A Joint Theory of Polarization and Deunionization[⋆]

Tobias Föll, Anna Hartmann

Center for Macroeconomic Research, University of Cologne

Abstract

Over the past 40 years, the U.S. and several European labor markets have undergone two important developments: job market polarization and deunionization. In this paper, we argue that routine-biased technical change not only drives polarization, as is commonly assumed, but that it is also the driving force behind deunionization. We show that the shifting demand structure in favor of low- and high-skill occupations worsens the bargaining position of unions in a search and matching framework with an occupational choice and endogenous union formation, and therefore makes collective bargaining coverage less attractive for workers. The ensuing deunionization provides further incentives for middle-wage workers to switch occupations and thus amplifies job market polarization.

Keywords: Unions, Polarization, Occupational Choice, Search and Matching

JEL classification: E02; E24; J51; J62; J64; O33

[⋆]We are very grateful to Michael Krause and Christian Bredemeier for all their guidance and support. For many useful comments we are also grateful to Almut Balleer, Dan Black, David Dorn, Mike Elsby, Judith Hellerstein, Barış Kaymak, Tali Kristal, Ilse Lindenlaub, Christian Merkl, Pascal Michaillat, Steffen Müller, Johannes Pfeifer, Robert Shimer, Nawid Siassi, Christian Siegel, Hale Utar, and seminar participants at Barcelona GSE, Cologne, the 5th International Conference on Technology, Demographics, and the Labor Market, the 2019 SMYE, the 9th Annual Search and Matching Conference, the 2019 Midwest Macroeconomics Meeting, the 2019 IZA Summer School, the 2019 EEA-ESEM, the 2019 EALE Conference, the 2019 VfS Conference, the 16th IWH/IAB Workshop, and the AASLE 2019 Conference.

Email addresses: `foell@wiso.uni-koeln.de` (Tobias Föll), `anna.hartmann@wiso.uni-koeln.de` (Anna Hartmann)

1. Introduction

Job market polarization and deunionization have radically changed the labor market over the last decades. Job market polarization refers to the falling employment shares in middle-skill occupations and increasing employment shares in low-skill and high-skill occupations. The share of employment in the middle range of skills in the U.S. has been continuously decreasing and is now more than 10 percentage points below its value in the 1980s. Deunionization describes the ongoing decline in union membership rates. According to the Union Membership and Coverage Database constructed by Hirsch and Macpherson (2003), U.S. union membership rates declined from 24.0% of all employed workers in 1973 to 10.5% in 2018. Remarkebly, this decline is driven by changes within occupations and not by changing occupational employment shares.

Polarization and deunionization have both proven to be especially harmful for low-wage to middle-wage workers: job market polarization because the relative shifts in labor demand away from routine occupations have suppressed wage growth in that area, and deunionization because unionization rates are typically highest among lower middle-skill workers. American middle class workers have been in the focus for U.S. politicians not just since President Barack Obama declared himself "a warrior for the middle class".[1] Even though the share of U.S. households classified as middle class by the American Institute for Economic Research (AIER) has declined steadily since the 1980s, in 2013 still roughly 50% of households count as middle class.[2] Thus, identifying and implementing suitable policies to support the middle class has become an ever more pressing issue for today's policymakers, especially considering the recent trends of political radicalization among this group.[3]

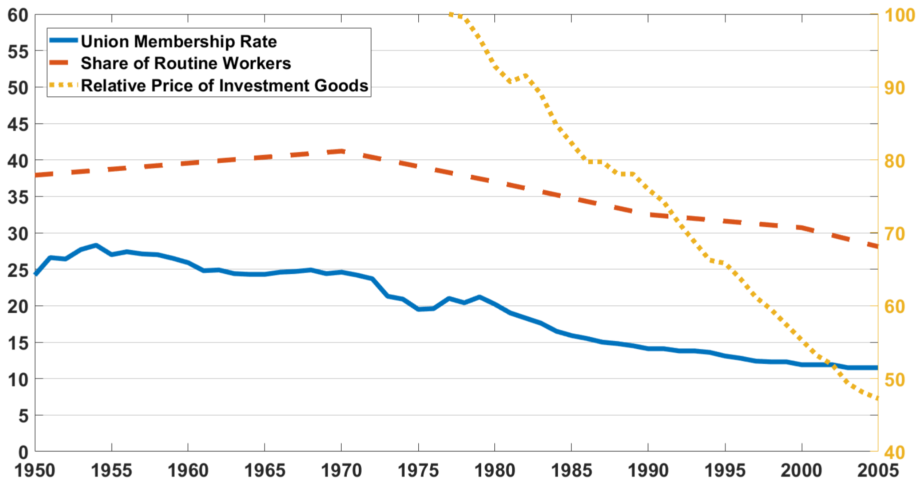
In this paper, we develop a joint theory of polarization and deunionization. Routine-biased technical change is shown to be the driving force behind both polarization and deunionization. Moreover, deunionization amplifies employment changes. Hence, ignoring the role of the union structure in a country might lead to substantial biases when assessing the

[1] Remarks by the president on the economy, Knox College, Galesburg, IL, 24.06.2013.

[2] The AIER defines households with a disposable income of two thirds to twice the median income for their household size as middle class.

[3] See Post (2017) for a detailed account of radicalization among the middle class.

Figure 1: Relative Price for Investment Goods, Share of Routine Workers, and U.S. Union Membership Rate



Note: The share of workers in routine occupations is constructed using the dataset and the occupational classification from Autor and Dorn (2013). Data for the union membership rates are taken from Mayer (2004) who merges data from the Current Population Survey, the U.S. union database constructed by Hirsch and Macpherson (2003), and from the Bureau of Labor Statistics Handbook and Employment and Earnings Survey. The membership rate includes all wage and salary workers. Public sector and agricultural workers are included in order for the data to be comparable to the data used in Autor and Dorn (2013). Missing data points are extrapolated from adjoining data points. The FRED series for the relative price of investment goods is measured as the investment deflator divided by the consumption deflator and displayed as an index with 1980 = 100. We display the relative price for investment goods rather than the price for computer capital since data on the former is more reliable and available for a longer time period.

effect of routine-biased technical change on the employment structure. To provide a first motivation for a joint theory of polarization and deunionization, Figure 1 depicts the relative price for investment goods (proxying routine-biased technical change), the employment share of workers in routine occupations, and the union membership rate for the U.S. between 1950 and 2005. The union membership rate and the share of routine workers display a very similar trend over the last decades (with a correlation of 0.92). Further empirical observations are provided in Section 2.

To study job market polarization and deunionization in a joint theoretical framework, we endogenize both the occupational choice of workers and the union status of a firm. We employ a search and matching model of the labor market with heterogenous workers that differ with respect to their ability. When unemployed, previous routine workers have the option to switch to manual occupations. Employees decide via an election whether they want to form a union, and consequently a collective bargaining unit, or whether they want to bargain individually over their wages with their employer.[4] Unions, which differ with respect to their bargaining power, distribute their share of the joint surplus equally across their members.

The main mechanism behind our results is quite simple. Relative prices for computer capital, which is able to replace routine tasks, fall (proxying for routine-biased technical change). This reduces the demand for routine workers, whereas manual and abstract workers, who are complementary to routine tasks, are in greater demand. The change in the labor demand structure implies that wages in manual occupations increase by more than wages in routine occupations. Manual workers, who benefit from the changing demand structure, are discouraged from voting in favor of a collective bargaining agreement.[5] Previously unionized low-skilled routine workers, when faced with lower wages compared to manual workers, decide to switch occupations. This amplifies the initial polarization caused by routine-biased technical change. Evidence for this amplification mechanism is provided in Section 6.

We quantitatively assess the effect of routine-biased technical change on occupational decisions and on union formation. The model is calibrated to match U.S. data for the time period between 1983 and 2005. Predicted changes in employment and wages are close to the data. Routine-biased technical change, through changes in the labor demand structure, leads to a drop of 9.3 percentage points in overall union density in the model compared to a drop of 6.6 percentage points in the data. About 15% of the simulated changes in low- and middle-skilled employment are driven by deunionization, as previously unionized routine workers are more likely to switch occupations when they are unable to find a routine job that is covered by a collective bargaining agreement.

The overall effect of deunionization on inequality is small.[6] However, deunionization has substantial effects for the lowest-skilled previously unionized routine workers. For this group of workers, wage growth in the model would be 60% larger if they were covered by one of the remaining collective bargaining contracts.

[4]A bargaining unit is commonly defined as a group of employees that shares a set of interests and may be reasonably represented by a collective bargaining agreement.

[5]This is in line with Baccaro and Locke (1998) and Checchi et al. (2010), who argue that disillusion with respect to potential wage growth is the reason for declining membership rates among the least-skilled workers.

[6]Inequality is measured by the Gini index. The small overall effect is in line with Frandsen (2012), Checchi et al. (2010), and DiNardo and Lee (2004), all of whom find small effects of deunionization on inequality.

In our model, unions could dampen polarization and deunionization if they were able and willing to adjust the wage distribution, allowing for less equality inside the collective bargaining agreement. However, empirical evidence suggests that unions are characterized by rigid structures that partly prevent them from adjusting to recent developments on the labor market.[7] Bryson et al. (2016) argue that the decline in union membership rates across countries is strongly related to the degree of progressiveness of the unions. Thus, it seems that unions are lacking the modern and progressive structures necessary to attract more and especially younger members.

The remainder of the paper is organized as follows. Previous research and the links between job market polarization and deunionization are discussed in the next section. The model, building on the union framework in the U.S. discussed in Section 3, is presented in Section 4. In Section 5 we provide a theoretical, and in Section 6 a quantitative evaluation of the model. Policy implications are discussed in Section 7. To conclude, the results of this paper are summarized in Section 8.

2. Linking Polarization and Deunionization

We begin by providing evidence for our argument that job market polarization and deunionization have a common cause in routine-biased technical change. While overall union membership rates in the U.S. began to decrease in the late 1950s, this is usually explained by political resistance and the sharp increase in labor force participation of women, who tend to be less unionized.[8] The statistics in Troy and Sheflin (1985) illustrate that in no year since the late 1890s were more unions started than in 1970. The most terminations in recent decades are observed in 1980, while in the 1950s and 1960s almost no unions were terminated. This evidence on union creation and termination suggests that the slow decline in union membership rates since the 1950s and the accelerated decline since 1980 might have very different causes. The accelerated decline in union membership rates fits well with the starting point of job polarization. Job polarization, and to a lesser extent also wage polarization, can be observed in the U.S. and several European countries at least since the 1980s. Additionally,

[7] See, for example, Waddington (2005) and Bryson et al. (2016).

[8] See, for example, Oh (1989) and Troy and Sheflin (1985).

Dinlersoz and Greenwood (2016) document that the steep decline in union membership rates in the 1980s followed the emergence and diffusion of early advanced technologies.

Moving to cross-sectional evidence, the degree of unionization and the decline in union membership rates is on average more pronounced in countries with larger degrees of job and wage polarization. This is visible when comparing the U.S. to Europe, but also within the group of European countries. The Nordic countries, which experienced upgrading rather than polarization, exhibit constant or even increasing union membership rates.

