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Robots Replacing Trade Unions: Novel Data and Evidence from Western Europe*

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Abstract

Historically, labor unions have played a crucial role in liberal democracies by hindering the increasing wage inequality, by channeling political demands and discontent into an organized voice, and by linking blue-collar constituencies to mainstream left parties. However, the importance and effectiveness of unions in the democratic process have progressively diminished in the last decades, combined with an atomization of political demands. We suggest that technological change, and robotization in particular, have directly contributed to weakening the role of unions. We employ novel granular data, at the subnational and sector level, on union density in Western Europe over two decades, to estimate the impact of industrial robot adoption on unionization rates. We find that regions more exposed to automation experience a decrease in union density. This evidence contributes to explain why technologically-driven economic grievances tend to express a decidedly right-wing character and do not favor pro-redistribution left-wing parties.

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1 Introduction

The wave of automation in recent decades has led to productivity and welfare gains, but it has substantial distributional effects, penalizing workers in regions that were historically specialized in industries adopting more robots, and individuals whose skills were more substituted than complemented by the new technologies. Traditional, relatively well-paid and stable jobs, prevalently in the manufacturing sector, have disappeared due to this process, while new jobs have been created in service sectors or in new sectors (i.e. the Gig economy sector). These newly created jobs are characterized by lower earning trajectories, temporary contracts, discontinuous careers and little or no employment protection. Overall, automation has led to an increase in earning inequality and triggered economic discontent of the "losers" of this process, which in turn triggered important political shifts. Anelli *et al.* (2021) indeed show that exposure to robot adoption increases support for nationalist and radical-right parties, both at the regional and at the individual level.

Throughout the 20th century, labor unions have played a crucial role in liberal democracies by hindering the increasing wage inequality and by channeling political demands and discontent into an organized voice. With technological change and automation polarizing wages, unions could have played a crucial role in cushioning the unequal distribution of welfare gains. However, the advent of the new century has seen a diminished importance and effectiveness of unions in the democratic process, combined with an atomization of political demands.

In this paper, we suggest that technological change, and robotization in particular, have directly contributed to weakening the role of unions. We employ novel granular data, at the subnational and sector level, on union density in Western Europe over two decades, to estimate the impact of industrial robot adoption on unionization rates. Furthermore, we aim to shed new light on the mechanism by which regions and individuals more exposed to automation tilt towards nationalist, isolationist, and radical right parties.

On the economics side, we theorize that the technological process is conducive to a weaker unions role, by drastically reducing employment in the large highly-unionized sectors (i.e. manufacturing) while boosting the creation of new jobs and new sectors which are outside the traditional scope of unions. Technological change, in the form of adoption of robots, can decrease the proportion of workforce that is unionized. We call this the extensive margin of technology on unions. Also, we claim that unions are weaker, in terms of bargaining power, in sectors more exposed to automation and they are less effective in translating productivity gains in workers' salaries. We call this the intensive margin of technology on unions. Finally, we expect weaker unions to exacerbate the effects of technological change on labor market polarization and wage inequality.

While studying the direct impact of technological change on worker representative bodies appears crucial to understand the structural societal changes taking place in western democracies and societies, the academic literature has so far produced limited empirical analysis to study this phenomenon. Moreover, there is slender empirical evidence about the evolution of labor unions in liberal democracies, especially in western Europe. This is most likely due to the absence of adequate data.

New fine-grained data on union density at the subnational level is crucial to explain economic and social phenomena that are politically consequential. Historically, labor unions played an important role in sustaining the embedded liberalism model that obtained in advanced democracies after WWII (Ruggie, 1982). Plausibly, automation, by tilting the bargaining power in favor of the owners of capital (Kristal, 2013), contributed to weakening the more inclusive "social market economy" model adopted especially by Western European countries. The crisis of embedded liberalism underpins the realignment currently taking place in many Western advanced democracies, and the success of (so-called "populist") radical right parties proposing platforms of economic nationalism, that are isolationist and protectionist in matters of international relations, but unsupportive or skeptical of redistribution and the welfare state (Colantone and Stanig, 2018).

From the perspective of voting behavior, labor unions have traditionally provided an important link between left parties and blue-collar constituencies. This link operated in two directions: on the one hand by inducing mainstream left parties to focus on the economic distributional issues relevant to workers (Pontusson and Rueda, 2010), and on the other mobilizing union members in support of mainstream left parties. The reduced importance of unions in the workplace led to a decreased importance of their role as brokers for mainstream social-democratic and labor parties (Piazza, 2001). The weakening of unions also made it more appealing for social democratic parties to move to the center on redistribution issues, in order to capture middle-class constituencies attracted to their cosmopolitan stances on non-economic issues (Kitschelt, 2012). This further weakened the connection between blue-collar constituencies and mainstream left parties. Balcazar (2022) shows that the robot adoption reduces the likelihood that congress people vote with unions' interests in the United States. Similarly, Becher and Stegmueller (2020b,a) provide evidence of how trade unions can mediate the political consequences of economics changes.

As suggested by Kitschelt (2012), this de-linking of working class constituencies from socialdemocratic parties might be a reason why losers from structural changes such as globalization and automation have turned towards nationalist and radical-right forces (Betz, 1993). We test the hypothesis that vote for radical right parties (and support for nationalist political platforms) is lower, while support for redistribution platforms of the economic left is higher, in districts located in regions with stronger unions.

Thus far, research on trade unions have been hindered by data limitations. At the moment, the most important source of macro-level data about unionization in Europe, collected and compiled by third parties, is the Visser (2019) data, which incorporates a set of different sources. These cross-national data sources have one main limitation, which is a level of aggregation too coarse for the purpose we set out to address. A sub-national and sectoral analysis is required if one aims, like we do, at clean identification of causal effects.

In this paper, we collected data on union membership at the region-by-sector level in

15 western European countries. One strategy we adopt to come up with usable measures of unionization at the level required for our analysis is multilevel regression with post-stratification (MrP) (Park *et al.*, 2004). MrP makes it possible to exploit information from nationally representative samples to estimate more disaggregated summaries at the sub-national level. We use this approach to combine information from the European Social Survey (ESS) and census information from 15 Western countries over two decades (2002-2020).

We adopt two complementary approaches to improve and validate our estimates. In the first approach, that we refer to as internal validation, we assess the relative performance of different families of multi-level mixed effect models in predicting union membership in the survey data (ESS) by using cross-validation. In the second approach, we compare our MrP estimates with estimates from other reliable sources, such as administrative data (external validation). We find that our MrP estimates are very highly correlated with estimates in the few countries in which administrative and high-quality subnational estimates can be obtained.

Then, we employ our novel granular data on subnational and sector level union density to estimate the impact of industrial robot adoption on unionization rates. We measure regional exposure to robotization based on the ex-ante industry specialization of each region.

Our findings show that regions more exposed to technological change exhibits decreasing union density. We estimate that an increase of one standard deviation of robot adoption leads to more than 14% decrease of union density, after residualizing with respect to the country-year and region fixed effects.

Finally, we relate union density in western European regions to electoral results at the district level. The district-level results suggest that the decrease in union density has contributed to a raise in political polarization. We find that electoral districts with declining union rates display an increase in radical right support. The success of radical right parties is mainly at the expense of mainstream right parties. Individual-level analysis based on the Comparative Study of Electoral Systems (CSES) provides further micro-level evidence reinforcing the district-level finding.

2 Background

Economics, political science, and sociology have started investigating the consequences of the latest spurts of technological change, in particular the ICT revolution and the robotization of manufacturing and services.

The starting point is that shifts in technology have distributional consequences: technological innovation produces economic winners and losers, at least in relative terms. New opportunities open for workers endowed with skills that are complementary to new technologies, while workers more substitutable by machines lose out. The identity of winners and losers varies depending on the nature of technological changes. On top of direct economic winners and losers, technological change also affects the distribution of power within society, and therefore political competition in democracy.

