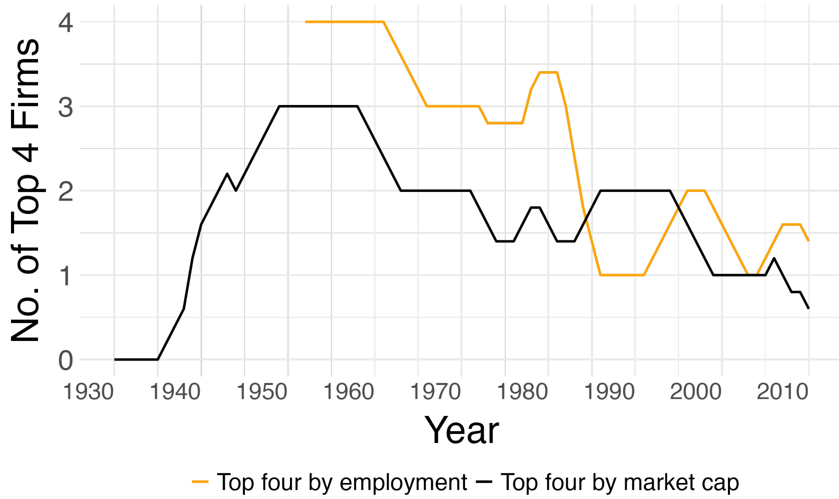
Contrary to the belief that these structural changes solely account for the decline in unionism, Linneman and Wachter (1986) suggest that within certain industries, the decrease in employment was largely confined to unionized positions, whereas nonunion jobs saw growth. They highlight an increase in union wage premiums during this time and argue that a significant portion of the union employment decline was due to these higher premiums. Subsequent work by Linneman et al. (1990) offers additional evidence and conclusions in line with their earlier findings.

Another critical perspective on the decline in unions focuses on their rent-seeking behavior, where unions extract a portion of the returns from long-term investments in capital and research and development. This behavior leads firms to reduce their investments in these areas strategically. Thus, the contraction of the union sector is partly seen as firms' long-term reaction to union rent-seeking, with the decline being seen as inevitable due to the poor economic performance and outlook of unionized firms over the past decades (Card et al., 2018; Kroft et al., 2020; Lamadon et al., 2022).

Furthermore, globalization, particularly offshoring jobs, may have significantly impacted union strength post–World War II. By relocating jobs to countries where labor is cheaper, companies could undermine unions' negotiating leverage, making union membership less attractive and leading to lower unionization levels (Rodrik, 1998). Choi et al. (2024) explore how offshoring weakens unions by offering firms a cost-effective alternative to domestic labor, diminishing unions' influence in negotiations. Their findings suggest that globalization plays a role in decreasing union presence.

Finally, an alternative explanation for the drop in union membership might be the high costs associated with coordinating unions. In the period following the war, the rapid expansion of job opportunities outpaced efforts to form new unions or grow existing ones, decreasing unionization rates (Western and Rosenfeld, 2012). Consequently, the density of the labor market appears to play a significant role. These suggest that there are other likely competing mechanisms in the decline of unionization beyond the adoption of automation technology, especially before the onset of productivity–wage decoupling in the mid to late 1970s. Therefore, in this paper, we focus on explaining one of

Figure 3. Decline in Union Contracts: 1930–2010



Note: The figure presents the number of top-four firms, based on market capitalization and employment, with significant union contracts during the same period. This data, sourced from Farber et al. (2021), combines market capitalization information from CRSP and employment figures from Compustat, with firms identified by PERMNO in CRSP and GVKEY in Compustat.

those mechanisms: the rise of automation technology.

2.3 Firm Size and Unionization

The prevailing argument in the literature is that increased firm size should naturally lead to more unionization, as larger firms have more resources for unions to negotiate. However, the trends presented in Figure 1b and Figure 2 indicate that as firm size has expanded over recent decades, the proportion of union representation has consistently declined. This decline in unionization is not limited to smaller companies but encompasses larger market players. In the mid–20$^{\text{th}}$ century, unionization was prevalent among the top four US companies. However, this landscape has altered significantly, with unionization rates among these large firms in the United States experiencing a marked decline, as detailed in Figure 3.

Historically, large firms have been more susceptible to unionization than smaller ones due to several key factors. The economies of scale in organizing a larger workforce allow for more efficient union formation and greater bargaining power (Capuano et al., 2014). Additionally, the substantial resources of larger firms can provide larger employment, higher wages, greater stability, and more clout to the union (Dinlersoz et al., 2017).

Union efforts have traditionally focused on the size and productivity of firms, with the most productive establishments being larger and yielding higher profits. The primary motivation for unionizing efforts is the anticipated long-term benefits of organizing nonunion firms (Dinlersoz et al., 2017). Evidence suggests that unions strategically target large, productive non-union firms, as highlighted by Jovanovic (1982). Yet, this perspective is challenged by the current trend of declining unionization rates, a paradox particularly striking given that firms today are larger than ever, underscored by the emergence of 'superstar firms.' This contradiction prompts a critical inquiry: If the scale of a firm is a significant determinant of unionization, what factors contribute to the reduced unionization rates observed? The key may lie in the changing nature of firm growth. In the modern era, firm expansion is often driven by automation, altering the traditional dynamics associated with workforce expansion. In an age dominated by technology–centric superstar firms, it becomes less clear whether the size of a company, now increasingly influenced by technological factors rather than workforce size, will continue to positively impact unionization in the manner it did in the mid–20$^{\text{th}}$ century.

2.4 Unions and Firm Productivity

The impact of unions on firm productivity is complex and can vary. From a neoclassical perspective, unions may be seen as labor market monopolies that raise wages above competitive levels, potentially reducing labor market efficiency and managerial flexibility, especially in staffing decisions based on seniority (Freeman and Medoff, 1984). Additionally, industrial unrest can negatively affect productivity by underutilizing firm resources and creating output uncertainty (Caves, 1980; Flaherty, 1987; Alder et al., 2023). Unions might deter investment by imposing a "tax" on returns through post-agreement rent-seeking (Grout, 1984). Additionally, Connolly et al. (1986) explore how unions impact investment in intangible capital and profitability, focusing on market value. The authors argue that unions can influence profitability by claiming a share of the returns from firm-specific intangible assets. The findings indicate that unionization diminishes the returns on research and development and consequently restricts innovation and technological advancement. Moreover, some union activities can strain industrial relations, potentially harming both productivity and earnings. However, productive collaboration between management and unions can enhance productivity by jointly focusing on increasing the overall 'pie' (Freeman and Medoff, 1984).

Efforts to understand the empirical effect of unions on productivity have yielded mixed outcomes. Brown and Medoff (1978) identified a significant positive impact of unions on U.S. manufacturing productivity, a finding later questioned due to data concerns (Hirsch and Addison, 1986). Hirsch (1991) studies how labor unions affect the performance and decisions of U.S. firms, focusing on how unions' pursuit of a portion of firms' earnings impacts investment in capital and research and development. The findings indicate that firms with significant union presence experienced lower profits, market value, and investments in capital, and research and development compared to their nonunion and less unionized counterparts. Subsequent U.S. research has reported varied results, showing both positive and negative influences of unions across different sectors (Allen, 1988; Clark, 1980). These findings underscore the complexity of determining unions' impact on productivity, highlighting that outcomes can vary based on the time frame, industry, and productivity measures.

2.5 What Do Unions Do?

The early discourse concerning labor unions' behavior primarily explored whether unions can be effectively modeled as entities aiming to optimize a coherent objective function. This discussion is primarily concerned with evaluating the significance of economic factors, such as market-induced constraints and employer reactions to wage negotiations, versus political factors, which encompass the amalgamation of worker and union leader preferences within the confines of market limitations, in shaping the wage policies or overall objectives of the union.

Bargaining structures in labor negotiations fall into two categories. In the first category, the focus of the negotiation between the union and the employer is solely on wages, with the employer retaining the authority to determine employment levels. The second category expands the scope of the negotiations to include wages and employment figures. These categories represent extremes within a broader framework where negotiations might cover wages and certain employment conditions (Hirsch, 1991).

The concept of monopoly unions represents the first categorization within bargaining structures, where such unions are viewed as entities striving to establish or leverage monopoly rents within a sector. This perspective suggests that monopoly unions possess the capacity to negotiate wages above market rates, potentially improving salaries for their members but possibly at the expense of increased unemployment among nonunionized workers or those sidelined from the job market by elevated wage costs (Dunlop et al., 1944). In this scenario, the union functions as a labor market monopolist, generating and seizing additional profits from the market (Oswald, 1982).

The efficient bargaining model, also known as the "right to manage" model, outlines a negotiation process where unions and employers discuss both wages and employment figures to ensure the greatest collective benefit. Introduced by McDonald and Solow (1981), this model implies a Pareto optimal outcome, where both sides see improved returns, balancing the interplay between wages and job numbers. Empirical research in this field demonstrates that while unions typically secure higher wages for their members, the impact on employment can vary, highlighting the importance of context and industry–specific factors in these negotiations (Card et al., 2017).

Hirsch (1990b,a, 1991) critiqued traditional models for treating union–imposed wage increases as exogenous changes in the factor price, overlooking long–term impacts. They noted that while firms might reduce employment to maintain profits after a wage hike, the effect on capital investment is unclear. The increased wage can make capital seem more cost–effective, potentially boosting capital use and investment (substitution effect). However, reduced output due to higher labor costs might also diminish demand for capital (scale effect). Therefore, the overall impact of wage increases on capital investment remains uncertain, depending on how these opposing forces balance out.

Consequently, Hirsch (1990b) introduced a long-term union approach, the rent-seeking model, where capital is adjustable over time. This model assesses how union efforts to secure economic rents impact a firm's investment decision. Essentially, union rent-seeking acts as a tax on capital returns, discouraging investment in physical assets, research and development, and other innovative activities (Hirsch, 1991). Given that research and development often yield long-lasting, firm–specific benefits, the potential for firms to capture returns from innovation means they are likely to cut back on these investments in response to union influence.