Figure 2: Polarization and Collective Bargaining Coverage across Countries, 2004

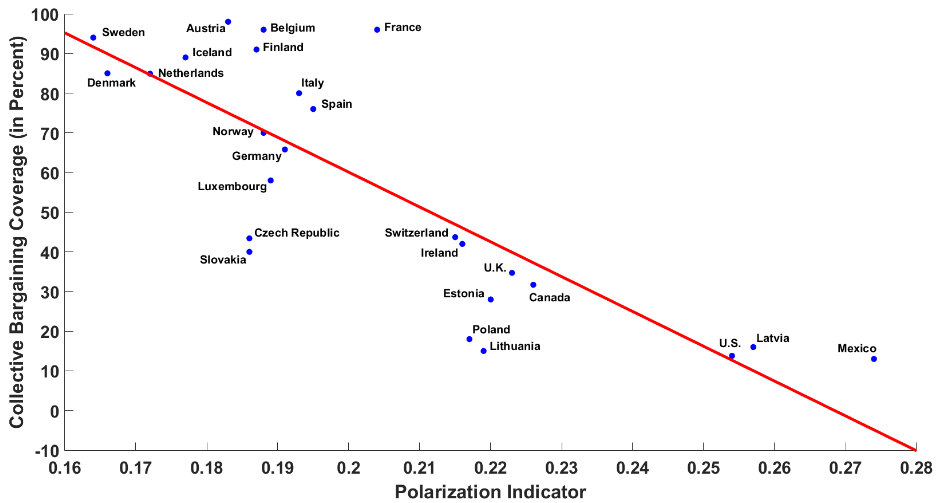


Figure 2 plots the polarization indicator developed in Duclos et al. (2004) against the collective bargaining coverage for the U.S., Canada, Mexico, and several European countries. Country selection is based on data availability. For all countries the polarization indicator is calculated for the year 2004. The collective bargaining coverage is the share of employed workers covered by a collective bargaining agreement in 2004 from the OECD data. The red line is the result of an OLS regression of the polarization indicator on the collective bargaining coverage. The regression coefficient is $\beta = -8.78$ and R^2 is 0.66.

Figure 2 plots the polarization indicator developed in Duclos et al. (2004), which evaluates the distance between and the distinction of income groups, against the collective bargaining coverage for the U.S., Canada, Mexico, and several European countries.[9] Despite the small sample size, the negative coefficient in the OLS regression of the collective bargaining coverage

[9]In contrast to the U.S., the differences between union membership rates and the percentage of workers covered by a collective bargaining agreement are large for most of the European countries. Thus, when looking at union influence, the share of workers covered by a collective bargaining agreement seems to be more appropriate. The results also hold when exchanging the collective bargaining coverage for union density. The results are very similar when using changes in collective bargaining coverage instead of collective bargaining coverage.

on the polarization indicator is statistically significant at the 0.1%-level.

The evidence presented in this section motivates us to develop a joint theory of polarization and deunionization. The prevalent explanation for polarization is the routinization hypothesis, which states that machines or computers replace middle-wage workers in occupations performing routine tasks.[10] The non-routine nature of tasks performed by low-wage and high-wage workers means that their jobs are more difficult to automate. In contrast to job polarization, no consensus has yet emerged regarding the source of deunionization.

To examine the impact of routine-biased technical change on both polarization and deunionization, we introduce endogenous union formation into the multi-sectoral search and matching model by Albertini et al. (2017). This paper is the first to theoretically evaluate how routine-biased technical change affects union membership decisions. Until now, technical change as a cause for deunionization has received only limited attention in the theoretical literature.[11]

Acemoglu et al. (2001) show that skill-biased technical change can trigger deunionization by increasing the outside option of skilled workers. In their model, deunionization is entirely driven by quitting high-skilled workers: skill-biased technical change weakens the incentives for skilled workers to join the unionized sector, which they interpret as the manufacturing industry. Thus, in contrast to our model, deunionization works entirely through between-industry shifts. However, Baldwin (2003) finds that more than 80% of the decrease in union membership rates between 1977 and 1997 is accounted for by within-industries changes in unionization rates. Furthermore, the lower share of high-skilled workers in the unionized sector in Acemoglu et al. (2001) implies declining union wage premia and less skilled union members over time.

Açıkgöz and Kaymak (2014) study deunionization in a search and matching framework with endogenous union membership. In their model, an exogenous increase in the skill premium encourages the most skilled workers to leave the union, while firms avoid to hire the least skilled union workers. This contrasts with evidence in Baccaro and Locke (1998)

[10] See, for example, Autor et al. (2003), Autor et al. (2006), Autor and Dorn (2013), Michaels et al. (2014), and Feng and Graetz (2015).

[11] Empirical contributions include von Brasch et al. (2018) and Meyer (2017).

and Checchi et al. (2010), who argue that disillusion about potential wage growth is the main driving force behind declining union membership rates among the least-skilled workers. In our model, low-skilled workers endogenously decide to vote against union coverage because of low wage growth in unionized firms. Additionally, the decline in the union membership rate in Açıkgöz and Kaymak (2014) is stronger for high-skilled than for low-skilled workers, implying a decrease in the relative skill level of union members.

Dinlersoz and Greenwood (2016) focus on the connection between technology, unionization, and inequality. In a general equilibrium model of unionization with heterogeneous firms, skilled, and unskilled labor, they show that when the productivity of unskilled labor is high, the union decides to organize a lot of firms and demands generous wages for its members. Therefore, skill-biased technical change leads to declining union membership premia. While union members are exclusively drawn from low-skilled workers in Dinlersoz and Greenwood (2016), the inclusion of union members of other skill types would, as in Acemoglu et al. (2001), Açıkgöz and Kaymak (2014), and in basically any model of skill-biased technical change, lead to union members becoming less skilled over time.

Thus, all three papers have trouble explaining at least one of two important empirical observations. First, the increasing relative skill of union members documented in Farber et al. (2018), and second the constant union wage premia over time documented in Hirsch and Schumacher (2004), Bryson (2002), and Farber et al. (2018). Both of these observations can be rationalized in a model with routine-biased technical change. Furthermore, wage changes caused by skill-biased technical change imply upgrading rather than polarization. As we have shown above, countries that exhibit upgrading tend to display both a smaller decline in and a larger degree of collective bargaining coverage.

3. Unions in the U.S.

This section provides a brief overview of how labor unions work in the U.S. These institutional features will be used when setting up the model in Section 4.

In the U.S., unions base their right to represent workers through collective bargaining on the voting decision of a so called *bargaining unit*. The National Labor Relations Act (NLRA) specifies the structure through which union organization and legal recognition takes place.

This structure focuses on a system of petitions and elections to determine whether a majority of employees in the workplace wants to be represented by a union. The union then becomes the exclusive representative of all employees in the bargaining unit, whether they are union members or not. If a majority of the employees votes against union representation, the unit is not represented by the union, no matter if workers individually choose to be union members or not. In the event of a lawfully-called strike, unions are allowed under the NLRA to fine members that still decide to work.

An appropriate bargaining unit, according to the NLRA, is a group of employees in a workplace that meets the legal test of sufficient community of interest to be represented by the union, whereby managers and supervisors are excluded from any bargaining unit. According to the National Labor Relations Board (NLRB), professional employees who engage in predominantly intellectual and not in routine mental, manual, or mechanical work are excluded from bargaining units with manual and routine workers, since they do not share a community of interests.

The structure of bargaining in the U.S. is highly decentralized, with the estimated number of separate collective bargaining agreements ranging between 170,000 and 190,000 according to the Bureau of Labor Statistics. Most collective bargaining in the private sector takes place at the level of the individual firm.[12]

4. The Model

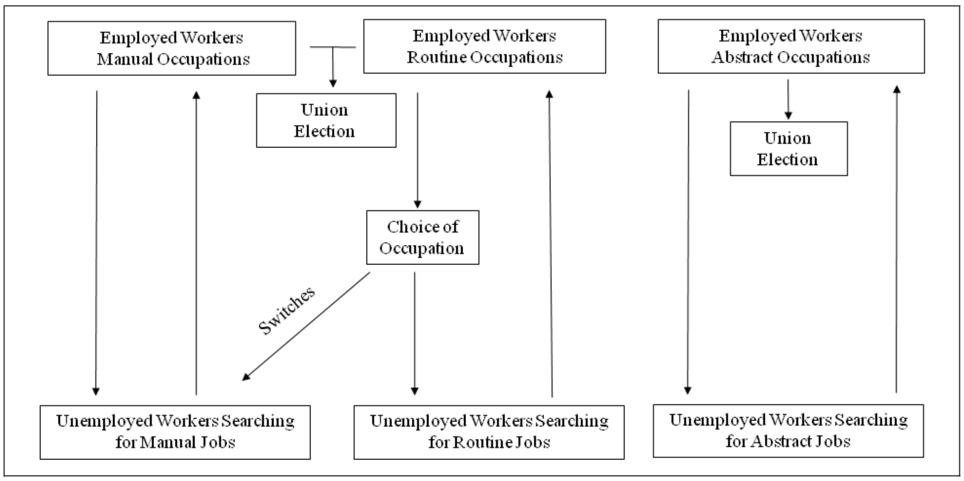
In this section, we present a discrete time search and matching model with an occupational choice and endogenous union formation. Non-abstract workers are heterogeneous and differ with respect to their ability η, which is uniformly distributed. For each ability level, there is a continuum of workers. Abstract workers are assumed to be homogenous. As depicted in Figure 3, workers can be specialized in manual, routine or abstract tasks. Upon becoming unemployed, workers previously employed in routine tasks can choose to switch occupations and join the unemployment pool of manual workers.[13] In line with Smith

[12]See, for example, Traxler (1994) and Nickell and Layard (1999).

[13]To ease notation, and in line with the empirical evidence in Smith (2013), we abstract from other switches. Thus, in our model there will be 'overqualified' routine workers in manual occupations but we rule out the

(2013), who shows that the increase in abstract employment is mainly driven by increased educational attainment and not by occupational switches, labor supply of abstract workers is assumed to increase exogenously.

Figure 3: Graphical Representation of the Model



In our model, unions arise endogenously through elections within firms.[14] When a simple majority of the respective bargaining unit votes in favor of a union, wages are bargained collectively between the respective firm and the union. The collective bargaining agreement covers all workers in the bargaining unit, regardless of the individual voting decision.

case of 'underqualified' manual workers in routine occupations. Neither the results on deunionization nor the results on polarization depend on the assumption that manual workers are unable to switch to routine occupations. Note that because of falling prices for computer capital, the relative demand for manual workers increases. Thus, switches from manual to routine occupations only occur whenever the job-finding rate for routine workers is larger than the job-finding rate for manual workers in a unionized environment. These inefficient switches would only increase the speed with which deunionization occurs.

[14]Our production function features constant returns to scale. In contrast to Taschereau-Dumouchel (2017), firms have no incentive to overhire high-wage and low-wage, and underhire middle-wage workers in our model.

4.1. Labor Market Frictions

The labor market is characterized by search and matching frictions à la Mortensen and Pissarides (1994). Search is directed, as there are labor sub-markets for each of the three occupations. Within each pool, vacancies and unemployed workers are matched randomly in any period and firms learn about the ability level of a worker upon matching. Given the number of vacancies v_i posted and the share of unemployed workers u_i for every occupation i, the number of matches is determined by the following Cobb-Douglas matching technology with matching efficiency Ψ_i

$$m_i = \Psi_i v_i^{\psi} u_i^{1-\psi} \text{ where } 0 < \psi < 1 \text{ and } i = a, r, m,$$

where a, r, and m refer to abstract, routine, and manual occupations, respectively. A vacancy is filled with probability $q_i = \frac{m_i}{v_i}$ and the job finding probability is $f_i = \frac{m_i}{u_i}$. The labor market tightness is defined as the ratio $\theta_i \equiv \frac{v_i}{u_i}$. When the labor market is tight, many firms compete for few unemployed workers. The job finding probability is high, but the job filling rate is low.

4.2. Occupational Choice

Workers can either be employed in abstract, routine, or manual occupations. Existing jobs are destroyed at the exogenous rates s_i, with $i = a, r, m$. The value function for unionized manual workers is given by

$$\begin{aligned} W_m^u(\eta) = w_m^u(\eta) + \beta[(1 - s_m)\big(\mathbb{1}_{u,+1} W_{m,+1}^u(\eta) + (1 - \mathbb{1}_{u,+1}) W_{m,+1}^n(\eta)\big) \\ + s_m U_{m,+1}(\eta)], \end{aligned}$$

where β is the discount factor and $w_m^u(\eta)$ denotes the wage received by a manual union worker with ability η. $\mathbb{1}_u$ is an indicator function with $\mathbb{1}_u = 1$ if and only if the worker is a union member. Thus, the term $\mathbb{1}_{u,+1}$ indicates whether a worker in the firm is covered by a collective bargaining regime in the next period.