2.1 Technological change and trade unions

The wave of automation in recent decades has led to productivity and welfare gains, but it has substantial distributional effects. Economic research has shown how automation penalizes workers in regions that were historically specialized in industries adopting more robots, and individuals whose skills were more substituted than complemented by the new technologies (e.g. Acemoglu and Restrepo, 2020). Automation has also shaped the allocation of labor market opportunities. Traditional, relatively well-paid and stable jobs, especially in the manufacturing sector, have disappeared, while new jobs have been created in service sectors or in new sectors (i.e. the Gig economy sector). However, these newly created jobs are characterized by lower earning trajectories, temporary contracts, discontinuous careers and little or no employment protection (Kaine and Josserand, 2019). As argued in Anelli *et al.* (2021), the structural process by which automation leads to increase in earning inequality and to economic discontent of "losers" of this process, is politically consequential. In fact, higher exposure to robot adoption increases support for nationalist and radical-right parties, both at the regional and at the individual level.

Throughout the 20th century, labor unions have played a crucial role in liberal democracies by hindering the increasing wage inequality and by channeling political demands and discontent into an organized voice (e.g. Ahlquist, 2017). With technological change and automation polarizing wages, unions could have played a crucial role in cushioning the unequal distribution of welfare gains. However, the advent of the new century has seen a diminished importance and effectiveness of unions in the democratic process, combined with an atomization of political demands.

Importantly, the adoption of robots and ICT has consequences for labor organizations, hence it is possible for technological change to affect the distribution of income in two ways: a direct one through labor markets, and an indirect one which is mediated by labor organizations. In fact, over the past decades, the role of labor unions has been weakened by processes related to technological change (as well as by other processes like global trade). In a study of wage inequality in the United States, Kristal and Cohen (2015) (see also Kristal, 2013) find that the indirect effects of computerization on inequality–channelled mainly through weakening unions and to a lesser extent by enhancing the rise of non-standard employment relations– were even greater than the direct effects.

Meyer (2019) suggests that routine task-biased technological change might cause union decline through three mechanisms. First of all, routine task occupations were among the most unionized. Second, routine- biased technological change increases between-worker skill heterogeneity, which reduces workers incentives for collective action. Finally, formerly routine task workers compete for lower-skill jobs, and the increased competition for these low-skill jobs gives employers greater leverage to resist attempts at unionization. Labor unions played an important role in terms of wage setting. Extant evidence (e.g., Western and Rosenfeld, 2011 for the US) shows that the decline of unionization is key to explain increases in inequality. It is therefore important to understand to which extent the now well-documented effect of automation on labor market polarization, and on increased inequality, is mediated by weakened labor organization and wage bargaining position rather than straightforward labor market effects. On the economics side, we theorize that the technological process has directly contributed to weakening the role of unions, by drastically reducing employment in the large highly-unionized sectors (i.e. manufacturing) while boosting the creation of new jobs and new sectors which are outside the traditional scope of unions. We propose four hypotheses that we plan to test empirically[1]:

1. Technological change, in the form of adoption of robots, decreases the proportion of workforce that is unionized. We call this the extensive margin of technology on unions.
2. Unions are weaker, in terms of bargaining power, in sectors more exposed to automation and they are less effective in translating productivity gains in workers' salaries. We call this the intensive margin of technology on unions.
3. Weaker unions amplify the political effects of automation, e.g., in terms of rising support for radical right

While studying the direct impact of technological change on worker representative bodies appears crucial to understand the structural societal changes taking place in western democracies and societies, the academic literature has so far produced limited empirical analysis to study this phenomenon. Moreover, there is slender empirical evidence about the evolution of labor unions in liberal democracies, especially in western Europe. This is most likely due to the absence of adequate data. We have collected region-by-sector data

[1] In this version of the paper, we provide evidence only on the first and third hypotheses. Future versions of this work will also test the second hypothesis

on union membership in 15 European countries to test our theory empirically and we are currently collecting data on bargaining power and minimum wages by industry. In labor economics research, technological change has been isolated as a main driver of the increase in wage inequality and educational premia, which have fostered social cleavages in Western democracies (Acemoglu and Autor, 2011). Since routine jobs –both manual and cognitive– were mostly middle-income and middle- skill jobs, a polarization of the labor market has been documented both in the US and in Europe (Autor and Dorn, 2013; Goos *et al.*, 2014). Polarization involves an increase in employment at the two tails of the wage and skill distribution, along with a shrinkage of the traditional middle class. For instance, computers have destroyed many decently paid clerical jobs, while the computer-based automation of production processes has reduced job opportunities for relatively skilled blue-collar workers. Workers (both actual and prospective) substituted by computer-based technology have been largely absorbed by the service sector in non-routine jobs, typically at lower wages and with less favorable contractual conditions (e.g., drivers and fast-food workers). The main computerization winners have been the high-skill (college-educated) workers in cognitive occupations: their incomes have been diverging from those of the impoverished middle class, which has been falling in the group of losers together with lowskill workers. The latter, even if employed in non-routine tasks, have been complemented by the new technologies much less than the high skilled, and their wage dynamics have been compressed by the additional supply of displaced middle-skill workers competing for the same jobs (Autor, 2015).

A growing literature documents the economic effects of the most recent automation wave. In particular, a strand of the literature uses data on the adoption of industrial robots at the industry level made available for many countries by the International Federation of Robotics (IFR). According to these data, the stock of operational robots in advanced economies has increased substantially between 1993 and 2016, a phenomenon commonly referred to as the “robot shock”. Focusing on the US, Acemoglu and Restrepo (2020) find that, at the level of commuting zones, a stronger exposure to the robot shock has a negative effect on local employment rates and wages. To illustrate, the adoption of one extra robot in a commuting zone reduces employment by around 6 workers. The negative effect of robots on employment is stronger in the manufacturing sector, and especially in industries that are most exposed to robots. Moreover, it is more pronounced for workers with less than college education, for blue collars employed in routine manual tasks and assembling, for machinists and transport workers, and for men in general. The negative effect of robots on wages is concentrated in the bottom half of the wage distribution, contributing to the increase in wage inequality. Graetz and Michaels (2018), using industry-level data on a larger sample of countries, find that robot adoption has a positive effect on productivity, but a negative impact on the share of hours worked by low- skill workers. Chiacchio *et al.* (2018) focus on six European countries and find a negative effect of robot adoption on employment at the level of local labor markets. Dauth *et al.* (2018) investigate the impact of industrial robots using matched employer-employee data for Germany and find that the adoption of robots leads to job losses in manufacturing, which are compensated by employment gains elsewhere, mostly in the business service sector. Importantly, fewer manufacturing jobs become available for new entrants in the labor market. Using individual data, they find that affected workers mostly stay with the same employer, but change their occupation and incur wage losses. Overall, automation increases wage inequality: it benefits managers and high-skill workers performing abstract tasks, while low- and medium-skill workers see their earnings decrease, leading to a general decline in the labor share of income.

2.2 Technological change and political behavior: the mediating role of trade unions

There is limited evidence, thus far, on the consequences of the most recent spurts of technological change on political preferences and behavior. Gallego *et al.* (2018), using data from the UK, show that the winners of computerization - educated workers in IT-heavy sectors - become more likely to vote Conservative and less likely to vote Labour, while losers are more likely to support the radical-right option, namely the UKIP. Yet, due to limited data to answer this type of question, they refrain from making more general claims about the radical-right turn of the losers in the British setting. Studying the 2016 US presidential election, Frey *et al.* (2018) show how voters in regions more affected by robotization in manufacturing were more supportive of the Republican candidate, Donald Trump, who was running on a nationalist platform, both in economic and in identitarian terms. Im *et al.* (2019), using data on eleven countries from the European Social Survey, show that workers in occupations at higher risk of automation are more prone to vote for radical right parties. Finally, Dal Bó *et al.* (2019) study patterns of support for the Sweden Democrats in local elections. They show that the share of automation-vulnerable workers in a municipality is robustly correlated with support for the radical-right option. Anelli *et al.* (2021) provide evidence on the effect of automation vulnerability on voting behavior using sub-national and individual-level data on automation exposure for fourteen Western European countries. Regions and individuals that are more exposed to automation tilt towards nationalist, isolationist, and radical right parties.

