

DISCUSSION PAPER SERIES

IZA DP No. 13633

**When the Minimum Wage Really Bites
Hard: Impact on Top Earners and Skill
Supply**

Terry Gregory
Ulrich Zierahn

AUGUST 2020 (UPDATE FEBRUARY 2021)

DISCUSSION PAPER SERIES

IZA DP No. 13633

When the Minimum Wage Really Bites Hard: Impact on Top Earners and Skill Supply

Terry Gregory

IZA and ZEW

Ulrich Zierahn

Utrecht University and ZEW

AUGUST 2020 (UPDATE FEBRUARY 2021)

Any opinions expressed in this paper are those of the author(s) and not those of IZA. Research published in this series may include views on policy, but IZA takes no institutional policy positions. The IZA research network is committed to the IZA Guiding Principles of Research Integrity.

The IZA Institute of Labor Economics is an independent economic research institute that conducts research in labor economics and offers evidence-based policy advice on labor market issues. Supported by the Deutsche Post Foundation, IZA runs the world's largest network of economists, whose research aims to provide answers to the global labor market challenges of our time. Our key objective is to build bridges between academic research, policymakers and society.

IZA Discussion Papers often represent preliminary work and are circulated to encourage discussion. Citation of such a paper should account for its provisional character. A revised version may be available directly from the author.

ISSN: 2365-9793

IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

When the Minimum Wage Really Bites Hard: Impact on Top Earners and Skill Supply*

This paper provides new insights into how wages and employment adjust to a minimum wage policy along different wage and skill groups. For this, we exploit a quasi-experimental setting in the 1990s, where a German industry introduced a minimum wage at an extraordinary high level during an economic downturn with falling revenues. We find positive wage spillovers to medium-skilled workers with wages just above the minimum wage. More striking, we also find negative wage effects for high-skilled workers situated higher up in the wage distribution, followed by reduced returns to skills and skill supply in the industry. We explain these adjustments, both theoretically and empirically, with a substitution-scale model that predicts negative spillovers whenever labour demand shifts from low- to more skilled workers (substitution effect) are overcompensated by an overall decline in labour demand (scale effect).

JEL Classification: J31, J38, J24, C21, J23

Keywords: minimum wages, wage effects, spillover effects, wage restraints, returns to skills, unconditional quantile regression, scale effect, substitution effect, skill supply

Corresponding author:

Terry Gregory
IZA - Institute of Labor Economics
Schaumburg-Lippe-Str. 5-9
53113 Bonn
Germany
E-mail: gregory@iza.org

* We thank Melanie Arntz, Stephan Dlugosz, Bernd Fitzenberger, Heinrich Kögel, Michael Maier, Joachim Möller, David Neumark, Anna Salomons as well as participants of the seminars at Utrecht University, ZEW Mannheim, University of Regensburg, DIW-Conference on the "Evaluation of Minimum Wages" and annual congresses of the Society of Labor Economists (SOLE), European Economic Association (EEA) and German Economic Association (VfS) for helpful comments and suggestions. Our paper was partly financed by the ZEW Sponsors' Association for Science and Practice and profitted from a preceding evaluation of minimum wage effects in the German roofing industry that was financed by the German Federal Ministry of Labour and Social Affairs (BMAS). The results and conclusions derived in this study do not necessarily reflect the views of the BMAS. This paper builds on an earlier version "When the Minimum Wage Bites Back: Quantile Treatment Effects of a Sectoral Minimum Wage in Germany", ZEW Discussion Paper No. 14-133.