In turn, the non-union manual workers' value function is given by

$$
\begin{aligned}
W_m^n(\eta) = w_m^n(\eta) + \beta[(1-s_m)\big(\big(\mathbb{1}_{u,+1}W_{m,+1}^u(\eta) + (1-\mathbb{1}_{u,+1})W_{m,+1}^n(\eta)\big) \\
+ s_m U_{m,+1}(\eta)],
\end{aligned}
$$

where $w_m^n(\eta)$ is the wage received by a manual non-union worker with ability η.

When unemployed, workers lose their union membership.[15] Therefore, the union and non-union value functions for an unemployed manual worker are identical and given by

$$
\begin{aligned}
U_m(\eta) = z_m(\eta) + \beta[(1-f_m)U_{m,+1} + f_m\big(\mathbb{1}_{u,+1}W_{m,+1}^u(\eta) \\
+ (1-\mathbb{1}_{u,+1})W_{m,+1}^n(\eta)\big)],
\end{aligned}
$$

where $z_m(\eta)$ denotes the unemployment benefits received from the government by a manual worker with ability η.

For abstract workers, the respective value functions are

$$
\begin{aligned}
W_a^u &= w_a^u + \beta[(1-s_a)\big(\mathbb{1}_{u,+1}W_{a,+1}^u + (1-\mathbb{1}_{u,+1})W_{a,+1}^n\big) \\
&\quad + s_a U_{a,+1}], \\
W_a^n &= w_a^n + \beta[(1-s_a)\big(\mathbb{1}_{u,+1}W_{a,+1}^u + (1-\mathbb{1}_{u,+1})W_{a,+1}^n\big) \\
&\quad + s_a U_{a,+1}], \\
U_a &= z_a + \beta[(1-f_a)U_{a,+1} + f_a\big(\mathbb{1}_{u,+1}W_{a,+1}^u \\
&\quad + (1-\mathbb{1}_{u,+1})W_{a,+1}^n\big)].
\end{aligned}
$$

[15] This is in line with Lewis (1989), who finds that unions are not perceived to represent the interests of the unemployed.

Analogously, the value functions for routine workers are

$$\begin{aligned}
W_r^u(\eta) &= w_r^u(\eta) + \beta \left[(1-s_r)\big(\mathbb{1}_{u,+1} W_{r,+1}^u(\eta) + (1-\mathbb{1}_{u,+1}) W_{r,+1}^n(\eta)\big)\right] \\
&\quad + \beta s_r \max\{U_{m,+1}(\eta), U_{r,+1}(\eta)\}, \\
W_r^n(\eta) &= w_r^n(\eta) + \beta \left[(1-s_r)\big(\mathbb{1}_{u,+1} W_{r,+1}^u(\eta) + (1-\mathbb{1}_{u,+1}) W_{r,+1}^n(\eta)\big)\right] \\
&\quad + \beta s_r \max\{U_{r,+1}(\eta), U_{m,+1}(\eta)\}, \\
U_r(\eta) &= z_r(\eta) + \beta[(1-f_r) \max\{U_{m,+1}(\eta), U_{r,+1}(\eta)\} + f_r\big(\mathbb{1}_{u,+1} W_{r,+1}^u(\eta) \\
&\quad + (1-\mathbb{1}_{u,+1}) W_{r,+1}^n(\eta)\big)].
\end{aligned}$$

Here the term $\max\{U_{m,+1}(\eta), U_{r,+1}(\eta)\}$ governs the occupational choice of routine workers when unemployed in the next period. Whenever the value of being an unemployed manual worker is larger than the value of being an unemployed routine worker, the worker switches occupations. Thus, the equation defining the endogenous occupational threshold between manual and routine occupations, η_m, is given by

$$U_r(\eta_m) = U_m(\eta_m). \tag{1}$$

4.3. Firms

The model features a continuum of final good firms and intermediate firms. As the setup admits the presence of a representative firm on each level, firm indices are dropped. To further ease notation, we only use indices related to the union status of a firm when they are necessary to understand the model mechanics.

The good-producing firm uses three homogeneous intermediate goods, Z_a, Z_r, and Z_m, as input factors to produce the final product Y. Intermediate goods are acquired at their competitive factor prices.[16] Z_a is produced with abstract jobs L^a, Z_r with computer technology K and routine workers $L^r(\eta)$, and Z_m with manual jobs $L^m(\eta)$. Routine workers and computer technology K are close substitutes, whereas abstract workers are complementary

[16] This production structure is chosen in order to facilitate representation, as it allows for solving the maximization problems of the good-producing firm and the intermediate firms consecutively. The job-creation conditions are identical if we instead assume that the good-producing firm directly uses manual, routine, and abstract workers as input factors.

to the intermediate good Z_r. The maximization problem of the goods-producing firm is given by[17]

$$\Pi = \max_{Z_a, Z_r, Z_m} \{Y - p_{Z_a} Z_a - p_{Z_r} Z_r - p_{Z_m} Z_m\}$$
$$\text{s.t. } Y \leq [(A Z_a^{\alpha} Z_r^{1-\alpha})^{\rho} + (A_m Z_m)^{\rho}]^{1/\rho},$$

where $0 < \alpha < 1$, $-\infty < \rho < 1$, A, and A_m are parameters of the production function.

Intermediate firms maximize profits by choosing employment next period and the number of vacancies to be posted, subject to the firm-level employment constraint. Job creation comes at a flow cost of c_a, c_r, or c_m. The behavior of the intermediate firm in producing the intermediate good Z_a, which is paid at price p_{Z_a}, is described by

$$\Pi^{Z_a} = \max \left\{ p_{Z_a} Z_a - \mathbb{1}_u w_a^u L_a - (1 - \mathbb{1}_u)\, w_a^n L_a - c_a v_a + \beta \Pi_{+1}^{Z_a} \right\}$$

$$\text{s.t. } Z_a \leq L_a$$
$$L_{a,+1} = (1 - s_a) L_a + q_a v_a,$$

where $L_{a,+1}$ denotes the total abstract workforce next period. $\mathbb{1}_u$ is again the indicator function with $\mathbb{1}_u = 1$ indicating if the workforce in the firm is covered by a collective bargaining regime.

The behavior of the firm producing the intermediate good Z_r, which is paid at price p_{Z_r}, is described by

$$\Pi^{Z_r} = \max \left\{ p_{Z_r} Z_r - p_K K - \mathbb{1}_u \int_{\eta_m}^{\bar{\eta}} w_r^u(\eta) L_r(\eta) \right.$$
$$\left. - (1 - \mathbb{1}_u) \int_{\eta_m}^{\bar{\eta}} w_r^n(\eta) L_r(\eta) - c_r v_r + \beta \Pi_{+1}^{Z_r} \right\}$$

[17]A nested production function is chosen in order to allow for larger complementarity in production between abstract and routine than between routine and manual tasks.

$$\text{s.t. } Z_r \leq \left[\left((1-\mu)\int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta)\,\mathrm{d}\eta\right)^{\sigma} + (\mu K)^{\sigma}\right]^{\frac{1}{\sigma}}$$
$$L_{r,+1} = (1-s_r)L_r + q_r v_r$$

where $0 < \mu < 1$ and $-\infty < \sigma < 1$ are production parameters, $\bar{\eta}$ denotes the upper bound on the ability distribution for non-abstract workers, and η_m the endogenous ability threshold between manual and routine workers. Following Albertini et al. (2017), firms can freely choose their desired level of computer capital K at the price p_K.

The behavior of the intermediate firm in producing the intermediate good Z_m, which is paid at price p_{Z_m}, is described by

$$\Pi^{Z_m} = \max\left\{p_{Z_m} Z_m - \mathbb{1}_u w_m^u L_m - (1-\mathbb{1}_u)\, w_m^n L_m - c_m v_m + \beta \Pi_{+1}^{Z_m}\right\}$$

$$\text{s.t. } Z_m \leq L_m$$
$$L_{m,+1} = (1-s_m)L_m + q_m v_m.$$

As in Autor and Dorn (2013), workers in manual occupations are homogenous with respect to their productivity in performing manual tasks. This implies that wages for manual workers are constant while wages for routine workers are increasing in the skill level η. Combining this with the definition of η_m in equation (1), it is straightforward to see that workers with an ability level lower than η_m work in manual occupations. The first order conditions and the job-creation conditions are derived in Appendix A and Appendix B.

4.4. Wage Bargaining Regimes

Since we focus on the U.S., we want our union framework to be as close as possible to the institutional framework presented in Section 3. Workers can decide to form a union on the level of the good-producing firm, which bargains with the firm and distributes the surplus according to a union wage schedule. Once new workers are hired, all workers vote to decide whether to form a union or not. Abstract workers are excluded from the collective bargaining unit with manual and routine workers. Thus, our model features one industrial union - aiming to cover workers of two different skill groups - and one craft union, covering only abstract workers. If a union is established, the collective bargaining agreement covers all workers in the bargaining unit, regardless of whether or not the individual worker voted in favor of the union. The voting decision of an individual worker is endogenously determined and depends directly upon the potential union wage premium. Workers vote in favor of a union if the value of being a worker in a unionized firm is higher than the value of being a worker in a non-unionized firm

$$W_i^u(\eta) > W_i^n(\eta), \text{ with } i = a, r, m.$$

In the model, the number of voting thresholds above or below which workers in a bargaining unit vote against the union depend on the choice of the union wage schedule. The thresholds are denoted by η_l^u and $\eta_l^{u,a}$ with $l \in [1, 2, ...]$, where the index a denotes the union for abstract workers.

If the majority of the bargaining unit votes against a collective bargaining agreement, workers in this bargaining unit are not represented by the union and wages are negotiated individually. Union and non-union wages are both determined by generalized Nash bargaining over the match surplus. However, the surplus that is bargained over differs between the two bargaining regimes: non-union workers bargain individually over their marginal product, whereas the union bargains over the entire match surplus of all workers in the bargaining unit.

Individual Bargaining

If a majority of the manual and routine workers votes against a union, each worker bargains individually with the firm. Denoting the worker's weight in the bargaining process by $\gamma^i \in [0, 1]$, this implies the following sharing rule for individual bargaining

$$W_i^n(\eta) - U_i(\eta) = \frac{\gamma^i}{1 - \gamma^i} J_i^n(\eta),$$

$$\text{with } i = a, r, m,$$

where $W_i^n(\eta)$ is the asset value of employment for non-union members, $U_i(\eta)$ is the value of being unemployed, and $J_i^n(\eta)$ is the value of the marginal non-union worker of type i and ability η to the firm. This results in the wage schedules for the three occupational types given below.[18]

Abstract Jobs:

$$w_a^n = \gamma^a p_{Z_a} + \gamma^a c_a \theta_a + (1 - \gamma^a)\, z_a \tag{2}$$

Routine Jobs:

$$w_r^n(\eta) = \gamma^r p_{Z_r} y_r(\eta) + \gamma^r c_r \theta_r + (1 - \gamma^r)\, z_r(\eta) \tag{3}$$

Manual Jobs:

$$w_m^n = \gamma^m p_{Z_m} + \gamma^m c_m \theta_m + (1 - \gamma^m)\, z_m(\eta) \tag{4}$$

It follows that the wages resulting from individual bargaining are given by the sum of the marginal productivity of the workers in each occupation, the search returns, and the outside option. This result is identical to the Nash-bargained wage in a standard Mortensen-Pissarides search and matching model.

Collective Bargaining

We consider unions which negotiate wages on behalf of all covered workers within a firm and thus bargain over the total surplus of all union members. We make the following assumptions based on the union framework in the U.S. outlined in Section 3:

Assumption 1. *All workers that are covered by a collective bargaining agreement are union members.*

[18]See Appendix C for a detailed derivation of the wage schedules.