We align more with Hirsch's rent-seeking model, which views unions as organizations pursuing economic rents and emphasizes a comprehensive, long-term perspective that includes firm investments. This approach becomes even more relevant today as the emergence of automation technologies offers firms the possibility to substitute labor with capital extensively, a factor not previously accounted for in union research. In the current landscape, unions, acting as rent-seeking organizations, are drawn to firms with the highest potential rents but lack outside options. Automation introduces such an outside option, allowing firms to replace labor, thereby diminishing the rents unions seek and making these firms less attractive targets for unionization. This shift necessitates a reevaluation of unions as organizations navigating a landscape where their traditional leverage—labor—is increasingly replaceable by technological progress.

3 A Model of Firms and Unions

We offer a macroeconomic model consistent with the stylized facts presented in the previous section. Our model explains the complex dynamics among firm size, automation, and labor unions in the United States, spotlighting the interactions between productivity, labor adjustment costs, automation efficiency, and firm growth. The model indicates that in an era of swift technological advancement, increased productivity might not ensure higher wages, owing to firms' inclination to automate tasks traditionally performed by laborers.

3.1 Benchmark: The Case of a Single Firm

The impact of increased automation on employment and wages is non–trivial. Its effects are determined by how labor and automation interact, the ease of scalability of automated and labor–-operated tasks, and the firm's productivity level. Our analysis starts by exploring how automation, productivity, and wages interrelate within a representative firm model. We then expand this analysis to a setting involving multiple firms. The firm's profit optimization problem is the following:

$$\max_{\{a,l\}} \Pi(a, l) - g(l),$$

or

$$\max_{\{a,l\}} z(\theta a + l)^{\alpha} - aw_a - lw_l - g(l). \tag{1}$$

This objective function incorporates several key elements: z represents the firm's total (general purpose) factor productivity, setting the production scale. θ is the relative productivity of automated tasks compared to labor. The function $g(l)$, specified as $g(l) = \frac{l^{1+\gamma}}{1+\gamma}$, represents the convex adjustment associated with employing labor.[2] In line with Acemoglu and Restrepo (2018), the pro-

[2] In the model, no research sector produces automation technology; it is available to firms at the technological frontier, with set productivity paths. Firms adopt automation when it becomes profitable, based on their production scale. Since automation is scalable, we do not include a separate cost factor for automation adjustment in the model.

duction model we adopt allows for perfect substitution between automated tasks (a) and tasks carried out by laborers (l).

From the first–order conditions, the demand for automation becomes:

$$a \quad = \quad \max\left\{0, \left(\frac{\theta\alpha z}{w_a}\right)^{\frac{1}{1-\alpha}} - \left(\frac{w_a}{\theta} - w_l\right)^{\frac{1}{\gamma}}\right\}. \tag{2}$$

The first–order conditions reveal two key properties. First, when the productivity of automation, θ, is held constant, an increase in the general-purpose productivity term, z, makes it more likely for a firm to adopt automation. Specifically, a firm will switch to automation if $z > \hat{z}$, where $\hat{z}$ is defined as $\left(\frac{w_a}{\theta} - w_l\right)^{\frac{1-\alpha}{\gamma}} \frac{w_a}{\alpha\theta}$. In our analysis, we treat the unit cost of automation w_a as exogenous, whereas the unit wage rate of labor w_l will be determined in the general equilibrium.

This observation suggests that even without an extrinsic innovation process enhancing the relative efficiency of automation technology, a firm experiencing productivity growth in general–purpose technology (TFP growth) would naturally begin substituting labor tasks with automated ones. The rationale behind this stems from firm size dynamics and automation's scalability. TFP growth leads to a larger optimal production scale. However, expanding firm size through labor incurs adjustment frictions, whereas scaling up through automation does not. This automation scalability is an empirically plausible characteristic, as noted by Acemoglu and Restrepo (2022) and Hubmer and Restrepo (2022).

The second property derived from the first–order conditions is that a representative firm already utilizing automation ($a > 0$) will increasingly rely on it if the firm's general purpose productivity (indicated by a high z) continues to rise, evidenced by $\frac{\partial a}{\partial z} > 0$. In this context, for a firm that is automating ($a > 0$), the following equation determines the demand for labor:

$$l = \left(\frac{w_a}{\theta} - w_l\right)^{\frac{1}{\gamma}}. \tag{3}$$

For this firm, the demand for labor remains unaffected by the level of general–

purpose productivity. When these firms undergo productivity growth, they tend to scale up production through increased automation rather than hiring additional labor.

Hence, for a firm that has not adopted automation ($a = 0$), the demand for labor can be expressed as follows:

$$\alpha z l^{\alpha-1} - l^{\gamma} = w_l. \tag{4}$$

Consequently, when a firm does not engage in automation ($a = 0$), it is inclined to increase its size and employ more labor at a given wage level as its TFP rises.

Our findings indicate that when a firm faces labor adjustment costs, growth in general–purpose productivity prompts the adoption of automation. This implies that a larger–scale firm would depend more on automation than a smaller–scale firm, with the efficiency of automation shaping the correlation between automation intensity and firm size. The dynamics between factor costs and demands follow conventional patterns: a decrease in the cost of automation leads to reduced demand for labor and increased demand for automation, $\left(\frac{\partial a}{\partial w_l} > 0,\ \frac{\partial a}{\partial w_a} < 0\right)$. Likewise, a rise in wage rates results in a lower demand for labor and a higher demand for automation, $\left(\frac{\partial l}{\partial w_l} < 0,\ \frac{\partial l}{\partial w_a} > 0\right)$.

Under the assumption that the total labor supply is fixed at $\bar{l}$ and supplied inelastically, the general equilibrium effects of productivity growth indicate that at lower productivity levels (low z), an increase in productivity will result in higher wage rates and an expansion of firm scale. However, when productivity exceeds a certain threshold, further growth might not continue to drive wage increases; instead, wages begin to stagnate. In general equilibrium, the wage rate for labor w_l adjusts to clear the market:

$$\begin{aligned} w_{l,a=0} &= \alpha z \bar{l}^{\alpha-1} - \bar{l}^{\gamma} \\ w_{l,a>0} &= \frac{w_a}{\theta} - \bar{l}^{\gamma} \end{aligned}$$

Let us assume $\bar{l} = 1$ for analytical tractability. First, note that $w_l(\bar{z}, a =$

$0) = w_l(\bar{z}, a > 0)$, where $\bar{z} = \frac{w_a \bar{l}^{1-\alpha}}{\theta\alpha}$. This formulation indicates that $\frac{\partial w_l(a=0)}{\partial z} > 0$ and $\frac{\partial w_l(a>0)}{\partial z} = 0$, as illustrated in Figure 4.

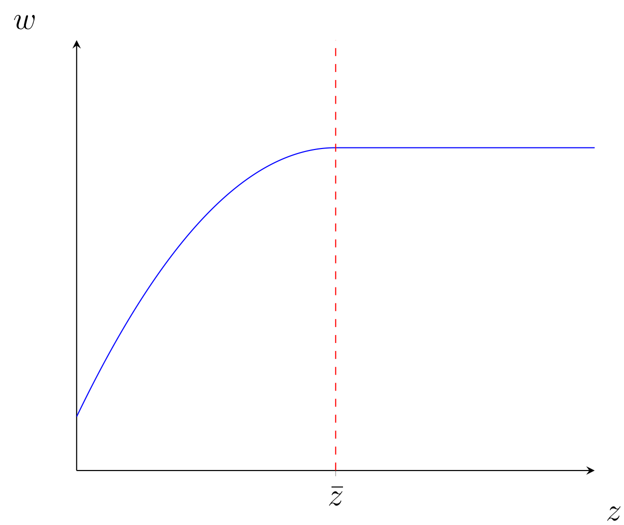
We must determine whether $\bar{z}$, the threshold productivity level at which wages begin to plateau for laborers, aligns in equilibrium with $\hat{z}$, the productivity level at which the firm transitions to automation. We need to verify this because if $\hat{z} < \bar{z}$, it would result in a sudden increase in the wage rate at the productivity level where firms switch to automation. This implies that automation could induce wage growth instead of a decline. We address this issue in our forthcoming lemma, and the detailed proof is provided in the Online Appendix Section A.1.

Lemma 1. *The two crucial threshold–productivity levels, $\bar{z}$ and $\hat{z}$, are found to be identical, meaning $\bar{z} = \hat{z}$. This implies that the equilibrium wage rate stagnates once the firm transitions to automation.*

The economic intuition behind this threshold is fundamentally tied to the efficiency of automation relative to labor. As a firm's general purpose productivity reaches this critical level, the benefits of automation, in terms of cost savings and production scalability, outweigh the benefits of additional labor employment. This transition point is crucial for understanding wage dynamics in an automated economy. While before the threshold point is reached, productivity growth leads to wage increases, wages stagnate beyond the threshold even with rising productivity.

The threshold at which firms decide to transition from labor-intensive production to automation might be influenced by a combination of technological, economic, and regulatory factors. Technological advancements in automation that either boost automation productivity or lower implementation costs can lower this threshold, making automating processes more appealing even at lower firm productivity levels. Similarly, any increase in labor costs—-stemming from wage growth or changes in regulatory frameworks, such as the introduction of higher minimum wage laws – can make automation a more cost–effective alternative to hiring more workers. Furthermore, economic policies and incentives designed to encourage investment in automation, including

Figure 4. Wage Stagnation: Single–Firm Case



Note: The figure demonstrates that, in a single–firm case, as general–purpose technology expands, worker wages initially increase but reach a plateau once a certain size threshold is crossed, $z > \bar{z}$, leading to wage stagnation thereafter.

tax breaks for technological investment, impact this threshold.