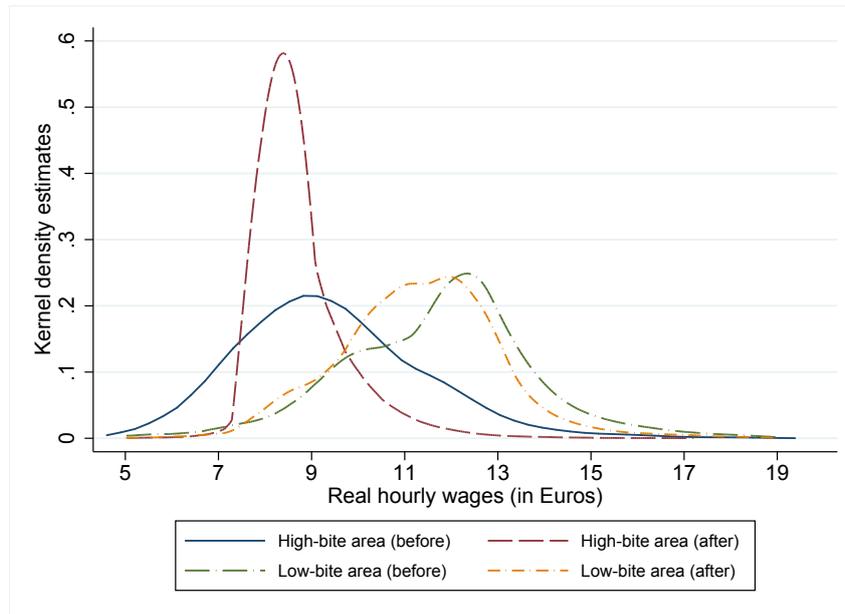
1 Introduction

The way a minimum wage affects the overall distribution of earnings, including the earnings of skilled high-wage workers, still remains a contested research question. Most evaluation studies focus on whether the minimum wage improved the outcomes of low-wage workers (for an overview, see Neumark and Wascher 2008). Fewer studies stress that minimum wage effects can spill over to workers with earnings above the minimum wage (see for instance Gramlich et al. 1976, Grossman 1983, Lee 1999, Manning 2003, Teulings 2003, Neumark et al. 2004, Dickens and Manning 2004 or, more recently, Autor et al. 2016, Cengiz et al. 2019 and Gopalan et al. 2020). According to this research, wage floors create a spike in the wage distribution at the minimum wage and boost wages of workers who earn somewhat more than the threshold. Depending on the bite, the effects then ripple up to wages at about 20% above the minimum wage level (Neumark and Wascher, 2008).

Conventional explanations for minimum wage spillovers put forward by the literature are that (1) firms substitute unskilled with skilled labour as a reaction to the change in relative input prices (Pettengill, 1981), (2) firms adjust their wage structure to maintain an internal wage hierarchy and hence fairness perceptions, motivation, and effort among their highly paid employees (Grossman, 1983; Falk et al., 2006; Dube et al., 2018) and that (3) firms which previously paid relatively high wages to attract workers must increase wages too, in order to recruit enough new employees (Manning, 2003). (4) More recently, Phelan (2019) argues that minimum wages raise wages of low-wage jobs relative to undesirable albeit higher paid jobs, reducing labor supply for the latter. This decline, in turn, raises wages for these undesirable albeit higher paid jobs in response to this declining labour supply, which then leads to positive wage spillovers. All these mechanisms lead to increasing demand and increasing wages for workers with earnings above the minimum wage.

While the existing literature focuses on positive wage spillovers for workers with wages just above the minimum wage, we show that a large-bite minimum wage can induce *negative* spillovers for top-earners. So far, only few empirical studies indicate the existence of negative spillovers for top-earners. For instance, Neumark et al. (2004) find negative wage responses of top earners to the minimum wage in the US and briefly argue that such negative spillover effects on top earners may arise through scale effects, but do not further test this hypothesis. Apel et al. (2012) and Aretz et al. (2013) find indications of upper-tail wage compression in response to the first industry-specific minimum wages in the German main construction and roofing industry, but also do not causally test and explain these findings. The observation becomes particularly clear in case of the German roofing industry, where in some areas the bite was extraordinary

Figure 1: Hourly Wage Distribution Before and After the 1997 Minimum Wage Introduction in the German Roofing Industry



Notes: The figure shows kernel density estimates of real hourly wages for East Germany (high-bite area) and West Germany (low-bite area) before (1995) and after (2008) the reform, based on a full sample of all roofers using the LAK data (see Section 4.1). Hourly wages are adjusted to prices in 1994.