When it comes to politics, labor unions played an important role in sustaining the embedded liberalism model that obtained in advanced democracies after WWII (Ruggie, 1982). In a nutshell, such a model entailed trade openness – and, more in general, an approximation to economic efficiency– accompanied by policies that compensated the possible losers from structural changes and more in general distributed the gains from economic growth according to criteria of equality or inclusiveness.

Embedded liberalism started entering a crisis towards the end of the XX century, in part due to increased capital mobility –that reduced revenues to finance the welfare state– and increased import competition with emerging economies –that increased the demand for compensation itself. (Rodrik, 1998; Colantone and Stanig, 2018). Plausibly, automation, by tilting the bargaining power in favor of the owners of capital (Kristal, 2013), contributed to weakening the more inclusive "social market economy" model adopted especially by Western European countries. The crisis of embedded liberalism underpins the realignment currently taking place in many Western advanced democracies, and the success of (so-called "populist") radical right parties proposing platforms of economic nationalism, that are isolationist and protectionist in matters of international relations, but unsupportive or skeptical of redistribution and the welfare state (Colantone and Stanig, 2018). From the perspective of voting behavior, labor unions have historically provided an important link between left parties and blue-collar constituencies. This link operated in two directions: on the one hand by inducing mainstream left parties to focus on the economic distributional issues relevant to workers (Pontusson and Rueda, 2010), and on the other mobilizing union members in support of mainstream left parties. Also, trade unions contributed to frame the political discourse and to make workers think in terms of class conflict rather than cultural and ethnic conflict. The reduced importance of unions in the workplace led to a decreased importance of their role as brokers for mainstream social-democratic and labor parties (Piazza, 2001). The weakening of unions also made it more appealing for social democratic parties to move to the center on redistribution issues, in order to capture middle-class constituencies attracted to their cosmopolitan stances on non-economic issues (Kitschelt, 2012; Kriesi, 1998). This further weakened the connection between blue-collar constituencies and mainstream left parties.

As suggested by Kitschelt (2012), this de-linking of working class constituencies from socialdemocratic parties might be a reason why losers from structural changes such as globalization and automation have turned towards nationalist and radical-right forces (Betz, 1993, 1994; Betz and Meret, 2012). In the context of the United States, Balcazar (2022) demonstrate that automation has political implications by reducing public policy to unions interests. Relying on post-election surveys, Rennwald and Pontusson (2021) shows that union membership can condition voters' abandonment of mainstream Left parties and the alternatives chosen by former mainstream-Left voters. We expect that radical right parties (and support for nationalist political platforms) should receive lower support, while support for redistribution platforms of the economic left is higher, in districts located in regions with stronger unions. Levi (2017) states that "the decline of labor unions has also facilitated the rise of populism by eliminating a source for a framework for understanding the situation of workers."

2.3 The absence of fine-grained data for Europe

Comparative research on the role of unions on recent developments in advanced democracies has been hindered by data limitations: as Ahlquist (2017) pointedly notes, "we have too many explanations chasing too few data points that are themselves interdependent in both time and space" and therefore he recommends "research designs explicitly taking advantage of heterogeneity in context and population". But in order to pursue such paths, better disaggregated data is required. In addition, as Pontusson and Rueda (2010) remark, the distribution of union members across income categories varies considerably across countries and therefore in order to better understand the role unions play in the political economy, further data collection is imperative.

At the moment, the most important source of macro-level data about unionization in Europe, collected and compiled by third parties, is the Visser (2019). This incorporates and updates also the information about union membership, density, and concentration in the Golden et al. (2009) and Ebbinghaus and Visser (2000) datasets, on which the seminal political science research on the role of unions was carried out. These cross-national data sources have one main limitation, which is a level of aggregation too coarse for the purpose we set out to address. As detailed in the previous section, country-level data do not allow to further our knowledge much, mostly because of too few data points. A sub-national and sectoral analysis is required if one aims, like we do, at clean identification of causal effects. For the US, researchers have exploited the more fine-grained data available via the Current Population Survey, that has an item about union membership and large samples that allow for disaggregation (see, for instance, Ahlquist and Downey, 2023). More recently, a flourishing stream of research on trade unions in the context of the United States has relied on the fine-graned data from Becher *et al.* (2018), with Balcazar (2022) and Becher and Stegmueller (2020b,a) as notable examples.

3 New data on union density

Sufficiently fine-grained data on union membership is key, if the aim is studying how structural changes, and in particular automation, have influenced income distribution and political orientations. Unfortunately, as we noted, for western Europe data of the kind we need is difficult to come by. One strategy we adopt to come up with usable measures of unionization at the level required for our analysis is multilevel regression with post-stratification (MrP). This approach was originally proposed by Gelman and Little (1997) and Park *et al.* (2004) and was popularized in applied political science research initially by Lax and Phillips (2009). See Gelman and Hill (2007) and Leemann and Wasserfallen (2020) for textbook treatments. MrP makes it possible to exploit information from nationally representative samples to estimate more disaggregated summaries at the sub-national level. At this stage, we use this approach to combine information from the European Social Survey (ESS) and census information from 15 western European countries. In the ESS, individual respondents are asked about union membership. Importantly, along with basic demographic information, the ESS also reports the occupation (ISCO), industry (NACE) and region of residence (NUTS) of each individual. We can exploit census information on the distribution of these in the population to post-stratify some multi-level probit models for unionization.

3.1 Models

For each country, we estimate models of the form

$$Pr(Union_i = 1) = Probit^{-1}(\alpha^{gndr} + \alpha^{age} + \alpha^{edu} + \alpha^{ind} + \alpha^{occ} + \alpha^{region} + \beta \cdot round + \boldsymbol{\beta} \cdot \boldsymbol{X_c})$$

where $Union_i$ is an indicator variable for whether the respondent is member of a union, and the α terms are random effects for gender, age category, education level, NUTS2 region of residence, NACE (rev 1.1) code of the industry in which the respondent is employed, and 2-digit ISCO for the occupation of the respondent. F() is the probit link. $\boldsymbol{X}$ is a vector of regional, context-level, pre-sample variables that includes the share of low and middle skilled workers, the share of low and medium tech, the share of finance and business, the share of primary and service sector, and the share of foreign-born workers. Throughout, we estimate the probit models separately for each country.

From the estimates, we can compute predicted probabilities for cells ("types") defined by gender, age group, education level, region, industry and occupation. We can then weight these predicted probabilities by the prevalence of a cell ("type") in the population, based on census data, and aggregate them at the desired level, for instance region or industry. We then assess the performance of the approach we propose. This refers both to the performance of the multi-level regression models themselves, and the performance of the post-stratification exercise relative to the true target values that we are trying to compute.

We adopt two complementary approaches to improve and validate our estimates. In the first approach, that we refer to as "internal validation", we assess the relative performance of different families of multi-level mixed effect models in predicting union membership in the survey data (ESS). In total, we estimate two dozen different models. Our specifications mostly follow a dynamic MrP approach (Gelman *et al.*, 2019) to model time variation. We apply a cross-validation procedure and compute a RMSE metric for every specification to identify the best models. In the second approach, we compare our MrP estimates with estimates from other reliable sources ("external validation"). We thus collect administrative data and large-sample labour force surveys from a few countries with unique availability of union membership estimates (i.e. Norway, Finland and UK). We find that our MrP estimates are very highly correlated with estimates in the few countries in which administrative and high-quality subnational estimates can be obtained.