Proposition 1. *As general-–purpose technology grows, the firm expands and automates tasks increasingly. Initially, this growth boosts wages, but beyond a certain productivity threshold, further expansion leads to wage stagnation in the general equilibrium despite continued firm growth.*

This key finding indicates that a model factoring in the scalability of automated tasks compared to labor effectively captures TFP and firm size growth, along with the historical wage trends documented in Section 2.

In the Online Appendix Section B, we further demonstrate that the decoupling of general equilibrium wages from the long–term general–purpose productivity triggered by automation persists even within a context that integrates complementary capital and labor inputs, as modeled through a Cobb–Douglas production framework.

3.2 The Case of Multiple Firms

We next examine if the properties identified in Proposition 1 can be generalized to a set–up involving multiple firms. This extension is crucial, as, in a single–firm case, the firm accrues positive profits in equilibrium, inherently suggesting the possibility of new firms entering the market to take away parts of those profit gains.

Without loss of generality, we assume that there are two firms in the economy.[3] These two firms and the general equilibrium of the economy exhibit:

$$z < \left(\frac{w_a}{\theta} - w_l\right)^{\frac{1-\alpha}{\gamma}} \frac{w_a}{\alpha\theta} \equiv \hat{z}, \tag{5}$$

z represents the productivity level of both firms, which is below the critical $\hat{z}$ threshold required for switching to automation. Let us assume once more that the labor supply is fixed at a measure of 1, with $\bar{l} = 1$. Under these conditions, the general equilibrium wage rate in an economy with two firms, each having a productivity of z, can be characterized as follows:

$$w_l(z, z) = z\alpha \left(\frac{1}{2}\right)^{\alpha-1} - \left(\frac{1}{2}\right)^{\gamma}. \tag{6}$$

Consider a productivity process that increases the productivity for both firms to z' with $z' > \hat{z}$. In this case, the general equilibrium wage rate would adjust to the following:

$$w_l(z', z') = \frac{w_a}{\theta} - \left(\frac{1}{2}\right)^{\gamma}. \tag{7}$$

Despite the overall economic productivity growth, wage stagnation, i.e., $w_l(z, z) = w_l(z', z')$, prevails beyond the productivity threshold $\bar{z}$ – as also noted in the case of the single–firm. As an essential difference, wage stagnation tends to begin earlier in industries that allow multiple firms to enter compared to industries dominated by a single firm. We formalize this result

[3]Our theoretical results in this section extend to the case of N firms. We present the analysis of the case of two firms for ease of exposition.

in the following proposition, whose proof we provide in the Online Appendix Section A.2.

Proposition 2. *In a multi–firm scenario, as with a single–firm, initial productivity gains in a general–purpose technology drive both firm growth and wage increases. However, once productivity surpasses a certain threshold, firm size expands while wage growth stalls. Moreover, while the general equilibrium wage is higher with multiple firms, wage stagnation occurs at a lower productivity than in a single–firm case.*

This proposition generalizes our previous finding and shows that firm entry does not alter the general equilibrium property that wage stagnation can go hand in hand with productivity growth. This result is a deviation from traditional general equilibrium growth models, which typically posit that increased firm productivity elevates equilibrium wage rates – as also found in the recent literature on automation and growth, such as by Acemoglu and Restrepo (2022) and Hubmer and Restrepo (2022). We show that wages can stagnate, as documented in the stylized facts, in a general equilibrium set–up with productivity growth.

As a standard property, in Proposition 2, we also find that the labor market competition by firm entry increases equilibrium wages, as firm entry improves the efficient scale. As a novel – yet intuitive – finding, we also observe that competition has an adverse effect on how soon automation shift occurs and wage stagnation starts on the productivity growth path. We obtain this additional result for the case of multiple firms – in comparison to the case of a single firm because the marginal cost of production is higher for labor–operated tasks with multiple firms, which induces firms to turn to automation earlier. We illustrate these findings in Figure 5. Furthermore, in the Online Appendix Section B we demonstrate that early automation trigger effects of firm entry also prevail under a Cobb-Douglas specification with capital-labor complementarity.

Our theoretical analysis reveals that industries that exhibit faster growth of automation efficiency (low w_a or high θ) and firm entry due to industry–

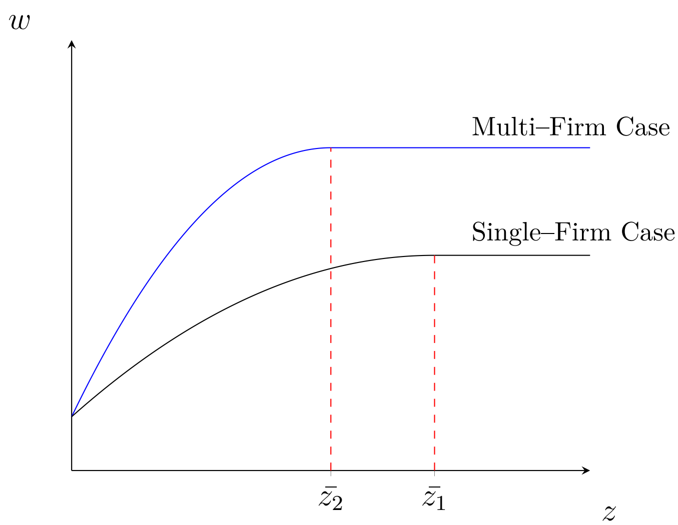
level institutional characteristics would experience earlier and larger wage–productivity decoupling. We support these theoretical properties with industry–level empirical trends that we document in Online Appendix Figure C1 and Figure C2, which provide data on wage–productivity decoupling, hourly compensation, and the number of firms in manufacturing, retail, and transportation industries. Notably, the manufacturing and retail industries, which embraced automation earlier than the transportation industry, exhibited lower and more stagnant wages than the transportation industry, where automation was less prevalent.[4] Additionally, the retail sector, characterized by a significantly higher number of firms than the transportation industry, experienced a more pronounced wage-productivity decoupling than the transportation industry. These empirical trends align with the assertions made in Proposition 2. They support our theoretical framework, highlighting the correlation between the number of firms in a sector, the extent of automation adoption, and its impact on wage trends.

One interesting implication of Figure 5 and Proposition 2 is that efforts to increase barriers to firm entry might not only come from the expected large incumbent firms seeking to protect their market position but also from unions. This is because Figure 5 shows that in a multi–firm case, wage-productivity decoupling occurs earlier than in a single–firm case; however, at a higher general equilibrium wage. This means that in industries where firm entry is restricted, progression to the automation–switch threshold, and thus to wage-productivity decoupling, is delayed. Therefore, unions might have a vested interest in delaying this transition to extend the period of surplus generation and their ability to capture these rents.[5]

[4] Autor et al. (2017); Acemoglu and Restrepo (2019, 2020); Acemoglu et al. (2020) highlight that both the manufacturing and retail sectors are among the early adopters of automation technologies. Furthermore, they state that the impact of robots on employment is most significant in the manufacturing sector, especially within industries with the highest exposure to robotic technologies.

[5] Farber (1986) suggests that unions act as gatekeepers in the labor market, effectively blocking the entry of new, non-unionized firms to maintain their monopolist position in the sale of labor.

Figure 5. Wage Decline: Multiple–Firm Case



Note: The figure illustrates that in a multi–firm case, the expansion of general–purpose technology initially leads to an increase in worker wages. However, as firms grow beyond a certain size threshold, $z > \bar{z}$, it plateaus (shown in blue). This flattening happens at a lower z value than the single–firm case (shown in black).

3.3 Union Rents

Our analysis revealed that automation could lead to stagnant wages, even as it increases firm value. This situation poses the question of whether such a trend might strengthen unionization efforts and lead to demands for higher wages from firms. In this part of the model, we conceptualize unions as rent-seeking organizations, aligning with Hirsch and Berger (1984); Hirsch (1990b, 1991). According to this framework, the union operates as a rent seeker, gravitating towards firms that offer the highest potential rents. This perspective deviates from traditional views of union behavior by adopting a forward-looking stance, incorporating the dimension of firm investment into the discourse on union activities. However, this model suggests that union rent-seeking effectively taxes capital, leading firms to cut back on their capital investments.

While we draw upon this body of literature, our model introduces a key extension by considering the role of labor-substituting technologies as an outside option for firms. This section aims to explore the implications of such options on the rents accessible to unions, examining the outcomes in cases with and without the availability of labor substituting technologies. We continue with the model above, featuring two firms and a unit labor supply chosen for its tractable characteristics.

Suppose that firms operate with or without automation based on the following timing of events:

1. Firms observe productivity z, automation efficiency θ, labor friction γ, take w_a and w_l as given, and decide whether they would like to automate ($a > 0$) or not ($a = 0$).

2a. Should a firm opt against automation, it employs laborers exclusively. Once this decision is made, the firm is committed to completing the production process solely with labor l, as automated factors are no longer an option if the automation technology is not implemented in the initial stage.

2b. If a firm decides to automate, the firm hires laborers and has automation technology in place. Consequently, the firm processes production using laborers (l) and automated factors (a).

3. Labor adjustment costs are sunk costs: once firms have hired laborers, these costs become irrevocable and cannot be recovered.

4. In the initial production stage, after completing hiring and automation technology placement, workers within a firm can form a union and demand a share of the profits from the firm owners. The extent of rents laborers can request is influenced by the availability of automation technology. If automation technology is accessible, firms can easily substitute labor at the marginal cost of automation, as automated factors represent an alternative option. In this scenario, the marginal cost of automated production limits the potential for union rents. Conversely, if automation technology is not available, laborers can disrupt the entire firm's

operation, as the firm owners lack an alternative production factor without automation (no outside option).