strong, such as in East Germany. There, the minimum wage coincided with a compression of hourly wages not only at the bottom of the distribution, but also at the top (compare Figure 1). In contrast, we do not observe larger changes in West Germany, where the bite was low. These descriptive findings are striking, because wage compression at the top can have negative long-term consequences such as declining returns to skills and reduced incentives to invest in skills. To the best of our knowledge, there does not yet exist a comprehensive framework that allows to study the conditions under which both positive and negative minimum wage spillovers may occur, as well as the potential implications for employment, wages, returns to skills and skill supply. As we argue throughout the paper, this is particularly relevant in a context of a rising minimum wage bite in combination with an economic downturn, both which can be observed currently worldwide (for evidence on OECD trends in minimum wages, see Figure 7 in Appendix A.3).

The present paper aims at filling this gap by making at least three major contributions: First, we estimate the minimum wage effects on the distribution of earnings by exploiting a quasi-experiment in the German roofing industry. The German roofing industry comprises an ideal setting to study minimum wage spillovers for two main reasons: (1) The minimum wage in the German roofing industry was introduced in 1997 and was subsequently raised several times. The Kaitz Index, i.e. the ratio of the minimum wage level and the median wage, increased to 100% in East Germany over the observed post-reform period between 1997 and 2008. Given that the average Kaitz-index in the OECD is around 50% (see Figure 7 in

Appendix A.3), the bite is exceptionally large by international standards, making unfavourable minimum wage effects more likely; (2) For institutional reasons, the minimum wage was introduced only in parts of the construction sector, one of which was the roofing industry. The wage distributions of uncovered, yet comparable, sub-construction industries thus serve as a counterfactual for the earnings of roofers in the absence of the policy reform. This setting is ideal to study the long-run impact of minimum wages on the earnings distribution, as has been done for employment by Aretz et al. (2013).¹ To do this, we use particularly rich administrative data that allows us to follow the approach by Firpo et al. (2009) and compare the unconditional wage distributions of treated and untreated workers before and after treatment, holding constant compositional changes resolving, for instance, from low productive workers leaving the workforce. Besides a large set of individual and firm level covariates, we also control for individual fixed effects in our quantile regression estimates, which only recently has become feasible to implement. To test the identifying assumptions underlying our quantile treatment effects (foremost the common trends assumption), we conduct several checks suggesting that our assumptions hold for our main findings: we demonstrate parallel trends in pre-treatment years in several specifications, including a dynamic specification and show that our results are robust to alternative control industries as well as to a changes-in-changes estimator proposed by Athey and Imbens (2006) that only relies on the assumption of common changes as opposed to common trends. Finally, we also contrast our unconditional quantile regression estimates to traditional conditional quantile regression (Koenker and Bassett, 1978) to shed light on the role of between vs. within-group inequality in driving the overall compression of wages that we discover. By following this approach to identify spillover effects along the wage distribution, we thus contribute to the empirical literature on the (long-run) minimum wage effects on earnings, wage inequality and minimum wage spillovers, outlined above.

Second, we develop a labour market model with labour-labour substitution and a scale effect that is able to explain how a minimum wage can induce both positive and negative spillovers to workers with different skills. In our model, spillover effects are moderated by two adjustments to the minimum wage: (1) Firms substitute low- by medium-skilled workers, but not by high-skilled ones, as only medium-skilled workers' tasks provide close substitutes to those of low-skilled. This is in line with Distance Dependent Elasticity of Substitution (DIDES) models, where minimum wage-induced substitution effects fade out at the top of the wage distribution (see e.g. Teulings 2000). (2) The minimum wage-induced cost-shock to

¹While this quasi-experiment has already been exploited by Aretz et al. (2013), their analysis is restricted to the empirical assessment of the minimum wage on the probability to remain employed, without testing further implications for wages and industry employment (by different wage and skill groups) as well as returns to skills and skill supplies. The biggest distinction is that they do not provide any theory and corresponding testing.

the industry leads to a decline of employment in the industry, as higher costs and prices induce a reduction in demand and production. The net effect on high-skilled workers is thus negative, whereas the effect on medium-skilled depends on the relative size of the scale and substitution effect. Both adjustments are moderated by the bite of the minimum wage. Our model thus extends the empirical and theoretical literature on minimum wage spillovers (see above) by allowing for negative minimum wage spillovers and by showing under which conditions spillovers may be either positive or negative. Moreover, it provides a potential explanation for the negative spillover effects found for the US (Neumark et al., 2004) as well as Germany (Apel et al., 2012; Aretz et al., 2013).