3.2 Cross-validation

One first evaluation of the performance of the procedure has to do with the predictive performance of the probit models of unionization ("internal validation"). In general, given that ultimately our goal is to predict unionization rates out of sample, we are not directly interested in the in-sample performance of the probit regressions themselves. One potential drawback of models that have very high in-sample predictive power is overfitting: the model might be very accurate in picking up what are ultimately idiosyncratic features of the specific sample one is dealing with. When these idiosyncratic features are then reproduced in out-of-sample prediction, they lead to lower predictive performance. Conversely, relatively parsimonious models might omit some idiosyncratic characteristic of the present sample but perform well out of sample.

For this reason, we use cross-validated predictions to assess model performance. Cross-validation is widely used in the statistical learning and machine learning literatures, but it is less common in economics or political science, hence we spend a few words on it.

In practice, we randomly split the sample into $K = 10$ folds. We then iteratively pick one fold k (which becomes the "test set") and use the sample without fold k as the training set. We estimate the model in 1 on the training set, and form predictions for fold k based on the estimates of the parameters from the training set and the values of the observable features in fold k. We repeat the operation for all folds, to arrive at a vector of predictions for all observations in the sample. We can then run diagnostics on these cross-validation predictions. As a performance metric, we can calculate the root mean square error as the square root of the average squared difference between the midpoint of the bin, and the sample proportion within that bin. Notice that this is expressed in the same units as the variable of interest. In this case, the variable is a probability, so the rmse can be interpreted (loosely) as a measure of how far "on average" the predicted probability and the actual proportion are from each other.

We develop a specific RMSE measure, inspired by the fact that we aim at group-wise unionization rates. For group g defined by observable characteristic (e.g., NUTS region) define Ω_g set of observations in group g, with cardinality N_g. We thus compute:

$$\hat{P}_g = \frac{\sum_{i \in \Omega_g} \hat{P}_i}{N_g}$$

Analogously, let us define the empirical frequency

$$F_g = \frac{\sum_{i \in \Omega_g} (Union_i = 1)}{N_g}$$

Finally, we define the group-wise calibration RMSE based on groups G as

$$\text{RMSE}_\text{G} = \left(\frac{\sum_g (\hat{P}_g - F_g)^2}{G} \right)^{\frac{1}{2}}$$

In a nutshell, this measure compares the (cross-validated) predicted probabilities for a given region or industry with the empirical frequency (i.e. the naive estimate of unionization rate) for survey respondents from that region or in that industry. In loose terms, this captures how far are, "on average" (loosely speaking), predicted probabilities and unionization rates in survey. Even though this group-wise approach may seem more demanding, it is similar in spirit to the standard calibration approach, characterised by binning predicted probabilities.

This metric allows us to rank estimation models based on their relative performance. To predict union density, we thus choose the model that ranks on average best across the countries we study, according to the RMSE. The model has the following form:

$$
\begin{aligned}
Pr(Union_i = 1) = \quad & Probit^{-1}(\alpha^{gndr} + \alpha^{age} + \alpha^{edu} \ + \alpha^{ind} + \alpha^{occ} + \alpha^{region} \\
& + \beta \cdot round + \alpha^{occ,edu} + \boldsymbol{\beta} \cdot \boldsymbol{X_c})
\end{aligned}
$$

Note that this specification, which overall performs better based on our RMSE metric, includes a random effect for the combination of occupation and educational attainment. As a benchmark, we will always first estimate our results with a baseline model, which allows for different time trends for industrial sector:

$$
\begin{aligned}
Pr(Union_i = 1) = \quad & Probit^{-1}(\alpha^{gndr} + \alpha^{age} + \alpha^{edu} \ + \alpha^{ind} + \alpha^{occ} + \alpha^{region} \\
& + \beta \cdot round + \beta^{ind} \cdot round + \boldsymbol{\beta} \cdot \boldsymbol{X_c})
\end{aligned}
$$

3.3 External validation

The main advantage of using a MrP approach to measure union density at the subnational level is that it allows to obtain subnational estimates from the combined use of a survey that is representative at the national level and census data that are highly informative about population composition at the subnational level. However, it is important to test the reliability of the estimates provided by such an approach. When available, administrative data and surveys representative at the sub-national level allow us to assess our estimates, with what we refer to as "external validation". Such reliable sources, however, are available only for a few countries in Europe. We collected administrative data from Norway and Finland to provide alternative estimates of unionization at the level of region by industry. These administrative data can be directly compared to our MrP estimates.

In Figure 1, we compare our estimates of union density aggregated at the regional

(NUTS-2) level with the corresponding value from administrative data in Finland and in Norway. We consider both the estimates provided by the baseline specification (left charts) and by the specification that ranks better according to the RMSE metric (right charts). Each observation in the charts represents a region in a given year. We see that in both Finland and Norway estimates of unionization from administrative data and data from MrP are highly correlated. The R-squared of an OLS regression in which administrative data are regressed on MrP estimates is 90% in Finland and 96% in Norway, with no appreciable difference across specifications. On average, we predict higher union density than administrative data, but the variation both across regions and over time is consistent across the two sources.

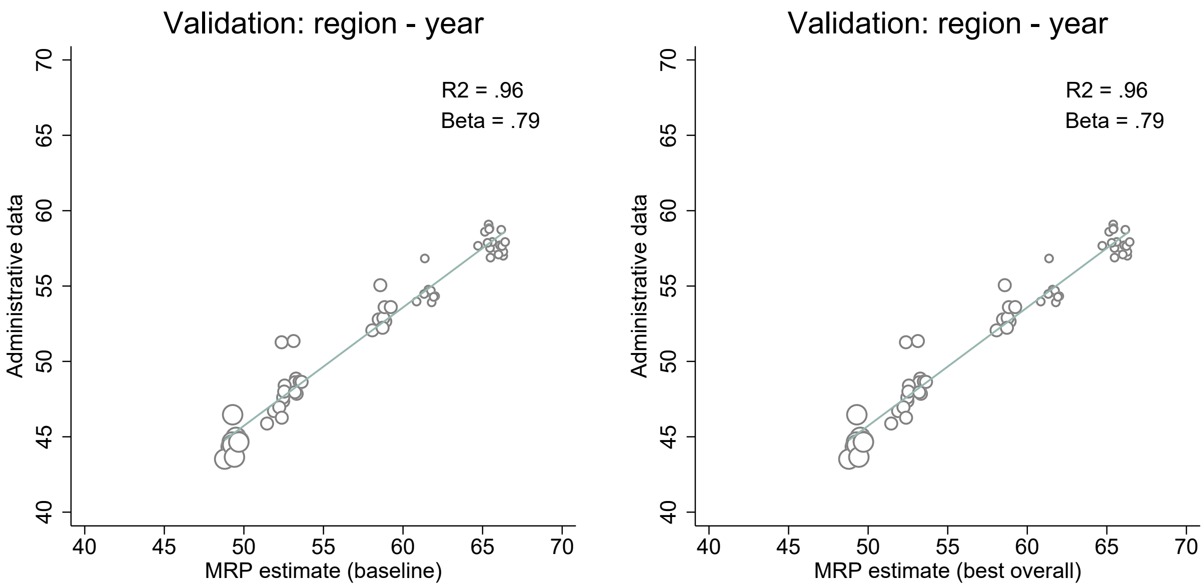
Table 2 shows another context in which an external validation can be performed. In the United Kingdom, the Labour Force Survey includes an item on union membership and thus allows to obtain a subnational estimate of union density, which is arguably representative at the regional level. Given that the Labour Fource Survey in the UK is not meant to be representative at more disaggregated levels, we have no prior about which source of information, between MrP and LFS, is superior, especially for smaller NUTS-2 region. That being said, the substantial convergence of predictions between the two approaches lends credence to the estimated values. Figure 2 shows that UK-LFS estimates are on average around 3 percentage points higher than MrP estimates, but that the correlation is very high (R-squared = 92%). To sum up, the results of our external validation provide reassuring evidence of the value of our general approach.