To investigate whether heightened automation and potential wage reduction encourage unionization, we assess two extreme scenarios: keeping all other parameters constant, we consider the case of low z, denoted with z_l satisfying $z_l < \bar{z} = \hat{z}$, and the case of high z, denoted with z_h satisfying $z_h > \bar{z} = \hat{z}$. These two cases allow us to study the union benefits and unionization dynamics in regimes with (z_h) and without (z_l) automation characterized by the productivity level of the general purpose technology.

Case 1 (z_l; the firm has no outside option). z is sufficiently low so that the firm opts not to automate, eliminating the threat of automation for laborers.

Under these circumstances, the maximum rent that the union can capture is determined as follows:[6]

$$R_{z_l} = \underbrace{z\left(\frac{1}{2}\right)^{\alpha}}_{\text{Total Output}} - \underbrace{\underbrace{\left(\alpha z\left(\frac{1}{2}\right)^{\alpha-1} - \left(\frac{1}{2}\right)^{\gamma}\right)}_{\text{Wage Rate } w_l} \times \underbrace{\left(\frac{1}{2}\right)}_{\text{Labor Employed}}}_{\text{Total Cost of Labor}} > 0.$$

Therefore, if workers unionize, there exists a potential for laborers to capture rents.

Case 2 (z_h; the firm has an outside option). z is sufficiently high that the firm chooses automation, posing a threat to laborers of being replaced by automated factors.

Here, firms have the option to substitute labor with automated factors. Referring to the equilibrium outlined in the previous subsection, the total

[6] It is important to note that each component of this rent equation was established in the previous subsection.

labor cost for the firm in this case is as follows:

$$\underbrace{\underbrace{\left(\frac{w_a}{\theta}-\left(\frac{1}{2}\right)^{\gamma}\right)}_{\text{Wage Rate } w_l} \quad\times\quad \underbrace{\left(\frac{1}{2}\right)}_{\text{Labor Employed}}}_{\text{Total Cost of Labor}} .$$

For the firm, the total cost of replacing the labor employed with automated factors is (firm's outside option):

$$\underbrace{\underbrace{\left(\frac{w_a}{\theta}\right)}_{\text{MC of Automation}} \quad\times\quad \underbrace{\left(\frac{1}{2}\right)}_{\text{Autom. Replac.}}}_{\text{Total Cost of Automated Replacement}} .$$

Hence, we can formulate the potential scope for unionization in case 2 as follows:

$$R_{z_h}=\left(\frac{w_a}{\theta}\right)\left(\frac{1}{2}\right)-\left(\frac{w_a}{\theta}-\left(\frac{1}{2}\right)^{\gamma}\right)\left(\frac{1}{2}\right)=\left(\frac{1}{2}\right)^{1+\gamma}>0.$$

However, whether these rents exceed or fall short of those in the previous case is yet to be determined. By subtracting R_{θ_h} from R_{θ_l}, we can observe the following:

$$R_{z_l}-R_{z_h}=z\left(\frac{1}{2}\right)^{\alpha}-\alpha z\left(\frac{1}{2}\right)^{\alpha-1}\left(\frac{1}{2}\right)=(1-\alpha)z\left(\frac{1}{2}\right)^{\alpha}>0.$$

$R_{z_l}-R_{z_h}>0$ indicates that while heightened automation efficiency enhances the industry's total value added and depresses wages, it diminishes the potential for unionization gains for laborers.

By analyzing the R_{z_l} function, we recognize another crucial relationship: in a no–automation (no outside option) context, increased value added (a rise in z) leads to increased gains from unionization. This relationship becomes evident when we calculate the first partial derivative of R_{z_l} concerning z, resulting in:

$$\frac{\partial R_{z_l}}{\partial z} = (1-\alpha)\left(\frac{1}{2}\right)^{\alpha} > 0,$$

This underscores a positive correlation between value–added and gains from unionization for an industry that did not replace labor with automated tasks. The following proposition summarizes our key findings regarding the relationship between growth and unionization.

Proposition 3. *Until the automation cut–off productivity level, $\bar{z} = \hat{z}$, is reached, higher general–purpose productivity increases the likelihood of forming unions and expansions in firms' value–added and equilibrium wages. However, after this threshold, the desirability of forming unions diminishes. This is because, considering the expected costs of unionization, the potential gains for unions, and consequently the net benefits, decrease as automation advances.*

Our rent-seeking argument is consistent with the implications of a union bargaining channel, which can easily be nested within our framework. To analyze the impact of this additional channel, we introduce union bargaining power as a function of the general–purpose technology in Online Appendix Section D.[7] This model merges union bargaining power with extractable rents, matching observed trends and explaining the delay between the post-1950s decline in union membership and the productivity-wage gap in the 1970s. It proposes that the decrease in union influence did not immediately impact wages between the 1950s and 1970s, during which extractable rents by unions and wages continued to grow despite weakening union strength. This period ended when automation started impacting the labor market, yet unionization rates continued to decline as firms found outside options through automation.

Our model aligns with the stylized facts in Section 2. Initially, as general–purpose technology productivity increases, it boosts total output, wages, and union rents. However, output continues to rise beyond a productivity threshold, but wages do not, while union rents start to decrease. Multiple firms'

[7] We define bargaining power as the proportion of the total available profits that a union can successfully obtain from the firm (Shister, 1943).

entry into the industry maintains these trends. It provides the additional empirically–supported insight that wage stagnation could happen earlier in sectors that allow firm entry. Finally, we show that labor–substituting technologies reduce potential union rents, making such firms less attractive to unions and, thus, redefining the strategic interplay between unions and firms in the context of modern technological advancements.

4 Conclusion

Recent decades, as exemplified by the growth of superstar firms, witnessed a convergence of increased automation and value-added alongside reduced labor share and union membership. In contrast, during the mid-20$^{\text{th}}$ century, productivity gains boosted both value-added and union rents with limited automation. Thus, historical productivity and automation efficiency shifts correlate with changing US unionization and firm dynamics trends.

Our paper presents a general equilibrium macro model that qualitatively aligns with these trends. It reveals a nuanced interaction between firm size, productivity, industry dynamics, automation, and unionization in the context of historical US economic trends. It underscores the pivotal role of automation's scalability in altering the labor landscape – heightening firm value – while concurrently eroding traditional labor benefits and union power. This dichotomy captures the essence of contemporary economic challenges, offering a comprehensive framework to understand the complex interplay between technological advancements and labor dynamics.

The implications of our findings are far-reaching for policymakers and the labor market. As firms continue to expand and automation becomes increasingly prevalent, the balance of power may shift further away from labor, exacerbating income disparities and reducing labor's bargaining power. This calls for reevaluating labor policies and union strategies, ensuring they evolve with technological progress. Future research could explore how these dynamics play out across different sectors and economies, offering a path to more equitable growth and labor representation in the age of automation.

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Online Appendix to:

Firms and Unions

by Hazal Sezer & Burak Uras

A Proofs

A.1 Proof for Lemma 1

At $\bar{z}$ the equilibrium wage rate is determined as $w_l(\bar{z}) = \alpha\bar{z} - 1 = \frac{w_a}{\theta} - 1$ with $\bar{z} = \frac{w_a}{\alpha\theta}$. We then plug in $w_l(\bar{z}) = \frac{w_a}{\theta} - 1$ in the expressions for the labor demand and $\hat{z}$. We first observe from equation (3) that the demand for labor equals to the aggregate supply of labor at $w_l(\bar{z}) = \frac{w_a}{\theta} - 1$, with $l(w_l(\bar{z})) = \left(\frac{w_a}{\theta} - \frac{w_a}{\theta} + 1\right)^{\frac{1}{\gamma}} = 1$. Plugging $w_l(\bar{z})$ in $\hat{z}$, we obtain

$$\hat{z} = \left(\frac{w_a}{\theta} - w_l(\bar{z})\right)^{\frac{1-\alpha}{\gamma}} \frac{w_a}{\alpha\theta} = \frac{w_a}{\alpha\theta} = \bar{z},$$

and thus the conclusion that $\bar{z}$ and $\hat{z}$ coincide.

A.2 Proof for Proposition 2

$w_l(z,z) \geq w_l(z',z')$, if

$$\alpha z \left(\frac{1}{2}\right)^{\alpha-1} - \left(\frac{1}{2}\right)^{\gamma} > \frac{w_a}{\theta} - \left(\frac{1}{2}\right)^{\gamma} \tag{A.1.1}$$

$$\Rightarrow z > \left(\frac{1}{2}\right)^{1-\alpha} \frac{w_a}{\alpha\theta} \equiv \bar{z}. \tag{A.1.2}$$

We then check the alignment between $\bar{z}$ and $\hat{z}$, which is the automation–switch cut–off productivity of firms. Utilizing $w_l(\bar{z},\bar{z})$ from (A.1.2) and $\bar{z}$ in $\hat{z}$ we get

$$\left(\frac{w_a}{\theta} - \frac{w_a}{\theta} + \left(\frac{1}{2}\right)^{\gamma}\right)^{\frac{1-\alpha}{\gamma}} \frac{w_a}{\alpha\theta} \equiv \hat{z}, \tag{A.1.3}$$

which yields

$$\hat{z} = \left(\frac{1}{2}\right)^{1-\alpha} \frac{w_a}{\alpha\theta} = \bar{z}.$$

To complete the proof of the proposition, we can first note that $w_l(z, z) > w_l(z)$ for all z, and thus, the wage rate for any given level of productivity is greater within a sector that exhibits multiple firms compared to the case of a single firm. Furthermore, the automation switch (the wage stagnation) cut–off productivity level, $\bar{z}$, with multiple firms is smaller than that of the single-firm case. We can observe this in

$$\underbrace{\left(\frac{1}{2}\right)^{1-\alpha} \frac{w_a}{\alpha\theta}}_{\equiv \bar{z}_2} < \underbrace{\frac{w_a}{\alpha\theta}}_{\equiv \bar{z}_1},$$

which compares the two $\bar{z}$'s between the cases of multiple firms and a single firm (for comparison purposes, $\bar{z}_1$ is utilized to denote the threshold in the single-firm case and $\bar{z}_2$ denotes the threshold in the multi–firm case).