Third, we empirically test our models' predictions for minimum wage spillovers related to wages and employment and their consequences for skill supply. In particular, we estimate the minimum wage effects on total industry employment and skill-specific employment shares in order to empirically quantify the scale- and substitution effects for each skill group together with their net effects.² We do this within a regional labour market approach, which is designed to capture aggregate effects. We thereby exploit differences in the minimum wage level over time and between East and West Germany, thus providing insights into the role of the minimum wage bite in explaining our findings. By doing so, we contribute to the literature on minimum wage spillovers as well as the literature on heterogeneous effects of minimum wages (in our case wage groups and skills). Finally, we estimate minimum wage effects on employment and skills of (new) apprentices to gain insights into adjustments in skill supply. We thus also complement research on the effects of minimum wages on (apprenticeship) training and skill supply, which so far reached mixed conclusions.³

Overall, we find significant real wage increases of up to 5-6% for lower-quantile workers between 1997 and 2008, rippling up to the 60th quantile. However, the minimum wage also caused a reduction in real wages by up to 5% (stagnation of nominal wages) among highest paid employees, who mostly comprise high-skilled workers. In line with our theoretical framework, we show that positive wage spillovers to medium-skilled workers were driven by a positive substitution effect that overcompensated a negative

²A few other studies have estimated minimum-wage induced scale and substitution effects for labour-labour substitution. Welch and Cunningham (1978) estimate aggregate employment responses of different age groups to minimum wages and extract the scale- and substitution effects from the aggregate responses based on a conceptual framework. They find that the negative scale effect dominates the positive substitution effect for young adults, whereas teenagers suffer from both negative scale and substitution effects. Pereira (2003) provides similar findings but does not extract the underlying scale- and substitution effects. Giuliano (2013) actually finds positive effects of minimum wages on teenage employment and explains this by firms' monopsony power. However, she does not differentiate the scale and substitution effects. Fairris and Bujanda (2008) estimate labour-labour substitution for different types of low-qualified workers, but they do not take into account scale effects.

³While some authors find negative effects of minimum wages on training (Fairris and Pedace, 2004; Hashimoto, 1982; Schumann, 2017), others find no effects (Acemoglu and Pischke, 2003; Arulampalam et al., 2004; Grossberg and Sicilian, 1999). A potential explanation for the mixed findings is that the effects depend on the type of training (Neumark and Wascher, 2001) and on the type of worker (Lechthaler and Snower, 2008).

scale effect, resulting in a net positive effect on employment and wages among medium-skilled workers. In contrast, the negative wage spillovers to high-skilled workers are the result of a negative scale effect without any substitution towards these workers, which are accompanied by negative net employment effects for these workers. As a result of declining returns to skills in the industry, we further find a negative effect of the minimum wage policy on the share of high-skilled entrants. The adjustments we find only occur when the minimum wage bite is high, namely in East Germany, where the bite (as measured by the Kaitz-Index) reached values of 100% during our observation period. In contrast, we do not find evidence for larger adjustments in West Germany where the bite is much smaller.

The structure of the paper is as follows. In Section 2, we provide a theoretical framework that is able to explain both positive and negative minimum wage spillovers for workers with different skills. In Section 3, we describe the German roofing industry as our main setting and discuss potential control industries for a quasi-experiment. In Section 4, we introduce the data and provide descriptive evidence on the minimum wage bite as well as trends in earnings. In Section 5, we discuss our identification strategy to estimate unconditional (and conditional) quantile treatment effects of the minimum wage on the distribution of earnings together with several robustness checks. In Section 6, we empirically test the mechanisms proposed by our theory by quantifying the minimum wage effects on total industry employment (scale effect) and skill-specific employment (substitution effect) within a regional approach. In Section 7, we test our models' predictions for skill supply. Finally, Section 8 concludes.