Assumption 2. *The union can force all of its members to strike.*

Under these assumptions, if no agreement on wages can be reached, all members of the respective bargaining unit in the unionized firm go on a strike and the firm can only produce using the remaining workers and computer capital.

Our approach only pins down the total share of the surplus going to the workers, not how it is shared among them. It is well-established in the literature that unions induce wage compression, that individual union wage premia decrease in the skill level of the worker, and that craft unions tend to negotiate higher union wage premia compared to industrial unions.[19] To keep the degrees of freedom in choosing the wage schedule small, we assume the simplest wage schedule that is in line with these observations: unions set a constant wage for all workers in the bargaining unit.[20] This accords with evidence in Fitzenberger et al. (2006), who show that unions tend to prefer wage equality over higher average wages. It follows that union wages are given by

$$w^u = S^u/(L_m + L_r). \tag{5}$$

and

$$w^u_a = S^u_a/L_a. \tag{6}$$

4.4.1. Non-Abstract Union

Under collective bargaining, the outside option of a union member is not the value of being unemployed, but the value of being a union member during a strike. Therefore, denoting the non-abstract union's weight in the bargaining process by $\gamma^u \in [0, 1]$, the following surplus

[19]See, for example, Card et al. (2004) and Streeck (2005).

[20]The evaluation in Appendix F establishes that the main mechanism behind falling union membership rates in our model is robust to alternative union wage schedules.

sharing rule holds in the case of collective bargaining

$$\max_{w^u} \left(\sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) \left[W_i^u(\eta) - W_i^{u,s}(\eta) \right] \mathrm{d}\eta \right)^{\gamma^u}$$
$$\left(\sum_i \left\{ p_{Z_i} Z_i - p'_{Z_i} Z'_i - \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta) \, \mathrm{d}\eta \right\} \right)^{1-\gamma^u}$$
$$\text{with } i = r, m,$$

where $W_i^u(\eta)$ is the asset value of employment for manual and routine union members with productivity η and $W_i^{u,s}(\eta)$ is the value of being a union member during a strike. Z_i is the production of the manual or routine intermediate good and Z'_i is the production in the manual or routine sector when workers are on a strike, which is compensated at price p'_{Z_i}.

It follows that the total surplus received by the non-abstract union S^u is given by [21]

$$S^u = \gamma^u \sum_i (p_{Z_i} Z_i - p'_{Z_i} Z'_i) + (1 - \gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w^{u,s} \, \mathrm{d}\eta \qquad (7)$$
$$\text{with } i = r, m,$$

where $w^{u,s}$ denotes the wage received by a worker during a strike, regardless of occupation and ability. The total surplus of the non-abstract union is a function of the productivity of all manual and routine workers, while the non-union wage is a function of the individual productivity of the respective worker.

4.4.2. Abstract Union

Analogously, denoting the abstract union's weight in the bargaining process by $\gamma_a^u \in [0, 1]$, the following surplus sharing rule holds in the case of collective bargaining

$$\max_{w_a^u} \left(L_a \left[W_a^u - W_a^{u,s} \right] \right)^{\gamma^u}$$
$$\left(p_{Z_a} Z_a - p'_{Z_a} Z'_a - L_a w_a^u \right)^{1-\gamma^u}$$

[21] See Appendix D for a detailed derivation.

where W_a^u is the asset value of employment for abstract union members and $W_a^{u,s}$ is the value of being a union member during a strike. Z_a is the production of the abstract intermediate good and Z_a' is the production in the abstract sector when workers are on a strike, which is compensated at price p_{Z_a}'.

Thus, the total surplus received by the abstract union S_a^u is given by

$$S_a^u = \gamma_a^u(p_{Z_a}Z_a - p_{Z_a}'Z_a') + (1-\gamma^u)L_a w_a^{u,s} \tag{8}$$

4.5. Households, Government Expenditures, and Transfers

In the model, there is one household for each occupation and for each employment status, i.e., employed and unemployed. Households own the firm and consume the final good Y. There are no savings. For each worker the budget constraint is given by

$$C = I$$

with $I \in \{w_a^n, w_r^n(\eta), w_r^u, w_m^n, w_m^u, z_a, z_r(\eta), z_m(\eta)\}$.

Since the government pays out unemployment benefits, government expenditures are

$$G = z_a u_a + \int_{\underline{\eta}}^{\bar{\eta}} (z_r(\eta)u_r + z_m(\eta)u_m)\,\mathrm{d}\eta.$$

Firms can generate profits, which are given by

$$\Omega = \Pi^{Z_a} + \Pi^{Z_r} + \Pi^{Z_m}.$$

Therefore, the transfers received by households are

$$\Gamma = -G + \Omega.$$

Total consumption in the economy is then given by the sum of individual consumption in addition to the transfers.[22]

[22]This allows us to abstract from the distribution of transfers to households. The results remain unchanged

4.6. Equilibrium

With the model completely described, we define the equilibrium.

Definition 1. *An equilibrium is defined as a set of i) firms' policy functions; ii) households' policy functions; iii) a union wage schedule; iv) prices; and v) a law of motion for the aggregate states, such that: i) for each firm the firm's policies satisfy the firms' first order conditions and the job-creation conditions; ii) for each household the households' policy functions satisfy the households' first order conditions; iii) the wage is determined through individual or collective bargaining; iv) the choices given the aggregate states clear the markets; v) the law of motion for the exogenous aggregate states is consistent with individual decisions and with the process for computer capital prices.*

5. Routine-Biased Technical Change

In Section 6 we evaluate a calibrated version of the model in order to quantify the effects of routine-biased technical change, in the form of an exogenous drop in the price of computer capital relative to the price of consumption, on occupational decisions and on union formation. It is well-established in the literature, that routine-biased technical change generates polarization in models of the labor market.[23] In our model, polarization is driven by occupational switches from previous routine workers to manual occupations. This result is formalized in Proposition 1.

Proposition 1. *Routine-biased technical change increases the incentives for previous routine workers to switch to manual occupations if $\sigma > 0$ and $\sigma > (1-\alpha)\rho$.*

Proof. See Appendix F for a proof of Proposition 1. □

Routine-biased technical change, by increasing the capital stock, raises the productivity of manual workers by more compared to the productivity of routine workers. This leads to higher relative wages and job-finding rates for manual workers. Thus, the incentives for

when lump-sum transfers are assumed instead.

[23]See, for example, Autor and Dorn (2013) or Albertini et al. (2017).

previous routine workers to switch to manual occupations increase. We add to this well-known result by demonstrating that routine-biased technical change additionally leads to deunionization in our model. Proposition 2 summarizes the main mechanism.

Proposition 2. *Routine-biased technical change reduces the incentives for manual workers to vote in favor of union coverage if $\rho > 0$.*

Proof. See Appendix F for a proof of Proposition 2. □

Intuitively, falling computer capital prices imply lower marginal costs of production. This increases the demand for workers in all three occupations. However, because of the complementarity of computer capital and routine workers in production, there is a negative substitution effect that reduces the demand for routine workers. Their marginal productivity increases by less than the marginal productivity of manual workers. Thus, the non-union wages of manual workers increase by more than the non-union wages of routine workers. The increasing relative demand for manual workers in response to the drop in the price of computer capital increases the size of the surplus the union can extract, while the negative substitution effect on the relative demand for routine workers tends to work in the opposite direction. Since unions set identical wages for manual and routine workers, routine workers benefit from the higher relative demand for manual workers while manual workers suffer from the lower relative demand for routine workers. This directly implies that non-union wages for manual workers grow by more than union wages. Furthermore, the increase in the amount of capital used in production lowers the implicit bargaining power of unions, as a potential strike becomes less harmful for the firm. This additionally dampens union wage growth compared to non-union wage growth. Thus, the incentives to unionize decrease unambiguously for manual workers.

The effect of routine-biased technical change on the voting incentives for routine workers is ambiguous and depends on the larger union wage growth due to the relatively larger productivity growth of manual workers and the lower union wage growth due to the larger amount of capital. In the quantitative evaluation, the incentives for routine workers to vote in favor of a collective bargaining agreement monotonically decrease with falling computer capital prices. However, even if the incentives were to increase for the lower-skilled routine workers, manual workers would still drive deunionization, as they make up between 46% and 53% of the bargaining unit inside firms.

6. Quantitative Analysis

In this section, all the parameters discussed above are calibrated to match different aspects of U.S. data for 1983, the date from which on the CPS provides union membership estimates by detailed occupation. In line with empirical data, we let computer capital prices fall by 48% until 2005.[24] We use the calibrated model to quantify the effect on the occupational choice of workers and on union elections. For the simulation we choose a setting with heterogeneous unions that differ with respect to their bargaining power γ^u and γ_a^u. We consider an economy that consists of a number N of independent islands, representing different firms in an industry.[25] All islands are identical except for the bargaining power of the potential union. The performance of the model is evaluated along several dimensions, especially with regard to the empirical evidence on deunionization in the U.S. We focus on steady states as we are mainly interested in the long-run effect of routine-biased technical change on the economy and on the wage bargaining regimes.

6.1. Calibration

The model is calibrated to quarterly frequencies. Target values pertain to economy-wide averages. Table 1 lists the exact parameter values as well as the source that encourages the specific choice. We first calibrate the discount factor β to a conventional value of 0.99, which implies an annual interest rate of 4%. Next, we calibrate the labor market variables. The separation rates of manual and routine workers are set to the standard value of $s_m = s_r = 0.1$. Following Albertini et al. (2017), we set the separation rate of abstract workers to the lower value of $s_a = 0.05$.

[24] 2005 is chosen as the endpoint for two reasons. First, 2005 marks the endpoint of the dataset compiled in Autor and Dorn (2013). Second, Beaudry et al. (2016) documents a reversal in the demand for cognitive skills since the early 2000s. Accounting for this reversal goes beyond the scope of our analysis.

[25] Empirical evidence suggests that both polarization and deunionization are driven by changes within rather than between industries. See Tüzemen and Willis (2013) for a decomposition analysis concerning polarization and Baldwin (2003) for a decomposition analysis concerning deunionization.

The matching efficiencies are calibrated in order to match the average job-finding rate between 1983 and 2005 reported in Shimer (2005). Under this calibration the job-finding rate increases with the skill level. A large literature documents no or only small effects of unionization on employment: Frandsen (2012) and Montgomery (1989) on the aggregate level, Boal and Pencavel (1994) on the industry level, and DiNardo and Lee (2004) on the firm level. Furthermore, using linked employer-employee data, Brändle and Goerke (2018) argue that negative employment effects might be caused by selection in cross-sectional studies. We take this evidence into account by calibrating the matching efficiency on unionized islands to match the same job-finding rates as on non-unionized islands.