B Productivity-Wage Decoupling with Capital–Labor Complementarity

This section shows that the relationship between firms' general–purpose technology growth and equilibrium wages can exhibit decoupling with endogenous automation (technological change) in a Cobb-Douglas production framework.

B.1 Endogenous Technological Choice: Single–Firm Case

To start discussing endogenous technological change, let us consider a framework with one firm, and the wage rate is determined in the general equilibrium. The firm's production function is given by

$$A\left(K^{\alpha}L^{1-\alpha}\right)^{\gamma},$$

where A is the general purpose technology (productivity), K is capital, L is labor, and α is the degree of labor-substituting automation. The parameter γ determines the decreasing returns to scale and generates room for firm profits. We assume that the cost of capital (rental rate), r, is given exogenously, while the wage rate of the labor, w, is determined in general equilibrium.

Solving the maximization problem of the firm,

$$\max_{\{K,L\}} AK^{\phi_1}L^{\phi_2} - rK - wL, \quad \text{where} \;\; \phi_1 = \alpha\gamma \;\; \text{and} \;\; \phi_2 = (1-\alpha)\gamma,$$

we find the wage (w) and profit (π) functions resulting from general equilibrium market clearing, where $\bar{L}$ is supplied inelastically:

$$\begin{aligned} w &= \phi_2 A^{\frac{1}{1-\phi_1}}\left(\frac{\phi_1}{r}\right)^{\frac{\phi_1}{1-\phi_1}}\bar{L}^{\frac{1-\phi_1-\phi_2}{\phi_1-1}}, \\ \Pi &= A^{\frac{1}{1-\phi_1}}\left(\frac{\phi_1}{r}\right)^{\frac{1}{1-\phi_1}}\left((1-\phi_2)\left(\frac{\phi_1}{r}\right)^{\phi_1} - r\right)\bar{L}^{\frac{\phi_2}{1-\phi_1}}. \end{aligned}$$

For parameter values $\alpha = 0.5$, $\gamma = 0.25$, $r = 0.05$, $\bar{L} = 100$, and $A = 50$, wages and profits can be depicted for varying levels of the general purpose technology A and capital intensity α.

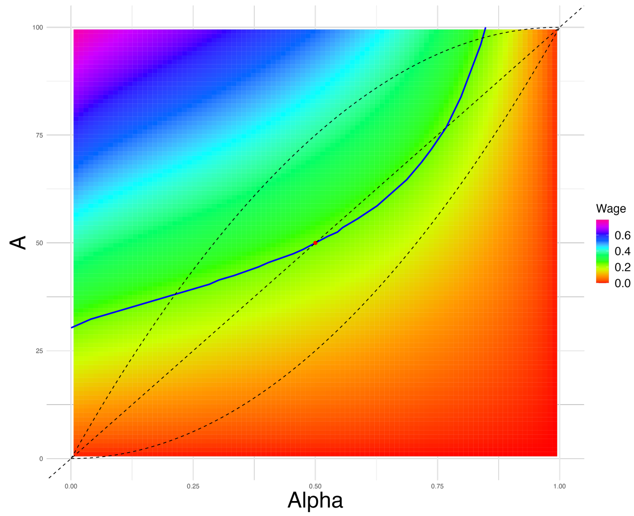


Figure B1. Wage (Single–Firm Case)

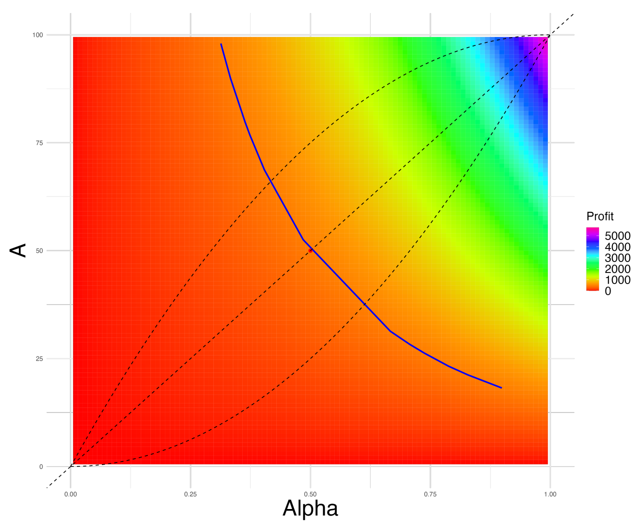


Figure B2. Profit (Single–Firm Case)

Using the wage dynamics in Figure B1, we can observe that wage stagnation (and even contraction) can go hand in hand with productivity growth. The dashed lines indicate that when A growth is positively related to α growth,

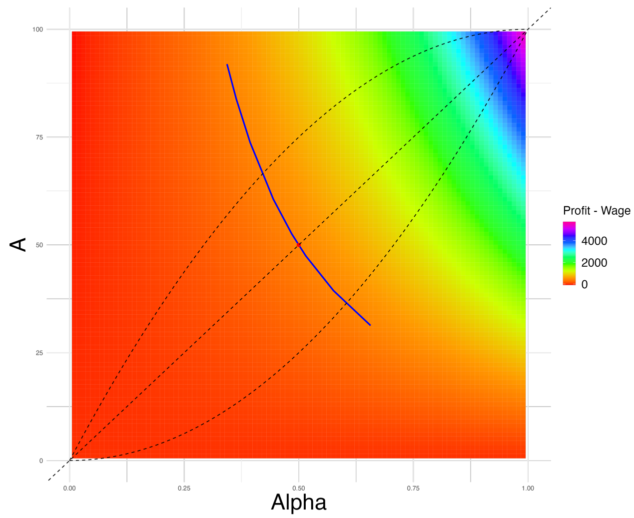


Figure B3. Profit–Wage (Single–Firm Case)

in linear, concave, or convex forms, wages would exhibit low growth (at best), stagnate, or even decline - as can be observed through dynamics of the colors that the dashed lines go through.

We need to address how capital intensity α evolves in an economy where firms' general-purpose productivity exhibits exogenous growth. More specifically, if the firm controls production techniques (e.g., automation of tasks), what would be the profit-maximizing α to be chosen by the firm owner as the general-purpose productivity grows, and how would this choice of α translate into general equilibrium wages paid by the firm?

To address this question, we refer to Figures B1 and B2, which depict the different values of wages and profits resulting from various combinations of A and α while retaining all other parameters at their benchmark levels. Figure B3 combines the two figures, depicting the gap between profits and the total wage bill. As Figure B3 illustrates, for low productivity levels (A), the difference between profits and wages - implied by different values of α's - is low. This difference monotonically increases as A grows, and for high levels of A, the difference becomes striking, which is also confirmed in the complementary Figure B1 and Figure B2. While wages get maximized at $\alpha = 0$ corner, the profits are maximized at $\alpha = 1$ corner.

The intuition for this result: With the interest rate set at r, and thus the cost of capital fixed, firms opt for labor–intensive technologies (low α) when the general equilibrium wage rate is low relative to capital cost. However, as productivity factor A increases, the equilibrium wage rate rises, making labor more expensive. Consequently, firms shift away from labor–intensive technologies in favor of capital–intensive methods to maximize profits.

This result implies that productivity growth induces a decoupling between firm profits and wages – concerning the production technologies that maximize profits vs wages. Suppose the firm owner controls the production technology choice (α's). In that case, this can very well imply wage stagnation (or decline) as the firm owner would be interested in adopting capital–intensive technologies in the face of productivity growth. This result shows that a firm would prefer to move away from labor–intensive technologies, reducing the equilibrium wages workers receive on a long-run productivity growth path.

Overall, the results of this subsection reinforce the findings from our benchmark (single–firm) specification presented in the main body of the paper: imposing capital–labor complementarity via Cobb–Douglas production and incorporating ease of scalability of automated tasks through constant interest rates allow us to obtain the same results we documented in Section 3.1. General–purpose technology growth gradually leads firms to switch to automation and wage stagnation.

B.2 Endogenous Technological Choice: Multi–Firm Case

In this subsection, we illustrate that firms of heterogeneous productivity easily reach a consensus that they would *all* benefit from higher capital intensity - and thus jointly prefer more automation - as the general purpose productivity grows.

For this purpose, let us consider a heterogeneous firm set-up with firms differing in general–purpose productivity and endogenously selecting production techniques (α's). We need to show that within such a framework, a GPT process that simultaneously increases all firms' productivity would eventually lead to the profit-wage decoupling property we described in the previous subsection.

To illustrate that property, let us consider the extension of the set-up into a framework with two firms, where individual productivity A_i satisfies $A_i = a_i + \theta$, where $i \in \{1, 2\}$, a_i is idiosyncratic productivity of firm i and θ is a common productivity term. We are interested in understanding what are the implications of growth in θ on profit-wage decoupling associated with different values of α. Importantly, we will also study whether we obtain a decoupling between the profit levels of the two firms concerning α.