3.4 Union density in Western Europe

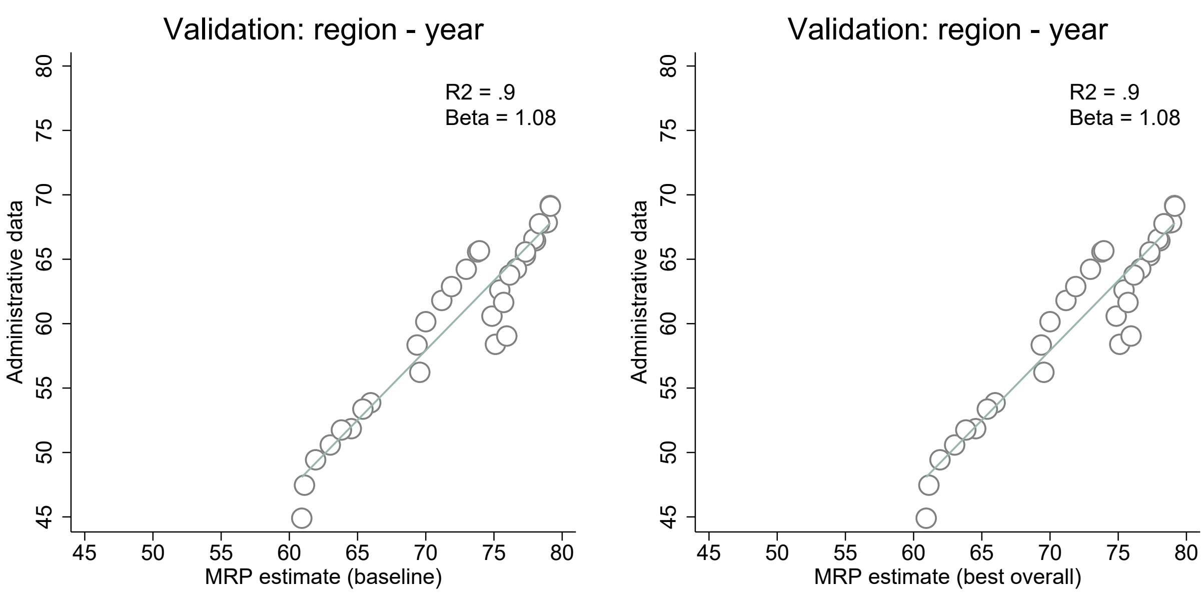
Our novel data of union density spans over around two decades (2002-2018) and include 15 western European countries. These are: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Sweden and the UK. Union density is measured at the region-by-industry level. Regions are at the NUTS-2 level for all countries, apart from Germany and UK that are at the NUTS-1 level. The industrial sectors refers to

Figure 1: External validation with administrative data

Norway



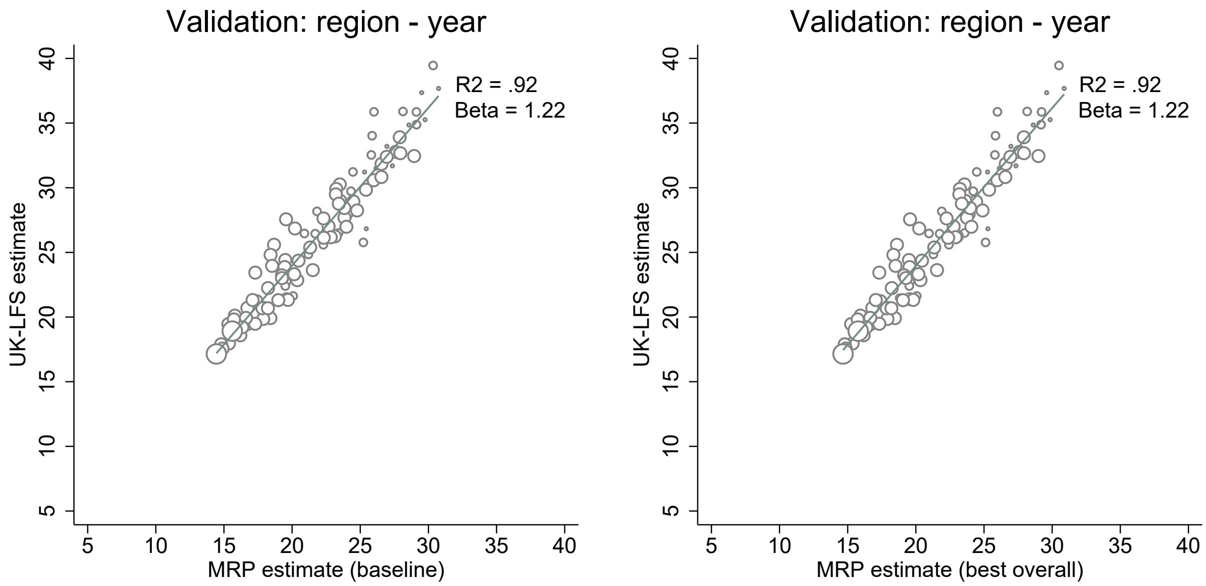
Finland



Note: Each observation in the chart represents a region in a given year.
The size of circles is proportional to regional population.

Figure 2: External validation with Labour Force Survey

United Kingdom



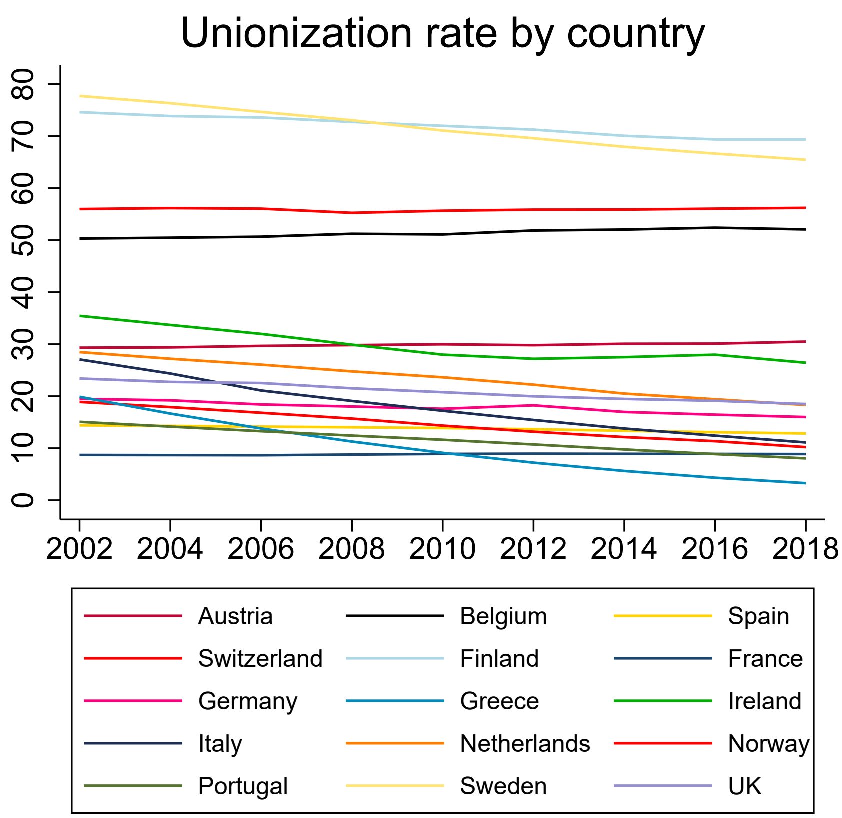
Note: Each observation in the chart represents a region in a given year.
The size of circles is proportional to regional population.

the revision 1.1 of the NACE classification and are at the 2-digits level.

In figure 3, we display the trends in union density over time after aggregation at the national level. As expected, we observe a rich heterogeneity of different levels of unionization, with countries like Finland, Sweden or Norway exhibiting values higher than 50%, whereas unionization reaches its lower levels in countries like France, Portugal and Greece. We observe that most of the countries displays a decreasing trend over time. Overall, the correlation between our measure of union density aggregated at the national level and national union density data from Visser (2019) is 0.96.