Vacancy posting costs are chosen to correspond on average to 35% of a worker's quarterly steady state wage, which lies well in the range of values found in the literature.[26] For simplicity, unemployment benefits and strike pay are both set to zero.[27]

Table 1: Calibrated Parameters

Symbol	Interpretation	Value	Source
β	Discount factor	0.99	Annual interest rate of 4%
s_m	Manual eparation rate	0.1	Garín (2015)
s_r	Routine separation rate	0.1	Garín (2015)
s_a	Abstract separation rate	0.05	Albertini et al. (2017)
Ψ_m	Manual matching efficiency	0.25	Job-finding rate 0.56
Ψ_r	Routine matching efficiency	0.33	Job-finding rate 0.56
Ψ_a	Abstract matching efficiency	0.8	Job-finding rate 0.56
ψ	Unemployment-elasticity of matching	0.5	Petrongolo and Pissarides (2001)
c_m	Manual recruiting costs	0.3	35% of wages
c_r	Routine recruiting costs	0.3	35% of wages
c_a	Abstract recruiting costs	0.5	35% of wages
A	Productivity routine and abstract input	3.4	Occupational shares in 1983
A_m	Productivity of manual input	0.77	Occupational shares in 1983
α	Marginal return to abstract labor	0.45	Occupational shares in 1983
ρ	Production parameter	0.65	Occupational shares in 1983
σ	Production parameter	0.74	Albertini et al. (2017)
μ	Production parameter	0.5	Albertini et al. (2017)
$\underline{\eta}$	Lower bound on skill	0.48	Occupational shares in 1983
$\overline{\overline{\eta}}$	Upper bound on routine skill	1.44	Occupational shares in 1983
$g_{L_a^S}$	Growth rate of abstract labor supply	0.015	Abstract employment in 2005
g_{p_K}	Growth rate of computer capital prices	-0.029	Investment prices in 2005
γ^m	Manual Worker's bargaining power	0.5	Midpoint of literature values
γ^r	Routine Worker's bargaining power	0.5	Midpoint of literature values
γ_a	Abstract Worker's bargaining power	0.8	College Wage premium 1983
γ^u	Union bargaining power	0.51 - 1	Non-Abstract Union Membership
γ_a^u	Abstract Union bargaining power	0.88 - 1	Abstract Union Membership

All production and skill specific parameters are set in order to match data on employment shares in 1983 (30.7% manual, 35.7% routine, and 33.6% abstract workers), as well as the

[26]See, for example, Garín (2015) and Michaillat (2012).
[27]The results are robust to alternative parameter choices.

abstract employment share of 40.9% in 2005. This leaves manual and routine employment shares in 2005 as untargeted moments to gauge the performance of the model. The growth rates of computer capital prices g_{p_K} and abstract labor supply $g_{L_a^S}$ are calibrated to match a drop in computer capital prices by 48% and an increase in the abstract employment share of 7.3 percentage points.

Depending on birth cohort, age group, and survey data, the difference in wages between high school graduates and college graduates amounts to 10%-29%. The average Mincer college wage premium - over age groups, birth cohorts, and survey data - amounts to roughly 15% to 20% in the U.S. in 1983.[28] Setting the bargaining power of abstract workers to $\gamma_a^n = 0.8$ and the bargaining power of manual and routine workers to $\gamma_m^n = \gamma_r^n = 0.5$ yields a college wage premium of 17% in the model in 1983 while leaving the average worker bargaining power in the standard range between 0.4 and 0.6.[29]

The union bargaining power of the potential unions is assumed to be equally distributed - on the interval between 0.51 and 1 for the potential non-abstract unions and on the interval between 0.88 and 1 for the potential abstract unions.[30] With the bargaining power of the most powerful unions set to one, a lower bound of 0.88 on the bargaining power of the unions for abstract workers matches the abstract union membership rate of 16.6% in 1983 reported in the U.S. union database constructed by Hirsch and Macpherson (2003). Given this calibration, a lower bound of 0.51 for non-abstract unions matches the overall union membership rate of 19.5% in 1983, calculated using the U.S. union database and the employment shares from Autor and Dorn (2013).

[28]See, for example, Ashworth and Ransom (2018). Mincer college wage premium refers to a wage premium that is adjusted for observable skills using the model proposed by Mincer (1974). Typically, the Mincer wage premium is roughly half the size of the raw wage premium.

[29]The college wage premium can be calculated when assuming that the individual skill η refers to the educational attainment of otherwise identical workers. If we further assume that on average manual workers have high school education, abstract workers a college degree, and routine workers some college or an associates degree, than the college wage premium is given by the ratio of abstract to manual wages in the model.

[30]The large differences between the union bargaining powers and the individual bargaining power of a worker are due to the fact that under collective bargaining workers are not lost to the firm when bargaining breaks down. If we instead assume that the firm loses its workforce when no agreement is reached, the calibration target for the union bargaining powers would be substantially lower than under individual bargaining. The reason behind this is that the union bargains over the average product of all workers in the bargaining unit, while each individual workers only bargains over his or her marginal product. The results are robust to alternative intervals of the union bargaining power.

6.2. Deunionization

As capital prices fall, the unions with the lowest bargaining power fail to gain majority support in the subsequent elections and are terminated.[31] Our model performs well in generating declining union membership rates between 1983 and 2005. The predicted and actual changes are given in Table 2. The union

Table 2: Union Membership Rate: Model versus Data

	1983		2005	
	Data	Model	Data	Model
Overall	19.5%	19.5%	12.9%	10.2%
Manual Workers	24.8%	21.0%	14.5%	6.3%
Routine Workers	17.7%	21.0%	10.2%	6.3%
Abstract Workers	16.6%	16.6%	13.4%	15.9%

Note: Data for union membership rates by occupations are calculated using the U.S. union database constructed by Hirsch and Macpherson (2003) and include all wage and salary workers. We use the occupational classification from Autor and Dorn (2013). The overall union membership rate is calculated using the employment shares reported in Autor and Dorn (2013) and the union membership rates by occupation.

membership rate falls by 9.3 percentage points from 19.5% to 10.2% in the model, compared to a drop by 6.6 percentage points from 19.5% to 12.9% in the model. The union membership rate for manual workers drops by 14.7 percentage points compared to 10.3 in the data, the membership rate for routine workers by 14.7 percentage points compared to 7.5, and the membership rate for abstract workers by 0.7 percentage points compared to 2.5. [32]

As abstract workers are unionized in a homogenous group, the higher marginal productivity due to technical change affects union and non-union wages for these workers similarly. However, under individual bargaining the higher demand for abstract workers increases the

[31] This model prediction is supported by evidence in the 2004 NLRB Performance and Accountability Report. Going from 1994 to 2004, the number of filed representation petitions has dropped by 25% and the share of won elections has increased by over five percentage points.

[32] The model slightly overpredicts the decline in the membership rates for manual and routine workers and underpredicts the decline in membership rates for abstract workers. Possible explanations for the former are workers that remain union members despite declining monetary incentives out of habit, due to peer pressure, or because of other non-monetary membership advantages. The latter might arise because we ignore heterogeneity among abstract workers.

cost of hiring a worker in the next period. The outside option under collective bargaining, i.e., a strike of abstract workers, is associated with the same costs as before. Thus, the incentives to unionize decrease slightly for abstract workers, but by less compared to manual and routine workers.

Result 1. *The drop in the overall union membership rate between 1983 and 2005 is mainly driven by decreasing membership rates within occupations and not by changing employment shares.*

In our model deunionization does not only, by construction, work entirely through changes within industries, but also mainly through changes within rather than between occupations. Baldwin (2003) conducts a decomposition exercise for the time period between 1977 and 1997 and finds that the within-industries contribution to falling unionization rates in the U.S. is, depending on the exact specification, at least 82%. Adopting the approach used in Baldwin (2003), we estimate the within-occupations component of the decline in the U.S. union membership rate between 1983 and 2005 to be over 90%.[33] In line with the data, 97% of the falling union membership rate is explained by the within-occupations component in our model.

Result 2. *Despite falling union membership rates, the average union wage premium stays roughly constant between 1983 and 2005.*

Estimates of the average union - non-union wage differential across workers range from close to zero in Bryson (2002) and Booth and Bryan (2004) to 25% in Hirsch and Schumacher (2004). Recent studies by DiNardo and Lee (2004) and Frandsen (2012), who focus on employer and union election data, find only very small or even negative union wage premia on average. Additionally, Streeck (2005) argues that because of its structure, industrial unions tend to exhibit even lower wage premia on average compared to craft unions.

As highlighted in Farber et al. (2018), existing models of union formation have trouble explaining the observation of a relatively constant union wage premium in times of rapidly declining union membership rates. The increased use of capital and high-skilled workers

[33] See Appendix E for a detailed account of the decomposition analysis.

reduces the value of low-skilled workers for the firm and thus depresses the implicit bargaining power of unions. A similar effect is at work in our model, as the increased use of capital in production lowers the value of routine workers for the firm. However, since our model predicts that the unions with the lowest bargaining power will be the ones that are terminated, union termination in the model is associated with an increasing average union bargaining power. These countervailing effects imply relatively constant union wage premia despite a sharp decline in union membership rates. The evolution of the average union wage premium in the model is given in Table 3. Despite a drop of close to 10 percentage points in the union membership rate, the average union wage premium decreases by only 1.2 percentage points in the model.

Table 3: Simulated Union Wage Premium and Skill Ratio

	1983	2005
Union Wage Premium	0.6%	-0.6%
Skill Ratio Non-unionized Workers	0.53	0.62
Skill Ratio Unionized Workers	0.4	1.75

Note: The skill ratio in the model is defined as the ratio of abstract to non-abstract workers.

Result 3. *Deunionization increases the relative skill level of union members between 1983 and 2005.*

Existing models of union formation mostly rely upon declining membership rates among the highest-skilled workers in order to explain deunionization. This stands in sharp contrast to the membership data in Hirsch and Macpherson (2003). In line with the data, the union membership rate of abstract workers decreases only slightly in our model. Consider an increase in the skill level of a worker and how this affects his or her probability of being a union member. Given the predicted changes in unionization rates between 1983 and 2005, an increase in the skill level of a worker decreased the probability of being a union member in 1983, but increases the probability of being a union member in 2005. This coincides with evidence on the effect of educational attainment on the union status of workers in Farber et al. (2018). The reason is that the union membership rate of abstract workers decreases by less compared to the union membership rates of the less-skilled manual and routine workers, both in the data and in our model. The ratio of abstract to non-abstract workers inside and outside of unions in our model is reported in Table 3.

6.3. Polarization

As shown in Section 5, falling computer capital prices lead to employment adjustments, with the lowest-skilled routine workers deciding to switch to manual occupations upon becoming unemployed.

The employment shares in the model and in the data are given in Table 4. The share of manual workers increases from 30.7% to 31.1% in the data and to 30.0% in the model between 1983 and 2005, while the employment share of routine workers decreases from 35.7% to 28.0% in the data and to 27.9% in the model. Figure 4 displays the respective percentage point changes in the employment share for each occupation.

Table 4: Employment Shares in 1983 and 2005: Model versus Data

	1983		2005	
	Data	Model	Data	Model
Manual	30.7%	30.7%	31.1%	31.0%
Routine	35.7%	35.7%	28.0%	27.9%
Abstract	33.6%	33.6%	40.9%	40.9%

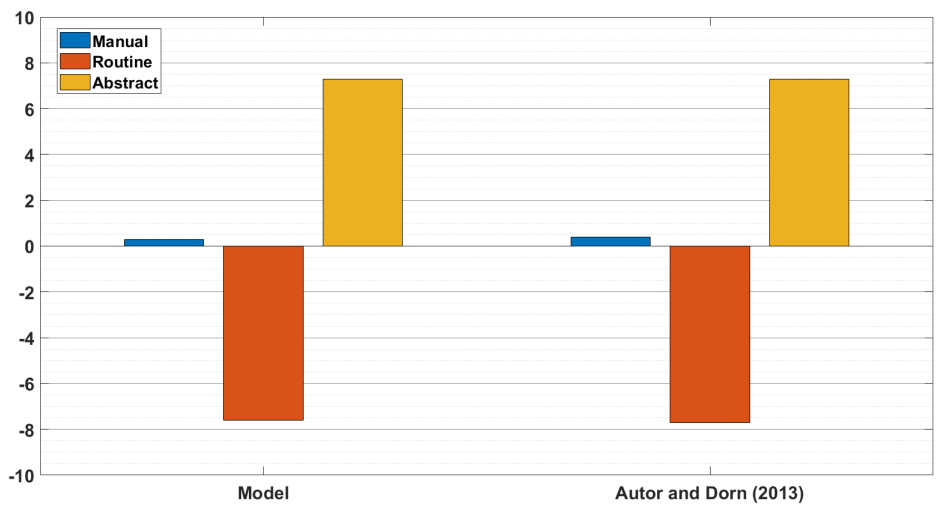
The share of workers in each occupation is constructed using the dataset and the occupational classification from Autor and Dorn (2013).