Firm 1's production function:

$$A_1 K^{\phi_1} L^{\phi_2} \text{ where } \phi_1 = \alpha\gamma \text{ and } \phi_2 = (1-\alpha)\gamma.$$

Firm 2's production function:

$$A_2 K^{\phi_1} L^{\phi_2} \text{ where } \phi_1 = \alpha\gamma \text{ and } \phi_2 = (1-\alpha)\gamma.$$

Solving the profit maximization problem of firms 1 and 2, we obtain the following:

$$w = \phi_2 \left((a_1+\theta)^{\frac{1}{1-\phi_1-\phi_2}} + (a_2+\theta)^{\frac{1}{1-\phi_1-\phi_2}} \right)^{\frac{1-\phi_2-\phi_1}{1-\phi_1}} \left(\frac{\phi_1}{r} \right)^{\frac{\phi_1}{1-\phi_1}} \bar{L}^{\frac{1-\phi_1-\phi_2}{\phi_1-1}}$$

$$\Pi_1 = (a_1+\theta)^{\frac{1}{1-\phi_1-\phi_2}} \left((a_1+\theta)^{\frac{1}{1-\phi_1-\phi_2}} + (a_2+\theta)^{\frac{1}{1-\phi_1-\phi_2}} \right)^{\frac{\phi_2}{\phi_1-1}} \left(\frac{\phi_1}{r} \right)^{\frac{1}{1-\phi_1}} \left((1-\phi_2) \left(\frac{\phi_1}{r} \right)^{\phi_1} - r \right) \bar{L}^{\frac{\phi_2}{1-\phi_1}}$$

$$\Pi_2 = (a_2+\theta)^{\frac{1}{1-\phi_1-\phi_2}} \left((a_1+\theta)^{\frac{1}{1-\phi_1-\phi_2}} + (a_2+\theta)^{\frac{1}{1-\phi_1-\phi_2}} \right)^{\frac{\phi_2}{\phi_1-1}} \left(\frac{\phi_1}{r} \right)^{\frac{1}{1-\phi_1}} \left((1-\phi_2) \left(\frac{\phi_1}{r} \right)^{\phi_1} - r \right) \bar{L}^{\frac{\phi_2}{1-\phi_1}}$$

For $r = 0.05$, $\bar{L} = 100$, $\gamma = 0.25$, $a_1 = 65$, $a_2 = 35$, $\alpha = 0.5$, and $\theta = 20$ we obtain:

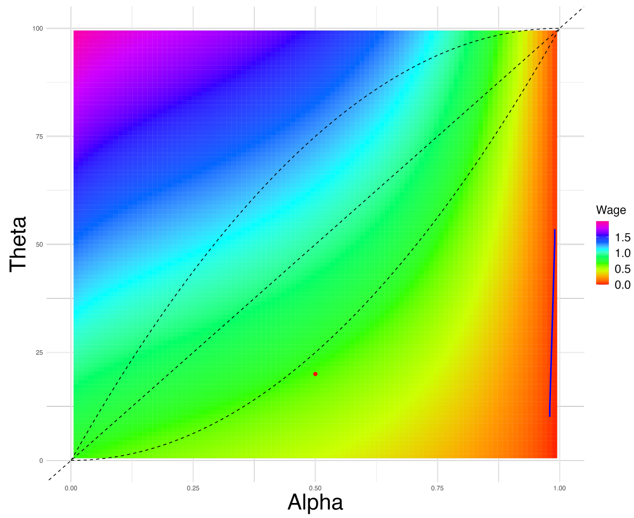


Figure B4. Wage (Multi–Firm Case)

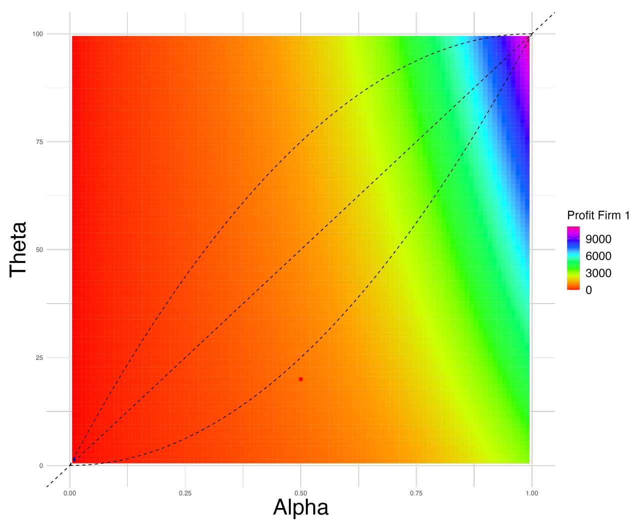


Figure B5. Profit Firm 1 (Multi–Firm Case)

The graphical illustrations make two critical points. First, the profit-wage decoupling property concerning "the α that maximizes wages and profits" continues to hold with two firms. Regardless of the productivity differential between the two firms, while firms prefer a large α (and more so for higher

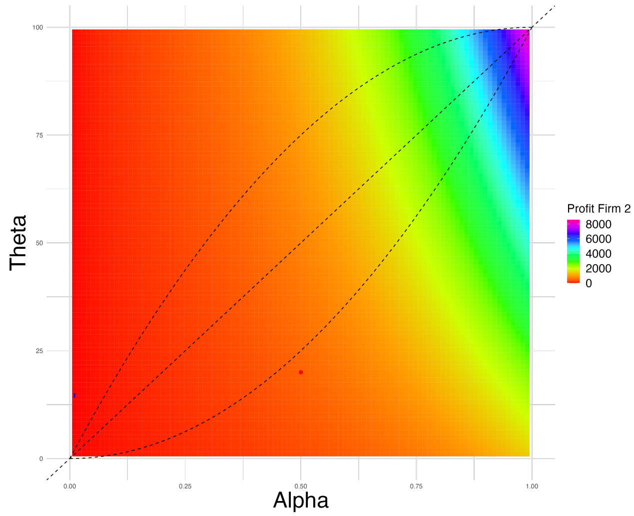


Figure B6. Profit Firm 2 (Multi–Firm Case)

levels of θ), laborers prefer a low α. This result indicates that firms of different productivity levels can reach a consensus and converge to a high capital intensity as the industry's overall productivity increases.

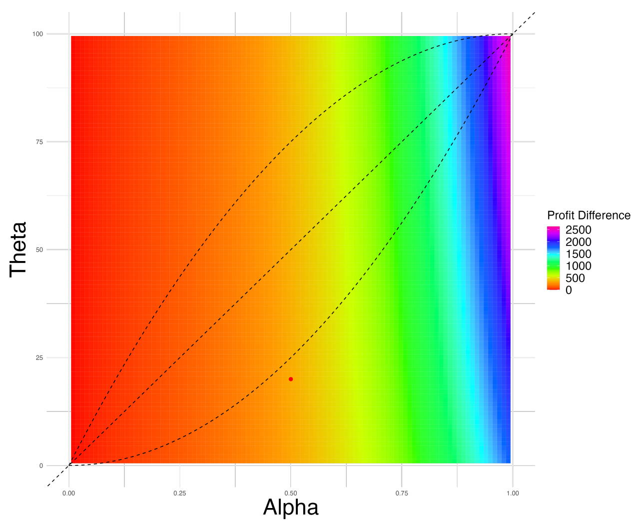


Figure B7. Differences in Profits for $a_1 = 65$, $a_2 = 35$, and baseline $\theta = 20$ (Multi–Firm Case)

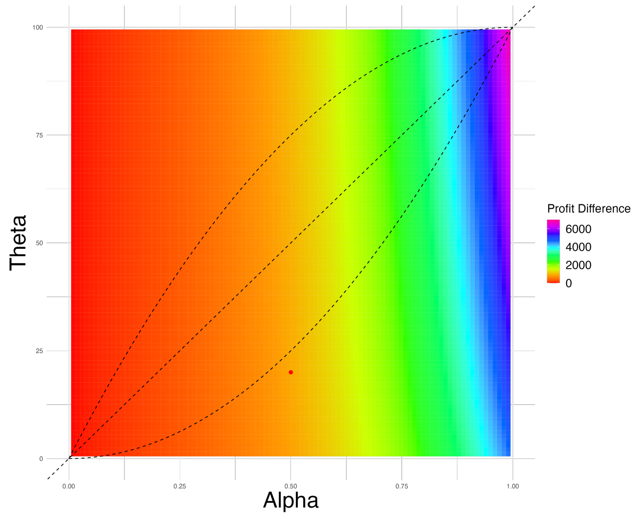


Figure B8. Differences in Profit for $a_1 = 90$, $a_2 = 10$, and baseline $\theta = 20$ (Multi–Firm Case)

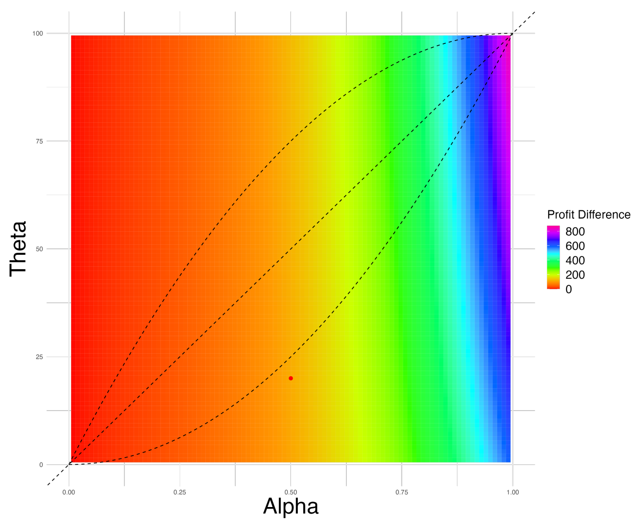


Figure B9. Differences in profit for $a_1 = 55$, $a_2 = 45$, and baseline $\theta = 20$ (Multi–Firm Case)

B.2.1 N–Firm Case

Finally, we generalize the multi-firm set-up to allow for the industrial entry of N firms and show that firm entry increases the benefits from automation and leads to earlier automation shifts as we had captured in the benchmark model in Section 3.2. As an additional insight into the Cobb-Douglas production technology, we also show that the strength in decoupling between wages and profits (i.e., by how much optimal wages and optimal profits deviate from each other concerning α) depends on the firm entry.