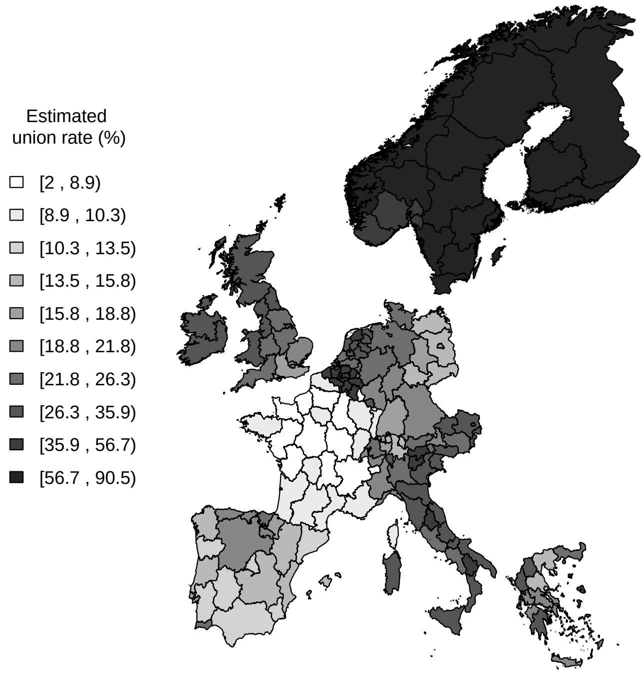
Figure 4 and Figure 5 display union density at the regional level in Western Europe in 2002 and 2018, respectively. These are the first and last year currently included in our data. In addition to the well-known variation of levels between different countries, which is rooted in deep historical and institutional factors, our new data allows to appreciate also some relevant variation within countries. For instance, union density is higher in

Figure 3: MRP estimates (baseline)



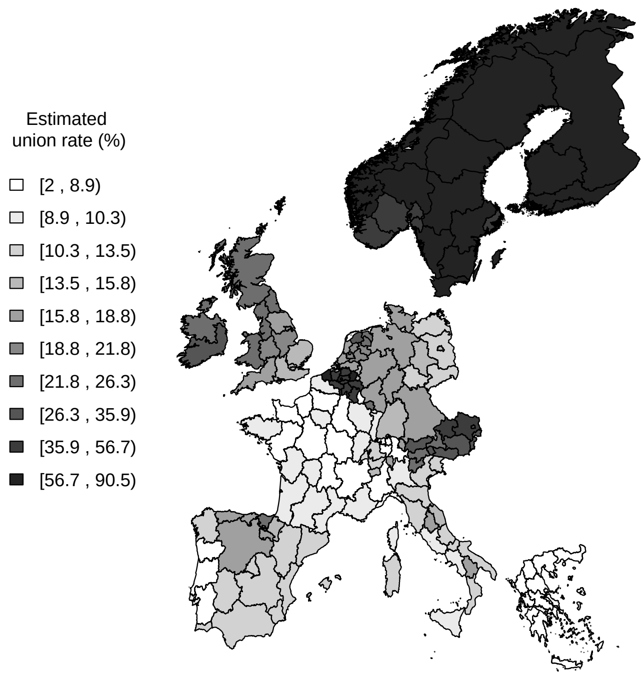
Note: Correlation with Visser (OECD/AIAS ICTWSS) data: 0.96

Figure 4: Estimated union density by region: 2002



the North of Spain than it is in the South, and it is higher in West Germany, industrial, regions than in the rest of the country. Union density is overall quite low in France, as it is between 8% and 10% in most regions. Figure 6 unveils a marked trend of deunionization in some European regions, especially in Greece, Ireland and Italy. Crucially, union density levels do not offer uniformly meaningful insights across nations. As Ahlquist (2017) perceptively observes, trade unions are inherently diverse organizations, varying along multiple dimensions. Consequently, caution is warranted when drawing cross-national comparisons of unionization trends. Nonetheless, to rigorously address research questions concerning trade unions, it is essential to employ research designs that strategically leverage subnational variation.

Figure 5: Estimated union density by region: 2018



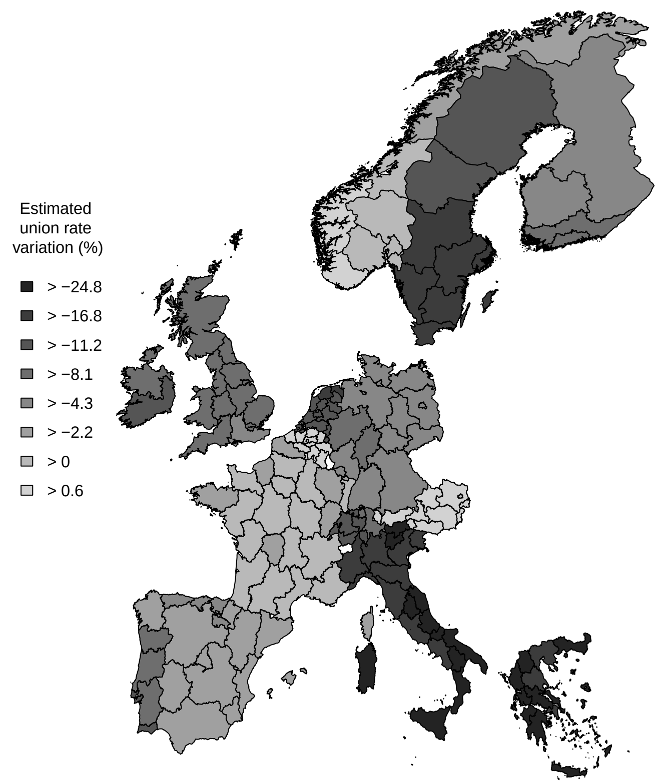
4 Automation and unionization

Our novel granular data on subnational and sector level union density are crucial to allow researchers to shed new light on a broad set of question about the role of trade unions in economic, social and political processes. In this section, we present the results of our analysis aimed at investigating the relationship between automation and unionization in Western Europe.

We employ our novel data on regional union density to estimate the impact of industrial robot adoption on unionization rates. We measure regional exposure to robotization based on the ex-ante industry specialization of each region.

Following Acemoglu and Restrepo (2020), we measure the time-varying exposure to automation at the regional level as:

Figure 6: Estimated union density variation (2002-2018)



$$\text{Regional Exposure}_{crt} = \sum_j \frac{L_{crj}^{\text{pre-sample}}}{L_{cr}^{\text{pre-sample}}} * \frac{R_{cj}^{t-1} - R_{cj}^{t-n}}{L_{cj}^{\text{pre-sample}}},$$

where: c indexes countries, r NUTS-2 regions, j manufacturing industries, and t years, $R_{cj}^{t-1} - R_{cj}^{t-n}$ is the change in the operational stock of industrial robots over the past n years, in country c and industry j. This change is normalized by the pre-sample number of workers employed in the same country and industry, $L_{cj}^{presample}$. This ratio provides a measure of the intensity of robot adoption at the industry level. To retrieve the regional-level exposure, we take a weighted summation of the industry-level changes, where the weights capture the relative importance of each industry in each region. Specifically, each weight is the ratio between the number of workers employed in a given region and industry ($L_{crj}^{presample}$), and the total number of workers employed in the same region ($L_{cr}^{presample}$). Importantly, weights are based on pre-sample figures, dating before the surge in the adoption of industrial robots observed from the mid-1990s onwards. Intuitively, regions that were initially specialized in industries in which the adoption of robots has later been faster are assigned stronger exposure to automation.

In order to address endogeneity concerns, we instrument robot adoption with a set of measures of technological progress. We use the following measures: a producer index of computer prices (from FRED), single-thread performance and number of transistors per microprocessor (from Rupp's 50 Years of Microprocessor Trend Data).

Regional automatability is thus computed based on:

$$\sum_j \frac{L_{crj}^{\text{pre-sample}}}{L_{cr}^{\text{pre-sample}}} Rep_j$$

where Rep_j for industries is derived from Graetz and Michaels (2018) labor replaceability.