2 Theoretical Framework

In this section, we develop a simple, stylized labour market framework with labour-labour substitution and a scale effect to explain how a minimum wage can lead to adjustments not only among low-skilled workers, but also among medium and high-skilled workers located higher up in the earnings distribution (minimum wage spillovers). The model also allows to derive implications for adjustments in the returns to skills and skill supply. In the following, we briefly summarize the main assumptions of the model and derive predictions regarding the adjustments to the minimum wage (for details, see Appendix A.1).

2.1 Model and Main Assumptions

There are I firms in the industry, producing varieties q_i of the industries' final output Q under monopolistic competition. Firms require a fixed high-skilled labour input $h_i = f$ as well as a variable labour input $n_i = \varphi q_i$ where $1/\varphi$ is labour productivity. The variable labour input n_i is composed of low and medium-

skilled workers, l_i and m_i . Note that skills are defined as fixed individual attributes which are rewarded on the labour market. We focus on three skill groups for simplicity. Low, medium and high-skilled workers earn wages w_L , w_M and w_H , respectively. We use \bar{w} as the wage cost index for the variable labour input (which is composed of medium and low-skilled workers). Firms can replace low by medium-skilled workers with constant elasticity of substitution η , whereas high-skilled workers provide no close substitute for low- and medium-skilled labour. This assumption is comparable to DIDES models (see e.g. Teulings 2000), where low-skilled tasks are more easily substituted by medium-skilled tasks than by high-skilled tasks, so that the substitution effects fade out at the top of the skill and wage distribution. Our assumption is in line with the empirical literature on spillover effects, which finds substitution only towards workers who earn slightly above the minimum wage, but not towards high-wage workers. In our case, this is particularly true due to industry regulations that require firms to be run by high-skilled workers (e.g. master craftsmen or vocationally trained workers with sufficient work experience), thus widening the gap between low- and high-skilled workers' tasks. Finally, this assumption is justified by the fact that we do not find substitution effects towards high-skilled workers in our empirical analysis.⁴

Consumers have Constant Elasticity of Substitution (CES) preferences for the varieties i produced by the firms with elasticity of substitution $\sigma > 1$ between the varieties. We further assume that the industry sells its output to the rest of the economy and is too small to affect the size of the economy. Demand for the overall output of the industry is price sensitive with the constant price elasticity of demand $\varepsilon < 1$. The market is governed by monopolistic competition among homogeneous firms and free entry.⁵

We solve the model as a flow equilibrium, where at each time instant t , a share δ of each type of worker exogenously retires. The supply of low-skilled workers greatly exceeds demand.⁶ This implies that they earn their reservation wage \underline{w} , unless there is a minimum wage w_{MW} that exceeds their reservation wage, $w_L = \max(\underline{w}, w_{MW})$. For simplicity, we assume that the minimum wage is binding only for low-skilled workers ($\underline{w} < w_{MW} < w_M, w_H$). At each time instant t , a mass of medium- E_M and high-skilled entrants E_H supply labour with wage elasticity of labour supply θ . In the steady state, the inflow (entrants) of workers equals the outflow (retirement), and expected wages correspond to actual wages. We abstract from any wage setting frictions; wages adjust until labour supply equals labour demand, which implies no unemployment among medium- and high-skilled workers.

⁴Relaxing the assumption of no substitution effects towards skilled workers would allow for potential positive spillover effects of minimum wages towards skilled workers at the cost of raising model complexity. We abstract from this complexity as our empirical analysis reveals that there are no such substitution effects towards high-skilled workers.

⁵We assume free entry to avoid making the model unnecessarily complex. Introducing Melitz (2003)-type entrance costs and firm heterogeneity does not change the main results.

⁶This assumption is motivated by the high unemployment rate among low-skilled workers.