Employment changes are less pronounced in unionized firms: as wages for manual and routine workers grow equally, the lowest-skilled unionized routine workers have no incentive to switch to manual jobs.[34] While there is no direct evidence on the polarization of the employment structure in unionized versus non-unionized firms, our model prediction is supported by two strands of the literature. First, Calmfors et al. (2001) and Rogers and Streeck (1995) argue that in many countries the management is under the obligation to at least consult with the relevant unions over restructuring and layoff plans. In these cases union officials tend to prefer policies that favor those workers who are most likely to be union members in order to improve their chances in future elections. Thus, unions will likely oppose plans

[34]This result does not depend on the specific choice of the union wage schedule but holds as long as union wages for routine workers are higher compared to union wages of manual workers.

that reinforce polarization. Second, Connolly et al. (1986), Hirsch and Link (1987), and more recently Bradley et al. (2015) argue that unions have detrimental effects on innovation and technology adaption. As technical change is the most important driving force behind polarization, less innovation is likely to be accompanied by less polarization. This implies, as our model predicts, that deunionization amplifies polarization.

Figure 4: Percentage Point Changes in Employment Shares, 1983 – 2005: Model versus Data



Note: The share of workers in each occupation is constructed using the dataset and the occupational classification from Autor and Dorn (2013).

Even though the manual employment share remains roughly unchanged, there has been substantial employment reallocation with more than 10% of all routine workers in 1983 deciding to switch to manual occupations. About 15% of the occupational switches in our model are triggered by the termination of unions. When low-skilled routine workers are unable to find unionized jobs, which would pay them a substantial union wage premium, their incentives to switch occupations increase. While the model, in line with the empirical literature, predicts routine-biased technical change to be the main explanation for job market polarization, deunionization substantially amplifies employment changes.

The changes in employment are accompanied by wage changes. The model predicts wages for abstract, routine, and manual workers to grow by 10%, 8%, and 8.5%, respectively. Although a bit smaller, these changes accord with the pattern of wage changes by skill levels reported in Autor and Dorn (2013) for the time period between 1980 and 2005.

6.4. Inequality

In contrast to the large effect on employment changes, deunionization has only modest effects on wage changes. Going from 1983 to 2005, the Gini index in our model increases by 18% compared to an increase of 12% for U.S. data.[35] However, since union wage premia are small on average and the unions with the lowest bargaining power are terminated, this increase in inequality is almost entirely driven by the increasing employment share and increasing relative wages for abstract workers. The small overall effects of deunionization on wage inequality in our model accord with the empirical findings in DiNardo et al. (1996), Frandsen (2012), and Farber et al. (2018).

The effects of deunionization for those groups that traditionally receive a high union wage premium, the lower middle-skilled workers, are substantial. For the lowest-skilled previously unionized routine workers, i.e., those workers who lose their union wage premium going from 1983 to 2005 and subsequently switch occupations, the wage growth would be 60% larger if they were covered by one of the remaining unions.

7. Discussion and Policy Implications

While routine-biased technical change hurts middle-wage workers, job market polarization per se, in the sense of changing employment shares, does not. In the model, the possibility to switch occupations allows labor supply to adjust to the changes in labor demand and thereby to partly offset the wage effects of routine-biased technical change. However, Kambourov and Manovskii (2009), Gathmann and Schönberg (2010), and Cortes and Gallipoli (2017) show that occupational switching costs are large. Therefore, as proposed for example in Autor et al. (2003), policies that simplify job switches or that aim at making them less costly for workers could serve to dampen income inequality caused by routine-biased technical change.

Additionally, our analysis has shown that while the overall effect of deunionization on income inequality is small, there are large effects for lower middle-skilled workers. Taking into account evidence from Frandsen (2012), who reports that most union elections are very closely contested, even small policy changes could lead to large effects on income inequality

[35] The Gini index in our model is computed using wage ventiles.

for these workers.

We briefly consider the effects of two policies in our model that aim at supporting lower middle-skilled workers. The first policy simply abolishes union elections after the first election in 1983 and maintains the established unions regardless of worker preferences. While this approach prevents deunionization, it also prevents efficient deunionization in the sense that even unions generating a highly negative average wage premium would be maintained. The second policy lowers the necessary voting threshold for unions. For specific voting thresholds, this policy achieves the same results as abolishing elections, with identical downsides. However, such an intervention is not well suited to stop the overall trend of declining union membership rates, as the threshold would have to be regularly adjusted to changes in the economy. Furthermore, low threshold values, apart from being difficult to justify, could in principle lead to the founding of further inefficient unions.

In our simulation, deunionization can always be prevented by adjusting the union wage schedule towards less equality inside the unionized firms. However, empirical evidence suggests that rigid organizational structures partly prevent unions from meeting today's challenges. Waddington (2005) contends that trade union practices are perceived as formal and old-fashioned and that the representative structures inside unions are often inappropriate for the participation of all members. Bryson et al. (2016) argue that union representatives have very long tenure and tend to become less representative of the membership over their term of office. While membership rates decline across all age groups, according to data from the Bureau of Labor Statistics, membership rates for workers aged between 16 and 24 declined at twice the rate of overall membership between 2002 and 2012. Data on the evolution of the median age of union members points in the same direction: Dunn and Walker (2016) stress that over half of all U.S. union members are between 45 and 64 years of age. Thus, it seems that unions are mostly controlled and influenced by older members that might display a tendency to stick to established practices. Bryson et al. (2016) argue that the decline in union membership rates across countries is negatively related to the degree of progressiveness of the unions. One straightforward policy suggestion would be restricting the tenure of union representatives to ensure that union officials are drawn from the current membership.

8. Conclusion

This paper explores how routine-biased technical change affects both the occupational and the union-membership choice of workers. To do so we develop a model that endogenizes both decisions in a search and matching framework.

We provide analytical results and use the calibrated model to show that routine-biased technical change, represented by a sharp drop in computer capital prices, not only generates employment and wage polarization but also deunionization. The drop in computer capital prices reduces the demand for routine workers, while the demand for abstract and manual workers increases. The changing demand structure influences the surplus unions can extract and thereby also the individual union wage premium of workers. Manual workers, who benefit from the changing demand structure, are discouraged from voting in favor of a collective bargaining agreement. As wage gains for manual workers would be distributed more equally between manual and routine workers by the union, manual workers are better off when bargaining individually with the firm. Former routine workers, when faced with lower wages compared to manual workers, decide to switch occupations.

We demonstrate that this effect can lead to a change in the voting outcome, with the majority of the workforce of previously unionized firms now voting against unionization and in favor of individual bargaining. In an economy in which unions differ with respect to their bargaining power, routine-biased technical change leads to a large decrease in union membership rates, as those unions with the lowest bargaining power are terminated. As about 15% of all job switches are triggered by deunionization, this contributes substantially to employment polarization. While overall effects on income inequality are small, low- to middle-skilled previously unionized workers are severely affected.

References

Acemoglu, D., Aghion, P., Violante, G.L., 2001. Deunionization, technical change and inequality. Carnegie-Rochester Conference Series on Public Policy 55, 229–264.

Açıkgöz, O.T., Kaymak, B., 2014. The rising skill premium and deunionization. Journal of Monetary Economics 63, 37–50.

Albertini, J., Hairault, J.O., Langot, F., Sopraseuth, T., 2017. A tale of two countries: A story of the French and US polarization. IZA Discussion Papers No. 11013.

Ashworth, J., Ransom, T., 2018. Has the college wage premium continued to rise? Evidence from multiple U.S. surveys. IZA Discussion Papers No. 11657.

Autor, D.H., Dorn, D., 2013. The growth of low-skill service jobs and the polarization of the US labor market. American Economic Review 103, 1553–1597.

Autor, D.H., Katz, L.F., Kearney, M.S., 2006. The polarization of the U.S. labor market. American Economic Review 96, 189–194.

Autor, D.H., Levy, F., Murnane, R.J., 2003. The skill content of recent technological change: An empirical exploration. Quarterly Journal of Economics 118, 1279–1333.

Baccaro, L., Locke, R., 1998. The end of solidarity? The decline of egalitarian wage policies in Italy and Sweden. European Journal of Industrial Relations 4, 283–308.

Baldwin, R., 2003. The decline of US labor unions and the role of trade. Peterson Institute for International Economics.

Beaudry, P., Green, D.A., Sand, B.M., 2016. The great reversal in the demand for skill and cognitive tasks. Journal of Labor Economics 34, 199–247.

Boal, W.M., Pencavel, J., 1994. The effects of labor unions on employment, wages, and days of operation: Coal mining in west virginia. Quarterly Journal of Economics 109, 267–298.

Booth, A., Bryan, M.L., 2004. The union membership wage-premium puzzle: Is there a free rider problem? International Labor Relations Review 57, 402–421.

Bradley, D., Kim, I., Tian, X., 2015. Do unions affect innovation? *Management Science*, Forthcoming.

Brändle, T., Goerke, L., 2018. The one constant: A causal effect of collective bargaining on employment growth? Evidence from German linked-employer-employee data. Scottish Journal of Political Economy 65, 445–478.

von Brasch, T., Gjelsvik, M.L., Sparrman, V., 2018. Deunionization and job polarization – a macroeconomic model analysis for a small open economy. Economic Systems Research 30, 380–399.

Bryson, A., 2002. The union membership wage premium: An analysis using propensity score matching. CEP Discussion Papers No. 530.

Bryson, A., Dale-Olsen, H., Nergard, K., 2016. Gender differences in the union membership wage premium? A comparative case study. IZA Discussion Papers No. 10435.

Calmfors, L., Booth, A., Burda, M., Checchi, D., Naylor, R., Visser, J., 2001. The Role of Unions in the Twenty-First Century: A Report for the Fondazione Rodolfo Debenedetti. Oxford University Press. chapter 1. pp. 1–158.

Card, D., Lemieux, T., Riddel, C.W., 2004. Unions and wage inequality. Journal of Labor Research 25, 519–559.

Checchi, D., Visser, J., van de Werfhorst, H.G., 2010. Inequality and union membership: The influence of relative earnings and inequality attitudes. British Journal of Industrial Relations 48, 84–108.

Connolly, R.A., Hirsch, B.T., Hirschey, M., 1986. Union rent seeking, intangible capital, and market value of the firm. Review of Economics and Statistics 68, 567–577.

Cortes, G.M., Gallipoli, G., 2017. The cost of occupational mobility: An aggregate analysis. Journal of the European Economic Association 16, 275–315.

DiNardo, J., Fortin, N.M., Lemieux, T., 1996. Labor market institutions and the distribution of wages, 1973-1992: A semiparametric approach. Econometrica 64, 1001–1044.

DiNardo, J., Lee, D.S., 2004. Economic impacts of new unionization on private sector employers: 1984-2001. Quarterly Journal of Economics 119, 1383–1441.

Dinlersoz, E., Greenwood, J., 2016. The rise and fall of unions in the United States. Journal of Monetary Economics 83, 129–146.

Duclos, J.Y., Esteban, J., Ray, D., 2004. Polarization: Concepts, measurement, estimation. Econometrica 72, 1737–1772.

Dunn, M., Walker, J., 2016. BLS spotlight on statistics: Union membership in the United States. U.S. Department of Labor, Bureau of Labor Statistics.

Farber, H.S., Herbst, D., Kuziemko, I., Naidu, S., 2018. Unions and inequality over the twentieth century: New evidence from survey data. NBER Working Papers No. 24587.

Feng, A., Graetz, G., 2015. Rise of the machines: The effects of labor-saving innovations on jobs and wages. CEP Discussion Papers No. dp1330.

Fitzenberger, B., Kohn, K., Lembcke, A., 2006. Union density and varieties of coverage: The anatomy of union wage effects in Germany. International Labor Relations Review 66, 169–197.

Frandsen, B.R., 2012. Why unions still matter: The effects of unionization of the distribution of employee earnings. Working Paper.