We first derive the general equilibrium wage rate and the profit for an arbitrary firm j among the distribution of N firms that enter the industry with varying degrees of idiosyncratic productivity:

$$\begin{aligned} w &= \phi_2 \left(\sum_{i=1}^{N} (a_i + \theta)^{\frac{1}{1-\phi_1-\phi_2}} \right)^{\frac{1-\phi_2-\phi_1}{1-\phi_1}} \left(\frac{\phi_1}{r} \right)^{\frac{\phi_1}{1-\phi_1}} \bar{L}^{\frac{1-\phi_1-\phi_2}{\phi_1-1}} \\ \Pi_j &= (a_j + \theta)^{\frac{1}{1-\phi_1-\phi_2}} \left(\sum_{i=1}^{N} (a_i + \theta)^{\frac{1}{1-\phi_1-\phi_2}} \right)^{\frac{\phi_2}{\phi_1-1}} \left(\frac{\phi_1}{r} \right)^{\frac{1}{1-\phi_1}} \left((1-\phi_2) \left(\frac{\phi_1}{r} \right)^{\phi_1} - r \right) \bar{L}^{\frac{\phi_2}{1-\phi_1}} \end{aligned}$$

Using the N firm case with $r = 0.05$, $\bar{L} = 100$, $\gamma = 0.25$, $\alpha = 0.5$, and $\theta = 20$, we first observe that aggregate general purpose productivity growth increases the desirability of more capital-intensive technologies for all firms - as shown in Figures B13 to B15. Furthermore, in line with our benchmark results, Cobb-Douglas production specification does not change the model's property, which is that increasing firms' entry increases automation's desirability and leads to earlier automation shifts on the general purpose productivity growth path.

While in Figure B10 to Figure B15 we illustrate an environment with heterogeneous firms by keeping the median idiosyncratic productivity a_i fixed at 50, in Figure B16 to Figure B21, we assign the same idiosyncratic level of $a_i = 50$ to each firm. As evident from these figures, the patterns in wages and profits are largely the same when we compare the specifications with and without firm productivity heterogeneity.

In addition, we capture an additional and exciting trend for the level of capital intensity (α) that maximizes the wages. As we note in Figures B10 to B12, the degree of capital intensity that maximizes wages increases as the number of firms in the industry increases. That means in a more competitive environment (captured by a larger number of firms), workers could also benefit from an expansion in capital share – and thus from a decline in their labor share.

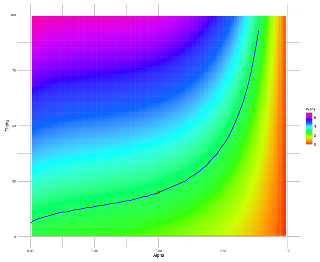


Figure B10. Wages - 10 Firms

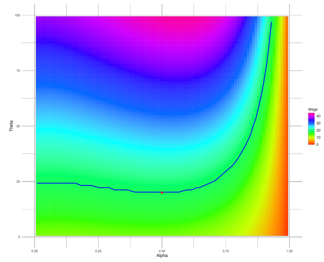


Figure B11. Wages - 100 Firms

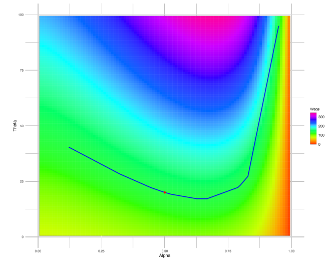


Figure B12. Wages - 1000 Firms

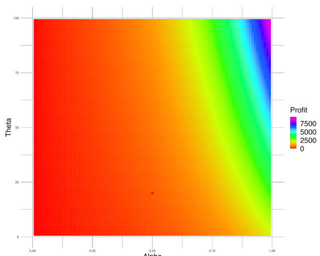


Figure B13. Profits - 10 Firms

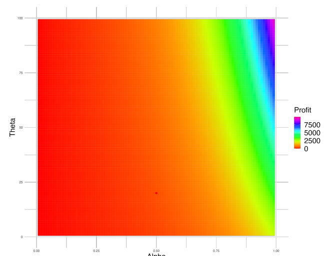


Figure B14. Profits - 100 Firms

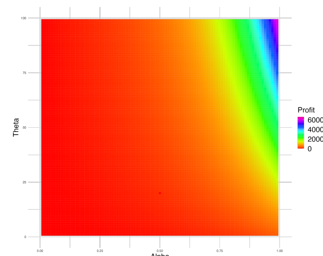


Figure B15. Profits - 1000 Firms

To formally explain the patterns observed in wages and the degree of automation that maximizes wages, suppose that there are N firms of the same idiosyncratic productivity (we focus on the case of homogeneous productivity across firms, as the graphical analysis reveals that the key results obtained above are due to increasing the number of firms and not so much due to increasing the heterogeneity across firms). As we observe in Figure B16 to Figure B21, a higher number of firms can indeed increase the desirability of a high capital intensity for the workers. Keeping a constant across firms, we can express the wage rate as:

$$w = \underbrace{N^{\frac{1-\gamma}{1-\alpha\gamma}}}_{\equiv\omega_1} \underbrace{\phi_2 \left(a+\theta\right)^{\frac{1}{1-\phi_1}} \left(\frac{\phi_1}{r}\right)^{\frac{\phi_1}{1-\phi_1}} \bar{L}^{\frac{1-\phi_1-\phi_2}{\phi_1-1}}}_{\equiv\omega_2}.$$

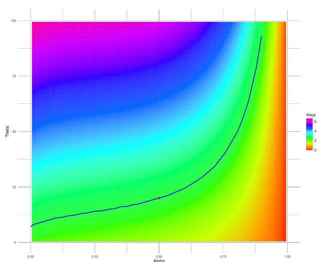


Figure B16. Wages - 10 Firms

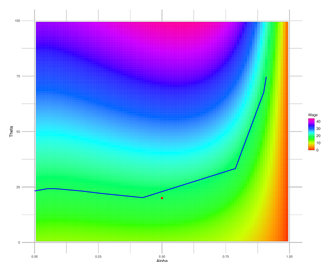


Figure B17. Wages - 100 Firms

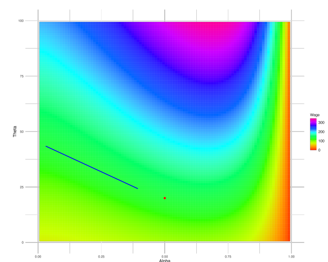


Figure B18. Wages - 1000 Firms

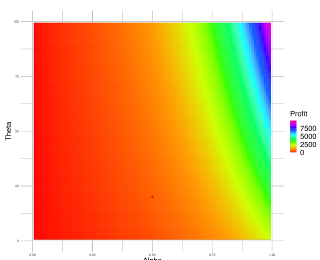


Figure B19. Profits - 10 Firms

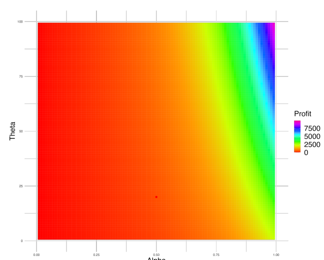


Figure B20. Profits - 100 Firms

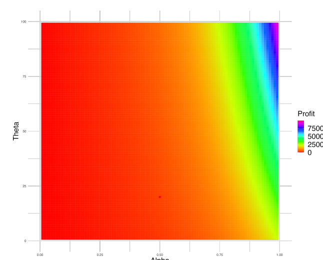


Figure B21. Profits - 1000 Firms

We can note that there is a strategic complementarity between N and α: referring to the definition of ω_1 above, we can easily observe that $\frac{\partial^2\omega_1}{\partial N \partial\alpha} > 0$, because taking logs at ω_1 and taking its second partial with respect to N and α gives

$$\frac{\partial^2 ln(\omega_1)}{\partial N \partial \alpha} = \frac{1}{N}\frac{\alpha\gamma(1-\gamma)}{(1-\alpha\gamma)^2} > 0.$$

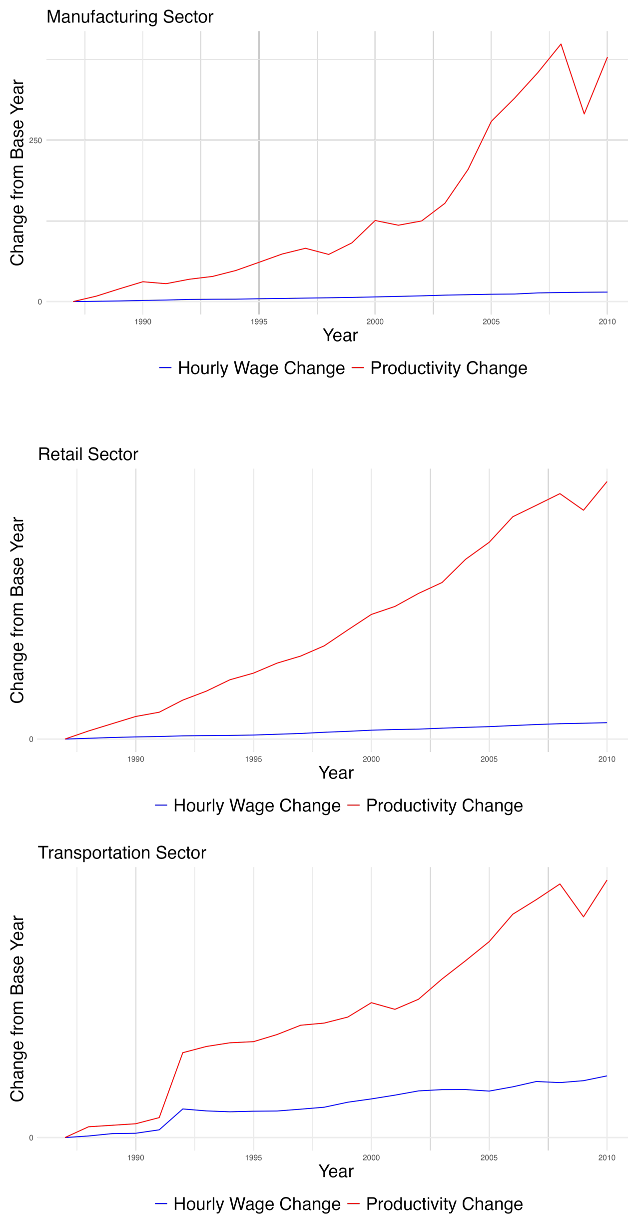
This strategic complementarity implies that the larger the number of firms in the industry, the higher the (positive) impact of α on wages - that is channeled through ω_1. Then, about the definition of ω_2 above, the term that solely determines the wage rate with one-firm-only set-up; that term's (negative) α effect on wages gets counteracted with the ω_1 term, and as a result as the number of firms goes up, workers' wages tend to increase with capital intensity. So, workers benefit to a certain extent from rising capital intensity and declining labor share if the industry's entry dynamics are high.