This captures how automatable is labor in sectors in which the region was historically specialized. The instruments are the interaction between the measures of technological progress (time-varying, but common to all countries) and regional automatability (time-invariant).

In our empirical analysis, we thus estimate the impact of robot adoption on union density in western European regions. The baseline specification we estimate has the general form:

$$Union\_rate_{crt} = \alpha + \beta \text{ Regional Exposure}_{crt} + \lambda_{ct} + \lambda_r + \epsilon_{rt}$$

where r indexes NUTS-2 regions, c countries, and t years. $Union\_rate_{crt}$ represents union density in NUTS-2 region r and year t, $Regional\ Exposure_{crt}$ is robot adoption at the regional level over the past three years in the baseline estimates, λ_{ct} are country-year fixed effects and λ_r are NUTS-2 region fixed effects. We estimate robust standard errors.

The dependent variable is union density at the regional level in a given year, and is provided by our novel dataset. Here, we consider two alternative variables about union density, based on two different specifications employed in the process of generating our measures. The first one refers to our baseline MrP specification, whereas the second one is the specification that ranked better according to our RMSE metric. The correlation between these two measures is around 1.

We employ two different models. First, we regress union density on automation shock in an OLS regression with country-year and region fixed effects. Then we run a 2SLS regression in which robot adoption in a country is instrumented using measures of technological progress. Results are displayed in table 1.

Table 1 shows a negative and statistically significant relationship between robot shock and unionization rates. The effect of automation on unionization is stronger in model (3) and (4), i.e. the instrumental variables specifications. The effect is stronger when we employ the measure of union density based on the best specification used in the MrP estimation. In

Table 1: Automation and union density

VARIABLES	(1) Union rate (baseline)	(2) Union rate (best)	(3) Union rate (baseline)	(4) Union rate (best)
Robot shock t:1-3	-0.176*** [0.048]	-0.177*** [0.051]	-0.361** [0.161]	-0.443*** [0.171]
Estimator	OLS	OLS	2SLS	2SLS
Observations	1,404	1,404	1,404	1,404
Country-Year FE	X	X	X	X
Region FE	X	X	X	X
Std dev. Y	0.521	0.526	0.521	0.526
Std dev. X	0.422	0.422	0.422	0.422
Magnitude	-0.143	-0.142	-0.292	-0.356
rkf			15.42	15.42

Robust standard errors in brackets
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

both the OLS and in IV specifications, the p-value of the robot shock coefficient is smaller than 0.05.

In model (1), an increase in one standard deviation of robots (i.e. 17 robots per 100 000 workers) leads to a decrease of 14% of a standard deviation of unionization in European regions. This is computed after residualizing with respect to fixed effects. Technological change, in the form of adoption of robots, decreases the proportion of workforce that is unionized. This provides evidence for the "extensive margin" of technology on unions. In model (2), the coefficient is slightly larger and is also strongly significant (p-value$<$0.01). When we look at the results estimated with the instrumental variable approach (columns (3) and (4)), the coefficients remain negative, are larger in absolute magnitude, and statistically significant at the 95% level. Here, an increase in a standard deviation of the robot shocks leads to a 29% or 36% decrease of a standard deviation of the outcome variable, depending on the specification.

To sum up, regions with larger adoption of industrial robots tend to exhibit a decrease in the percentage of workers that are members of trade unions over the total of the labor force. These findings are robust to different specification and estimation strategies.

5 Unionization and electoral results

We expect the decrease in unionization rates triggered by automation to be politically consequential. The disappearance of a key intermediate body like trade unions can contribute to explain why many voters and regions have turned toward nationalist and radical right forces.

In order to shed new light on this question, we run some analysis linking unionization rates and district-level summaries of voting behavior, for the fifteen western European countries for which we have MrP-based estimates of unionization.

The outcome variables come from an updated version of the data used in Colantone and Stanig (2018) and Anelli *et al.* (2021). Official election results are sourced from the Constituency-Level Election Archive (CLEA, Kollman *et al.*, 2019), the Global Election Database (GED, Brancati, 2016), and a number of national sources. For each district, in each election, we have information on vote shares at the party level.

In particular, we define p_{ldt} as the vote share for party l, in district d, at time (election) t.

We thus estimate the association between regional unionization rates and district-level electoral results with the following equation:

$$Electoral\_outcome_{cdt} = \alpha + \beta \, \text{Union\_rate}_{cd(r)t} + \lambda_{ct} + \lambda_r + \epsilon_{rt}$$

where d indexes the electoral districts, $d(r)$ maps the electoral district to the corresponding NUTS-2 regions, c countries, and t years. $Union\_rate_{crt}$ represents union density in NUTS-2 region r and year t, $Electoral\ outcome_{cdt}$ is one of the dependent variable used to characterize electoral outcomes in district d at time t, λ_{ct} are country-year fixed effects and

Table 2: Voting and union density (baseline)

VARIABLES	(1) Radical Left	(2) Mainstr. Left	(3) Mainstr. Right	(4) Radical Right
Union rate	-0.100	0.287	0.629***	-0.552**
(baseline)	[0.141]	[0.302]	[0.232]	[0.219]
Estimator	OLS	OLS	OLS	OLS
Observations	7,193	7,193	7,193	7,193
R-squared	0.747	0.536	0.569	0.820
Country-Year FE	X	X	X	X
Region FE	X	X	X	X
Std dev. Y	3.577	9.969	10.70	3.313
Std dev. X	1.174	1.174	1.174	1.174
Magnitude	-0.0327	0.0338	0.0690	-0.196

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

λ_r are NUTS-2 region fixed effects. We cluster standard errors at the NUTS-2 regional and year level.

To characterize more broadly the association between union density and voting, we estimate our baseline regression using four alternative outcome variables. These are variables denoting the share of votes for parties belonging to one of the following party families: Radical Left, Mainstream Left, Mainstream Right and Radical Right.

Table 2 reports the estimates of four models that regress the district-level variables of voting behavior on the unionization rate (as predicted with MrP baseline specification) in the NUTS-2 region in which the district is located. The data cover, at this stage, only elections between 2002 and 2019 in fifteen western European countries.

Overall, decreasing unionization seems to determine an increase in political polarization, with rising support for extremist forces at both ends of the political spectrum and diminishing support for mainstream parties. The coefficient on unionization in the regression for the vote share of the radical right (column (4)) is negative, and statistically significant.

Given that both unionization and radical right support are expressed as percentage points, this coefficient can be read as indicating that a 1 percentage point decrease in unionization in the region is associated with a 0.55 percentage points increase in support for the radical right. Equivalently, a drop in unionization by 1.8 percentage points is associated with a one percentage point increase in support for the radical right. The effect is comparatively large.

The residual standard deviation in the outcome (after partialing out the fixed effects as per Mummolo and Peterson, 2018) is 3.31 percentage points; the analogous quantity for unionization is 1.17. One standard deviation increase in unionization is therefore associated with a decrease by almost one fifth of a standard deviation in support for the radical right at the district level.

In line with the polarization hypothesis, the effect on the radical left has the same direction of that of the radical right, but is much smaller in magnitude and is not statistically different from zero. Thus, it is not possible to conclude that higher unionization affects radical left support.

Table 2 also shows that the decrease in union density penalizes mainstream parties, in particular the mainstream right. The coefficients on unionization in the regression for the vote share of the mainstream left and right (columns (2) and (3)) suggest that mainstream parties are more succesfull in districts with lower deunionization (or higher unionization). However, the coefficient is statistically different from 0 only for the mainstream right, that seems to suffer more, in a context of successful radical right parties.

Finally, table 3 display analogous results in regressions that employs union rates estimated with the model that performed better according to our RMSE cross-validation procedure of MrP estimates. As compared to previous results, the coefficient on unionization in the regression for mainstream left voting increases in magnitude, but remains statistically insignificant. The coefficient for the radical right also increases in absolute value, and remains negative and strongly statistically significant.