Garín, J., 2015. Borrowing constraints, collateral fluctuations, and the labor market. Journal of Economic Dynamics and Control 57, 112–130.

Gathmann, C., Schönberg, U., 2010. How general is human capital? A task-based approach. Journal of Labor Economics 28, 1–49.

Hirsch, B.T., Link, A.N., 1987. Labor union effects on innovative activity. Journal of Labor Research 8, 323–331.

Hirsch, B.T., Macpherson, D.A., 2003. Union membership and coverage database from the current population survey: Note. Industrial and Labor Relations Review 56, 349–354.

Hirsch, B.T., Schumacher, E.J., 2004. Match bias in wage gap estimates due to earnings imputation. Journal of Labor Economics 22, 689–722.

Kambourov, G., Manovskii, I., 2009. Occupational specificity of human capital. International Economic Review 50, 63–115.

Lewis, P., 1989. The unemployed and trade union membership. Industrial Relations Journal 20, 271–279.

Mayer, G., 2004. Union membership trends in the United States. Congressial Research Service.

Meyer, B., 2017. Financialization, technological change, and trade union decline. Socio-Economic Review .

Michaels, G., Natraj, A., Reenen, J.V., 2014. Has ICT polarized skill demand? Evidence from eleven countries over twenty-five years. Review of Economics and Statistics 96, 60–77.

Michaillat, P., 2012. Do matching frictions explain unemployment? Not in bad times. American Economic Review 102, 1721–1750.

Mincer, J., 1974. Schooling, experience, and earnings. Columbia University Press, NY.

Montgomery, E., 1989. The employment and unemployment effects of unions. Journal of Labor Economics 7, 170–190.

Mortensen, D.T., Pissarides, C.A., 1994. Job creation and job destruction in the theory of unemployment. Review of Economic Studies 61, 397–415.

Nickell, S., Layard, R., 1999. Labor market institutions and economic performance. Handbook of Economics 3, 3029–2084.

Oh, W., 1989. Craft versus Industrial Unions: Union Organization Within the Work Place. Ph.D. thesis. The Ohio State University.

Petrongolo, B., Pissarides, C.A., 2001. Looking into the black box: A survey of the matching function. Journal of Economic Literature 39, 390–431.

Post, C., 2017. The roots of Trumpism. Cultural Dynamics 29, 100–108.

Rogers, J., Streeck, W., 1995. Works councils: Consultation, representation, and cooperation in industrial relations. National Bureau of Economic Research, Inc.

Shimer, R., 2005. The cyclical behavior of equilibrium unemployment and vacancies. American Economic Review 95, 25–49.

Smith, C.L., 2013. The dynamics of labor market polarization. Finance and Economics Discussion Series 2013-57, Board of Governors of the Federal Reserve System (U.S.).

Streeck, W., 2005. The Sociology of Labor Markets and Trade Unions. In: N.J. Smelser and R.Swedberg *The Handbook of Economic Sociology*. Princeton University Press. pp. 254–283.

Taschereau-Dumouchel, M., 2017. The union threat. Working Paper.

Traxler, F., 1994. Collective bargaining: Levels and coverage. Employment Outlook 1994, OECD, 167-194.

Troy, L., Sheflin, N., 1985. U.S. union sourcebook. Industrial Relations Data and Information Services, West Orange, New Jersey.

Tüzemen, D., Willis, J.L., 2013. The vanishing middle: Job polarization and workers' response to the decline in middle skill jobs. Economic Review Q I, 5–32.

Waddington, J., 2005. Trade union membership in Europe: The extent of the problem and range of union responses. Host publication.

Appendix

Appendix A. First Order Conditions of Firms

Defining the value of a marginal worker in an abstract non-routine cognitive occupations for a firm as J_a, the first-order conditions for hiring and for vacancy posting are given by

$$c_a = \mu_a q_a,$$

$$\mu_a = \beta J_{a,+1},$$

where μ_a is the Lagrange-multiplier on the employment constraint for workers in abstract occupations. The corresponding value of a marginal worker in abstract non-routine cognitive occupations is given by

$$J_a = p_{Z_a} - \mathbb{1}_u w_a^u - (1 - \mathbb{1}_u) w_a^n + (1 - s_a)\beta J_{a,+1}.$$

Defining the value of a marginal worker with ability η in a routine occupation for a firm as $J_r(\eta)$, the first-order conditions for hiring workers in routine tasks and for vacancy posting are given by

$$\begin{aligned} c_r &= \mu_r q_r \\ \mu_r &= \beta J_{r,+1}, \end{aligned}$$

where μ_r is the Lagrange-multiplier on the employment constraint for a worker in routine occupations. The corresponding value of a marginal worker with ability η in routine occupations is given by

$$\begin{aligned} &J_r = p_{Z_r}\overline{y_r} - \mathbb{1}_u\overline{w_r^u} - (1 - \mathbb{1}_u)\overline{w_r^n} + (1 - s_r)\beta J_{r,+1}, \\ &\quad \text{with } y_r(\eta) = \frac{\partial Z_r}{\partial L_r(\eta)} = \eta(1-\mu)^\sigma\left[(1-\mu)^\sigma + (\mu k)^\sigma\right]^{\frac{1}{\sigma}-1} \text{ and } k \equiv \frac{K}{\int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta)}, \end{aligned}$$

where $\overline{y_r}$ is the expected marginal product of a routine worker, $\overline{w_r^u}$ is the expected union wage, and $\overline{w_r^n}$ the expected non-union wage. The average marginal product and the average wages are used here, as firms are unable to condition their job search on the ability level η.

Defining the value of a marginal worker with ability η in a non-routine manual occupation for a firm as J_m, the first-order conditions for hiring workers in manual tasks and for vacancy posting are given by

$$c_m = \mu_m q_m,$$
$$\mu_m = \beta J_{m,+1},$$

where μ_m is the Lagrange-multiplier on the employment constraint for worker in manual occupations. The corresponding value of a marginal worker with ability η in manual occupations is given by

$$J_m = p_{Z_m} - \mathbb{1}_u w_m^u - (1 - \mathbb{1}_u) w_m^n + (1 - s_m)\beta J_{m,+1}.$$

Appendix B. Job Creation Conditions

The job creation conditions are given by

$$\frac{c_i}{q_i} = \beta J_{i,+1}$$
$$\text{with } i = a, r, m,$$

Together with the values of marginal workers for firms, it follows that

$$\begin{aligned}
\frac{c_a}{q_a} &= \beta \left[p_{Z_a} - \mathbb{1}_{u,+1} w_a^u - (1 - \mathbb{1}_{u,+1})\, w_a^n + (1 - s_a) \frac{c_a}{q_{a,+1}} \right], \\
\frac{c_r}{q_r} &= \beta \left[p_{Z_r} \overline{y_r} - \mathbb{1}_{u,+1} \overline{w_r^u} - (1 - \mathbb{1}_{u,+1})\, \overline{w_r^n} + (1 - s_r) \frac{c_r}{q_{r,+1}} \right], \\
\frac{c_m}{q_m} &= \beta \left[p_{Z_m} - \mathbb{1}_{u,+1} w_m^u - (1 - \mathbb{1}_{u,+1})\, w_m^n + (1 - s_m) \frac{c_m}{q_{m,+1}} \right].
\end{aligned}$$

As we are mainly interested in the long-run effect of routine-biased technical change on the economy and on the wage bargaining regimes, we focus on the steady state of the economy. The steady state job creation conditions are given by

$$\frac{c_a}{q_a} = \beta \left[p_{Z_a} - \mathbb{1}_u w_a^u - (1 - \mathbb{1}_u)\, w_a^n + (1 - s_a) \frac{c_a}{q_a} \right], \tag{B.1}$$

$$\frac{c_r}{q_r} = \beta \left[p_{Z_r} \overline{y_r} - \mathbb{1}_u \overline{w_r^u} - (1 - \mathbb{1}_u)\, \overline{w_r^n} + (1 - s_r) \frac{c_r}{q_r} \right], \tag{B.2}$$

$$\frac{c_m}{q_m} = \beta \left[p_{Z_m} - \mathbb{1}_u w_m^u - (1 - \mathbb{1}_n)\, w_m^n + (1 - s_m) \frac{c_m}{q_m} \right]. \tag{B.3}$$

A firm hires workers of each type and each ability level η until the costs of labor are equal to the discounted expected marginal product. Here the costs consist of the vacancy posting costs and the discounted expected wage minus the discounted cost of hiring next period.

Appendix C. Derivation of Wages

This section derives the non-union wages in the model. The first order conditions are given by

$$W_i^n(\eta) - U_i(\eta) = \frac{\gamma^i}{1 - \gamma^i} J_i^n(\eta),$$

with $i = a, r, m$.

Abstract Workers

After replacing the value function, the Nash sharing rule for abstract workers is given by

$$\begin{aligned} & w_a^n + \beta \left[(1 - s_a) W_a^n + s_a U_a \right] - z_a - \beta [(1 - f_a) U_a^n + f_a W_a^n \} \\ & = \frac{\gamma^a}{1 - \gamma^a} \left[p_{Z_a} - w_a^n + (1 - s_a) \beta J_a^n \right]. \end{aligned}$$

After some rearrangement, we have

$$\begin{aligned} w_a^n = {} & \gamma^a p_{Z_a} + (1 - \gamma^n) z_a + \gamma^a (1 - s_a) \beta J_a^n \\ & + (1 - \gamma^a) \beta \left[f_a \left(W_a^n - U_a^n \right) - (1 - s_a) \left(W_a^n - U_a^n \right) \right]. \end{aligned}$$

By using the job creation condition (B.1) and $\frac{c_a}{q_a)} = \beta J^n_{a,+1}$ as well as the first order condition resulting from the Nash sharing rule:

$$(1-\gamma^a)\left(W^n_a - U^n_a\right) = \gamma^a J^n_a = \gamma^a \frac{c_a}{\beta q_a}$$

we obtain the following wage equation

$$w^n_a = \gamma^a p_{Z_a} + \gamma^a c_a \theta_a + (1-\gamma^a) z_a.$$

Routine Workers

After replacing the value function, the Nash sharing rule for routine workers of ability level η is given by

$$\begin{aligned}
&w^n_r(\eta) + \beta\left[(1-s_r)W^n_r(\eta) + s_r U_r(\eta)\right] - z_r(\eta) - \beta[(1-f_r)U^n_r(\eta) + f_r W^n_r(\eta)\} \\
&= \frac{\gamma^r}{1-\gamma^r}\left[p_{Z_r} y_r(\eta) - w^n_r(\eta) + (1-s_r)\beta J^n_r\right].
\end{aligned}$$

After some rearrangement, we have

$$\begin{aligned}
w^n_r(\eta) = {} & \gamma^r p_{Z_r} y_r(\eta) + (1-\gamma^r) z_r(\eta) + \gamma^r (1-s_r)\beta J^n_r \\
& + (1-\gamma^r)\beta\left[f_r\left(W^n_r(\eta) - U^n_r(\eta)\right) - (1-s_r)\left(W^n_r(\eta) - U^n_r(\eta)\right)\right].
\end{aligned}$$

By using the job creation condition (B.2) and $\frac{c_r}{q_r(\eta)} = \beta J^n_r(\eta)$ as well as the first order condition resulting from the Nash sharing rule:

$$(1-\gamma^r)\left(W^n_r(\eta) - U^n_r(\eta)\right) = \gamma^r J^n_r(\eta) = \gamma^r \frac{c_r}{\beta q_r}$$

we obtain the following wage equation

$$w^n_r(\eta) = \gamma^r p_{Z_r} y_r(\eta) + \gamma^r c_r \theta_r + (1-\gamma^r) z_r(\eta).$$