The following is the intuition for this result: When there is only one firm, due to the decreasing returns to scale property of the production function ($\gamma<1$), the revenue productivity associated with a higher capital intensity is low, since the firm is "too large" from a socially efficient point of view. However, with the entry of firms, which is desirable from a "social scale efficiency point of view" - given the decreasing returns to scale property ($\gamma<1$), the revenue productivity associated with a higher capital intensity increases at the level of each firm. This revenue productivity gain in general equilibrium also accrues to higher-wage workers, so they also benefit from the rising capital intensity.

From a quantitative point of view, Figures B10 to B12 and Figures B16 to B18 delineate that the mechanism we described above is quite strong: from a wage maximizing perspective, we show that the optimal α approaches the corner of very high capital intensity as the industrial entry rises.

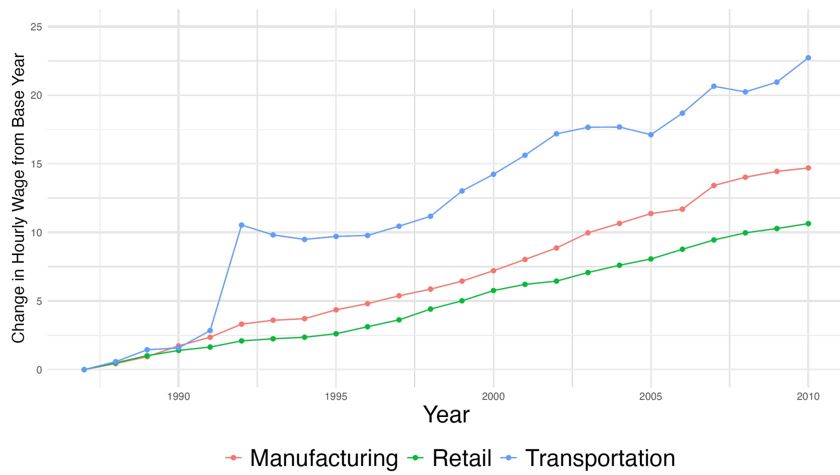
C Additional Figures: Industry Breakdown

Figure C1. Productivity–Wage Decoupling by Industry: 1987–2010

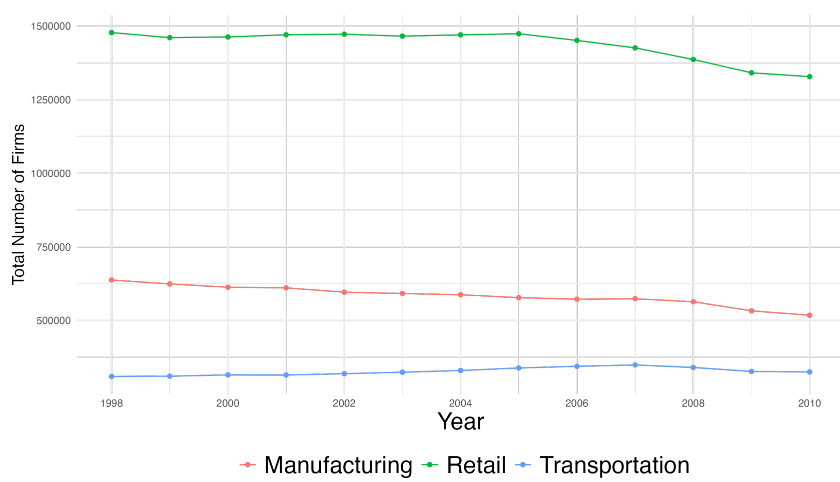


Note: The figure represents the decoupling of worker productivity and wages in the United States from 1987 to 2010 by industry, utilizing data from the BLS Labor Productivity and Costs program, Current Employment Statistics, and BEA National Income and Product Accounts.

Figure C2. Hourly Worker Compensation and Number of Firms by Industry



(a) Hourly Worker Compensation



(b) Number of Firms

Note: Panel (a) presents the hourly worker compensation for the manufacturing, retail, and transportation industries between 1987 and 2010. Panel (b) presents the total number of firms for the manufacturing, retail, and transportation industries between 1998 and 2010. Both panels utilize data from the BLS Labor Productivity and Costs program, Current Employment Statistics, and BEA National Income and Product Accounts.

D Union Bargaining Power

This section describes the dynamics of productivity and unions in the post–1950s era, during which unions exhibited declining bargaining power due to other institutional changes. Our rent-seeking argument from the benchmark specification is consistent with the implications of such a union bargaining channel. To analyze the impact of this additional channel, let us introduce union bargaining power as a function of the general–purpose technology, $\lambda(z)$, under the following assumption:[8]

Assumption. *The first partial of union bargaining power satisfies* $\lambda'(z) < 0$.

This assumption is credible, as institutional changes post-WW2 and simultaneous globalization weakened union bargaining power (Hirsch, 1991). This period also saw an increase in aggregate productivity, represented by z.

Then, we denote *extractable rents* by unions with V_{z_s}, where $s \in \{l, h\}$. Extractable rents incorporate union bargaining power ($\lambda(z)$) alongside total rents (R_{z_s} with $s \in \{l, h\}$), and they are characterized for non-automation and automation regime as the following:

$$\begin{aligned} V_{z_l} &= \underbrace{\left[(1-\alpha)z\left(\frac{1}{2}\right)^{\alpha} + \left(\frac{1}{2}\right)^{1+\gamma}\right]}_{R_{z_l}} \lambda(z), \\ V_{z_h} &= \underbrace{\left[\left(\frac{1}{2}\right)^{1+\gamma}\right]}_{R_{z_h}} \lambda(z). \end{aligned}$$

[8] We define bargaining power as the proportion of the total available profits that a union can successfully obtain from the firm. For instance, a union (A) is stronger in negotiations than another union (B) if it can achieve larger rents from employers at the same cost as B. This idea also applies when comparing the same union (A) at different times. For instance, if union A in 1950 secured more rents than in 1970, it is said to have more bargaining power in 1950 than in 1970 (Shister, 1943).

Mirroring the analysis in Section 3.3, it becomes clear that

$$V_{z_l} - V_{z_h} > 0 \quad \text{since} \quad \lambda'(z) < 0.$$

More specifically, union bargaining power declined following WW2 as general-purpose productivity grew, a trend that drove the shift towards automation and diminished unions' extractable rents beyond the automation threshold. This finding aligns with the insights of Proposition 3.

Furthermore, we also obtain:

$$\begin{aligned}
\frac{\partial V_{z_l}}{\partial z} &= \left[(1-\alpha)\left(\frac{1}{2}\right)^{\alpha}\right]\lambda(z) + \left[(1-\alpha)z\left(\frac{1}{2}\right)^{\alpha} + \left(\frac{1}{2}\right)^{1+\gamma}\right]\lambda'(z), \\
\frac{\partial V_{z_h}}{\partial z} &= \left[\left(\frac{1}{2}\right)^{1+\gamma}\right]\lambda'(z).
\end{aligned}$$

Since $\lambda'(z) < 0$, it follows that $\frac{\partial V_{z_h}}{\partial z} < 0$, indicating a continuous decline in extractable rents by the unions beyond the automation threshold - the era during which wages decouple increasingly from the general purpose productivity trend.

However, before reaching the automation cutoff, reductions in union bargaining power could coincide with rising extractable rents. Specifically, if the condition

$$\left[(1-\alpha)\left(\frac{1}{2}\right)^{\alpha}\right]\lambda(z) > -\left[(1-\alpha)z\left(\frac{1}{2}\right)^{\alpha} + \left(\frac{1}{2}\right)^{1+\gamma}\right]\lambda'(z)$$

is met, then $\frac{\partial V_{z_h}}{\partial z} > 0$, indicating that the union's extractable rents can increase even as union bargaining power decreases. This occurs because the gains from total rents due to advancements in general-purpose technology ($R'_{z_l}(z)$) surpass the loss in union bargaining power ($\lambda'(z)$). This dynamic suggests that amidst declining union influence, the growth in general-purpose productivity, firm size, and wages—bolstered by rising unions – can coexist.

A model that integrates union bargaining power and, thus, extractable rents aligns with a theoretical framework that models only total rents. Furthermore, this approach harmonizes with empirical observations and clarifies the temporal gap between the decline in union membership from 1950 onward and the onset of productivity-wage decoupling in the 1970s. Figures 1a and 2 illustrate that union membership in the US began to decline shortly after WW2, leading to diminished union bargaining power. However, this decline did not immediately result in a productivity-wage gap. Our model accounts for this 20–year lag, suggesting that a decrease in union bargaining can coexist with rising extractable rents by unions and sustained wage growth until the shift toward automation begins.

Proposition D1. *A framework combining union bargaining power and extractable rents shows that declining union share and the subsequent drop in bargaining power can still align with continued union-related rents and wage increases until the automation threshold is* $\bar{z} = \hat{z}$*.*