The potential endogeneity of changing union rates necessitates caution in interpreting

Table 3: Voting and union density (best overall)

VARIABLES	(1) Radical Left	(2) Mainstr. Left	(3) Mainstr. Right	(4) Radical Right
Union rate	-0.058	0.512	0.626***	-0.679***
(best)	[0.135]	[0.373]	[0.228]	[0.229]
Estimator	OLS	OLS	OLS	OLS
Observations	7,193	7,193	7,193	7,193
R-squared	0.747	0.536	0.569	0.820
Country-Year FE	X	X	X	X
Region FE	X	X	X	X
Std dev. Y	3.577	9.969	10.70	3.313
Std dev. X	1.176	1.176	1.176	1.176
Magnitude	-0.0190	0.0604	0.0688	-0.241

Robust standard errors in brackets
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2 and 3. Nevertheless, by employing fixed effects and previously unexplored territorial variation, this study provides the first sub-national evidence on the effect of (de)unionization on electoral outcomes at the sub-national level in European countries. While we observe a positive association between unionization and support for the mainstream left, our findings cannot definitively link decreased unionization to declining support for these parties. Nonetheless, we identify a statistically significant association between decreasing unionization and the success of the radical right, primarily at the expense of moderate right-wing parties.

The finding that success of the radical right in Western European countries takes place at the expenses of mainstream parties aligns with existing research on electoral flows. To explain this regularity, emphasis has been given in the literature to political opportunity structures and positioning of competing parties. Notably, Kitschelt (2007) theorized that convergence of mainstream parties on economic issues has paved the way for more radical platforms. To further substantiate our findings, we present supplementary descriptive

Table 4: Electoral flows (CSES)

	Vote in last election			
	Radical Left	Main. Left	Main. Right	Radical Right
Vote in prev. elec.:				
Radical Left	0.62	0.04	0.01	0.01
Main. Left	0.24	0.80	0.10	0.11
Main. Right	0.10	0.13	0.84	0.22
Radical Right	0.02	0.01	0.04	0.61
Other	0.02	0.01	0.01	0.04
Total	1	1	1	1

evidence that the electoral shift from mainstream to radical right parties extends beyond the district level to the individual voter level.

We utilize survey data from the Comparative Study of Electoral Systems (CSES) fourth and fifth waves, encompassing 14 Western European countries[2] from 2011 to 2021. CSES asks voting choices from participants in both the most recent and preceding legislative elections, enabling analysis of party-family shifts. This allows us to investigate the flows of voters from a party family to another. Table 4 shows the breakdown of voters that voted for one of the four party families in the last legislative election according to their previous party-family choice. Predictably, most voters maintain loyalty to either the same party or party family (e.g., 80% of mainstream left voters and 84% of mainstream right voters stayed within their respective families). Consistent with our district-level findings, we also observe significant inter-family electoral flows. Notably, we observe that 24% of radical left voters were previously within mainstream left, while 22% of radical right voters supported the mainstream right in the previous election.

Descriptive evidence highlights the presence of a substantial electoral inflows from mainstream right parties to the radical right. What's the role of trade unions in this transition? Previous research has investigating the moderating effect of individual union membership. For instance, Rennwald and Pontusson (2021) finds that union members who

[2]Unlike previous analyses, the list of countries considered here does not include Spain, that was not surveyed in CSES 4 and 5. Our data include 20,396 respondents from wave 4 of CSES and 32,853 from wave 5.

abandon mainstream Left parties are more likely to remain on the Left, broadly conceived, than leavers who are not union members. Combininig post-electoral individual data from CSES with our data on regional union density, we can distinguish between contextual and individual effects of unionization. That is, we can investigate not only the relationship between individual union membership and political preferences, but also about the role of changing contextual unionization levels.

To further substantiate our findings on the electoral flows from the mainstream to the radical right, we condition the CSES sample to respondents who declared to vote for the mainstream right in previous elections. Table 5 displays the results of voting regression that includes not only a dummy variable on whether the respondent is a union member but also the unionization rate in the region of residence and an interaction term of individual and contextual unionization. Regressions always control for age, gender, and a set of dummy variables for educational attaiment and social class. Also, we include country-year and NUTS-2 region fixed effect. Standard errors are clustered ant the country-year and region level.

We find that union members who previously voted for the mainstream right are more likely not to confirm their vote for the same party family and tend to prefer instead the mainstream left (columns (2-3)). Also, we find evidence of a negative and statistically significant interaction between individual and contextual unionization in the regression about voting for the radical right(column(4)). This means that union members who used to vote for the mainstream right decide to vote for the radical right only in places where unionization rates are declining. In other terms, in regions with constant or growing unionization rates, union members who are former mainstream right voters are less likely to move to the radical right.

Table 5: Party outflows from Mainstr. Right and unionization

VARIABLES	(1) Radical Left	(2) Mainstr. Left	(3) Mainstr. Right	(4) Radical Right
Indiv. union	0.007	0.029**	-0.065**	0.028
membership	[0.009]	[0.012]	[0.027]	[0.016]
Union rate	0.032	-0.050	0.205	0.840
(baseline)	[0.268]	[1.046]	[1.502]	[1.671]
Interaction	-0.012	-0.014	0.104*	-0.077***
	[0.016]	[0.021]	[0.060]	[0.026]
Constant	0.010	0.269	0.627	-0.260
	[0.081]	[0.313]	[0.440]	[0.501]
Estimator	OLS	OLS	OLS	OLS
Observations	9,091	9,091	9,091	9,091
R-squared	0.035	0.076	0.062	0.062
Country-Year FE	X	X	X	X
Region FE	X	X	X	X
Previous vote	Mainstr. Right	Mainstr. Right	Mainstr. Right	Mainstr. Right

Control variables: age, gender, educational attainment and social class. Standard errors are clustered at country-year and region NUTS-2 level

*** p<0.01, ** p<0.05, * p<0.1

6 Conclusions

The results of our analysis provide the first available evidence that automation has led to a decrease of union density in western European regions. We have theorized that the technological process is conducive to a weaker unions role, by drastically reducing employment in the large highly-unionized sectors while expanding less-unionized new jobs and new sectors. We find that technological change, in the form of adoption of robots, decreases the proportion of workforce that is unionized and therefore the relevance of trade unions in a society.

The findings of this paper confirm our hypothesis on the extensive margin of technology on unions. In future revisions, we will also test our hypothesis on the intensive margin. That is, we expect unions to be weaker, in terms of bargaining power, in sectors more exposed to automation and to be less effective in translating productivity gains in workers' salaries.

In line with Kitschelt (2012), we argue that the weakening link of working class constituencies and socialdemocratic parties contributes to explain why the economic losers of structural changes such as globalization and automation have increased their support for nationalist and radical-right parties. Our evidence that automation has directly affected trade unions in western European countries factors into why technologically-driven economic grievances trigger such political shifts. Also, we have empirically tested the hypothesis that vote for radical right parties is lower, while support for redistribution platforms of the economic left is higher, in districts located in regions with stronger unions. While we have found evidence of the effect of deunionization on the radical right surge, the parties bearing the higher political costs of this electoral dynamic seems to be on the mainstream right.

The possibility to empirically address the set of research questions raised herein is made possible only by the availability of fine-grained data about union density. Thus far, research on trade unions have been hindered by data limitations. In this paper, we have contributed to make up for this deficiency. We have gathered a wealth of census data about population composition in 15 western European countries that, combined with nationally-representative survey data, have allowed to obtain a measure of union density at the region-by-industry level. We have validated our measure by comparing it with other reliable estimates of subnational union density. Although we have primarily used regional-level data on trade unions in the empirical analysis of this paper, our novel data opens up a much wider range of research possibilities. The presence and role of unions significantly varies both across space and industrial sectors. Fine-grained data on trade unions are crucial to explain economic, social and political phenomena. As the data collected for this paper will be publicly available, they will enable the empirical examination of a broad set of research questions on the role of trade unions.

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