Manual Workers

After replacing the value function, the Nash sharing rule for manual workers is given by

$$\begin{aligned}
&w_m^n + \beta\left[(1-s_m)W_m^n + s_m U_m\right] - z_m(\eta) - \beta[(1-f_m)U_m^n + f_m W_m^n\}\\
&= \frac{\gamma^m}{1-\gamma^m}\left[p_{Z_m} - w_m^n + (1-s_m)\beta J_m^n\right].
\end{aligned}$$

After some rearrangement, we have

$$\begin{aligned}
w_m^n &= \gamma^m p_{Z_m} + (1-\gamma^m)z_m(\eta) + \gamma^m(1-s_m)\beta J_m^n\\
&\quad + (1-\gamma^m)\beta\left[f_m\left(W_m^n - U_m^n\right) - (1-s_m)\left(W_m^n - U_{m,+1}^n\right)\right].
\end{aligned}$$

By using the job creation condition (B.3) and $\frac{c_m}{q_m)} = \beta J_m^m$ as well as the first order condition resulting from the Nash sharing rule:

$$(1-\gamma^m)\left(W_m^n - U_m^n\right) = \gamma^m J_m^n = \gamma^m \frac{c_m}{\beta q_m}$$

we obtain the following wage equation

$$w_m^n = \gamma^m p_{Z_m} + \gamma^m c_m \theta_m + (1-\gamma^m)z_m(\eta).$$

Appendix D. Union Surplus

In this section we derive the non-abstract union surplus. The derivation of the abstract union surplus proceeds analogously. The first order condition in the collective bargaining problem is given by

$$\begin{aligned}
&\sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta)\left[W_i^u(\eta) - W_i^{u,s}(\eta)\right] \mathrm{d}\eta\\
&= \frac{\gamma^u}{1-\gamma^u}\sum_i \left\{p_{Z_i} Z_i - p'_{Z_i} Z'_i - \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\,\mathrm{d}\eta\right\},
\end{aligned}$$

with $i = r, m$.

After replacing the value function and using the job creation conditions (B.2) and (B.3), the Nash sharing rule is given by

$$\sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta)\left[w_i^u(\eta) - w_i^{u,s}(\eta)\right] \mathrm{d}\eta$$
$$= \frac{\gamma^u}{1-\gamma^u} \sum_i \Big\{ p_{Z_i} Z_i - p'_{Z_i} Z'_i - \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\,\mathrm{d}\eta \Big\}.$$

After some rearrangement, we have

$$\gamma^u \sum_i \left(p_{Z_i} Z_i - p'_{Z_i} Z'_i\right) + (1-\gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^{u,s}(\eta)\,\mathrm{d}\eta$$
$$= \gamma^u \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\,\mathrm{d}\eta + (1-\gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\,\mathrm{d}\eta.$$

Thus, the total union surplus is given by

$$S^u = \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^u(\eta)\,\mathrm{d}\eta$$
$$= \gamma^u \sum_i \left(p_{Z_i} Z_i - p'_{Z_i} Z'_i\right) + (1-\gamma^u) \sum_i \int_{\underline{\eta}}^{\bar{\eta}} L_i(\eta) w_i^{u,s}(\eta)\,\mathrm{d}\eta$$

with $i = r, m$.

Appendix E. Decomposition Analysis of Deunionization

In this section we apply the methodology used in, among others, Baldwin (2003) to decompose changes in union membership rates to occupations. We use this decomposition to assess the relative importance of each component for deunionization.

The within-occupation component measures the effect of a change in the membership rate for a specific occupational group, keeping the employment share of that group constant. The between-occupation component measures the effect of a change in the employment share of a specific occupational group, keeping the membership rate constant. Summing up both components over all occupational groups yields the estimated overall change in the union membership rate.

For the estimation, we use data on occupation-specific union membership rates provided in the U.S. union database described in Hirsch and Macpherson (2003). Occupations are

Table E.5: Changes Union Membership Rates: Data versus Model, 1983 – 2005

	Percentage Point	Share
Data		
Total Change	-7.24	100%
Within-occupations	-7.18	99.17%
Between-occupations	-0.06	0.83%
Model	Percentage Point	Share
Total Change	-10.27	100%
Within-occupations	-9.97	97.08%
Between-occupations	-0.30	2.92%

Note: Data for occupational employment shares are taken from Autor and Dorn (2013), and data on union membership rates from the U.S. union database constructed by Hirsch and Macpherson (2003).

classified as either manual, routine, or abstract, based on the classification used in Autor and Dorn (2013).

We use the same methodology to calculate the within-occupations and between-occupations component for the three occupations in our model. In line with the data, over 90% of the changes in union membership rates between 1983 and 2005 are driven by the within-occupations component in our model.

Appendix F. Theoretical Evaluation of the Main Mechanisms

The arguments in this section proof Propositions 1 and 2, which state the main mechanisms in our paper.

Appendix F.1. Polarization

Routine-biased technical change is modeled as a drop in p_k, the relative price of computer capital. As we are concerned with the incentives of previous routine workers to switch to manual occupations, we consider the effects of a decrease in p_k before any employment adjustment occurs. Thus, L_a, L_r, and L_m are constant.

Note, that the decrease in the relative price only affects the intermediate firm producing

Z_r directly. From the first order condition with respect to computer capital

$$\frac{\partial Z_r}{\partial K} = \mu^\sigma \left[\left(\frac{1-\mu}{k} \right)^\sigma + \mu^\sigma \right]^{\frac{1}{\sigma}-1}$$

it follows that K increases if and only if computer capital and workers performing routine tasks are substitutes, i.e, if $\sigma > 0$.[36] The increasing computer capital stock increases production of the intermediate good Z_r.

Keep in mind that a unemployed routine worker switches occupations if $U_m(\eta) > U_r(\eta)$. Thus, given that unemployment benefits and separation rates are not affected by the drop in capital prices, the two variables driving changes in the incentives are wages and job-finding rates. From the wage equations and job creation conditions for both types of occupations it immediately follows that both variables of interest are driven by changes in the marginal productivity of the respective workers.

As the relevant elasticities (the elasticity of the wage with respect to productivity and labor market tightness, and the elasticity of the job-finding rate with respect to productivity and wages) are identical for both types of occupations, it remains to show that the marginal productivity of manual workers increases by more compared to the marginal productivity of routine workers due to routine-biased technical change.

The relative marginal productivity of routine workers compared to manual workers is given by

$$\frac{p_{Z_r} y_r(\eta)}{p_{Z_m}} = \eta(1-\alpha)(1-\mu)^\sigma \left(\frac{A^{1+\frac{1}{\rho}}}{A_m} \right)^\rho \left(\frac{Z_a^{\frac{\alpha\rho}{\rho-1}}}{Z_m} \right)^{\rho-1}$$
$$\left((1-\mu) \int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta) \, \mathrm{d}\eta \right)^{\sigma-1} Z_r^{(1-\alpha)\rho-\sigma}.$$

Thus, the relative productivity of routine workers decreases in Z_r, if $\sigma > (1-\alpha)\rho$, which proofs Proposition 1. Intuitively, in order for routine-biased technical change to increase the incentives for occupational switches, capital and routine tasks need to be substitutes and

[36] Since the computer capital stock can be adjusted instantaneously and without frictions, an increase in K before occupational switches occur is in line with the model setup.

they need to be better substitutes than routine and manual tasks in the production of the final good.

Appendix F.2. Voting Incentives

A manual worker inside a unionized firm votes in favor of collective bargaining coverage, if the value of being a manual worker in a unionized firm is larger than the value of being a worker in a non-unionized firm, i.e., if $W_m^u > W_m^n$. As in Appendix F.1, the relevant variables are again the wages and the job-finding rates. As the marginal productivity of a manual worker is independent of the union status of the firm, relative changes in the job-finding rates are entirely driven by relative wage changes. Thus, it suffices to show that the non-union wage rate for manual workers increases relative to the union wage rate.[37]

Using the equation for the union surplus (7), the union wage schedule (5), and the non-union wage for manual workers (4), the relative union wage for a manual worker is given by[38]

$$\frac{w_m^u}{w_m^n} = \frac{\left[\gamma^u(p_{Z_m}Z_m - p'_{Z_m}Z'_m) + \gamma^u(p_{Z_r}Z_r - p'_{Z_r}Z'_r)\right]/(L_m + L_r)}{\gamma^m p_{Z_m} + \gamma^m c_m \theta_m^n}.$$

Using the production functions, this expression can be rewritten as

$$\frac{w_m^u}{w_m^n} = \frac{\left[\gamma^u p_{Z_m} Z_m\right]/(L_m + L_r)}{\gamma_m p_{Z_m} + \gamma_m c_m \theta_m^n} + \frac{\left[\gamma^u(p_{Z_r}Z_r - p'_{Z_r}Z'_r)\right]/(L_m + L_r)}{\gamma_m p_{Z_m} + \gamma_m c_m \theta_m^n}. \tag{F.1}$$

First, following the arguments in Appendix F.1, routine-biased technical change implies an increase in Z_r and thus an increase in the marginal productivity of manual workers, p_{Z_m}. Second, note that the effect of routine-biased technical change on the first term only depends on the elasticity of this term with respect to p_{Z_m}. Combining the job creation condition (B.3) and the wage for manual workers (4) yields

$$((1/\beta) - 1 + s_m)c_m\Psi_m(\theta_m^n)^\eta + c_m\gamma^m\theta_m^n = (1 - \gamma^m)p_{Z_m}.$$

[37]Note, that the positive effect of a wage increase on the value function is not offset by a decrease in the job-finding rate.

[38]Since w_i^u and $z_i(\eta)$ are both unaffected by routine-biased technical change and set to zero in the simulation, they are left out in order to facilitate representation.

From this expression it is easy to see that the elasticity of θ_m^n with respect to p_{Z_m} is larger than one. Next, we use that for two functions f and g the elasticity of $(g+f)$ is given by $\epsilon_{f+g} = \frac{f\epsilon_f + g\epsilon_g}{f+g}$ to establish that the elasticity of the non-union wage of manual workers is larger than one. This directly implies that the first term of equation (F.1) decreases in p_{Z_m}.

Intuitively, routine-biased technical change increases the productivity of and therefore the demand for manual workers. The non-union wage for manual workers increases as both the productivity and the labor market tightness increase. The union wage for manual workers increases by less, as the different outside options in the two bargaining regimes imply that the greater labor market tightness does not affect the collective bargaining.

For the second term in equation (F.1), note that

$$\frac{Z_r}{Z_r'} = \left[1 + \left(\frac{(1-\mu)\int_{\eta_m}^{\bar{\eta}} \eta L_r(\eta)\,\mathrm{d}\eta}{\mu K}\right)^{\sigma}\right]^{\frac{1}{\sigma}}.$$

Thus, an increase in K due to routine-biased technical change reduces $\frac{Z_r}{Z_r'}$. After some rearrangement, $\frac{p_{Z_r} Z_r}{p'_{Z_r} Z' r}$ is given by

$$\frac{p_{Z_r} Z_r}{p'_{Z_r} Z_r'} = \frac{[(AZ_a^{\alpha} Z_r^{1-\alpha})^{\rho} + (A_m Z_m)^{\rho}]^{1/\rho} - 1}{[(AZ_a^{\alpha} (Z_r')^{1-\alpha})^{\rho} + (A_m Z_m)^{\rho}]^{1/\rho - 1}} \left(\frac{Z_r}{Z_r'}\right)^{(1-\alpha)\rho}.$$

Thus, using that $\frac{Z_r}{Z_r'}$ decreases with K, it is straightforward to show that an increase in K reduces $\frac{p_{Z_r} Z_r}{p'_{Z_r} Z' r}$ if routine and manual tasks are substitutes, i.e, if $\rho > 0$.

Taken together, routine-biased technical change reduces the union wage of manual workers relative to the non-union wage of manual workers, if $\rho > 0$. This proofs Proposition 2. Note, that the provided proof also holds if we exchange the union wage of manual workers for the union surplus. Thus, the result does not depend on our choice of the union wage schedule.