With these assumptions, we can solve for medium- and high-skilled workers' equilibrium wages:

$$w_H = \left(\frac{\delta}{\sigma E_H} \right)^{1/\theta} Q_0^{\frac{\tilde{\varepsilon}/\varepsilon}{\theta}} \bar{w}^{-\tilde{\varepsilon}/\theta} \quad (1)$$

$$w_M = \left(\frac{\delta(\sigma - 1)}{\sigma E_M} \right)^{1/(\theta + \eta)} Q_0^{\frac{\tilde{\varepsilon}/\varepsilon}{\theta + \eta}} \bar{w}^{\frac{\eta - \tilde{\varepsilon}}{\theta + \eta}}, \quad (2)$$

where Q_0 , E_M and E_H are constants and $\tilde{\varepsilon} = \varepsilon \frac{\sigma - 1}{\sigma - \varepsilon}$ is the overall price elasticity of industry-level output. Jointly with low-skilled wages $w_L = w_{MW}$ and the CES wage cost index \bar{w} , these equations describe the equilibrium in our industry.

2.2 Adjustments to the Minimum Wage

Based on the above model assumptions, we can derive the following propositions w.r.t. the minimum wage adjustments:

Proposition 1 (Scale Effect). *The introduction or rise of a minimum wage*

a) *raises average wage costs* $\frac{\partial \ln \bar{w}}{\partial \ln w_{MW}} > 0$, and

b) *reduces industry-level employment* $\frac{\partial \ln N}{\partial \ln w_{MW}} < 0$.

Proof. Using $\frac{\partial \ln \bar{w}}{\partial \ln w_{MW}} = (1 - \alpha) \frac{\partial \ln w_M}{\partial \ln w_{MW}} + \alpha$ (where α is the steady-state cost share of low-skilled workers) and the equilibrium medium-skilled wage (2), we derive $\frac{\partial \ln \bar{w}}{\partial \ln w_{MW}} = \frac{(1 - \alpha)(\theta + \eta)}{\theta + (1 - \alpha)\eta + \alpha \tilde{\varepsilon}}$. This is strictly positive for $0 < \alpha < 1$, $\theta > 0$, $\eta > 0$, $\tilde{\varepsilon} > 0$, showing that a minimum wage raises average wage costs.

Rising wage costs imply a decline in demand for the variable labour input, $\frac{\partial \ln N}{\partial \ln w_{MW}} = -\tilde{\varepsilon} \frac{\partial \ln \bar{w}}{\partial \ln w_{MW}}$. \square

The intuition of the scale effect is as follows: The minimum wage for low-skilled workers is a cost-shock, raising average wages (Proposition 1.a). This implies that the prices of the industry increase, such that it can sell less to the rest of the economy due to the negative slope of industry product demand, i.e. output and net employment decline (Proposition 1.b). The size of the negative scale effect depends on the price elasticity of industry level output $\tilde{\varepsilon}$ and on the size of the minimum wage. The more sensitive consumers respond to price changes, the larger the negative effect of a minimum wage-induced cost shock to the industry. For instance, if consumers are more price sensitive, such as during recessions, the scale effect is larger. Moreover, the stronger the minimum wage bite, the larger is the cost-shock to the industry and the larger are the disemployment effects.

Proposition 2 (Substitution Effect). *The introduction or rise of a minimum wage*

a) reduces the wage of medium- relative to low-skilled workers $\frac{\partial \ln w_M/w_L}{\partial \ln w_{MW}} < 0$, and

b) raises the share of medium-skilled workers $\frac{\partial \ln M/N}{\partial \ln w_{MW}} > 0$.

Proof. The implications for medium-skilled workers' relative wages are (using the result for average wages as before) $\frac{\partial \ln w_M/w_L}{\partial \ln w_{MW}} = -\frac{\tilde{\epsilon} + \theta}{\theta + (1-\alpha)\eta + \alpha\tilde{\epsilon}}$. This is strictly negative for $0 < \alpha < 1$, $\theta > 0$, $\eta > 0$, $\tilde{\epsilon} > 0$, showing that the minimum wage reduces the wages of medium- relative to the low-skilled workers.

The decline of medium-skilled workers' relative wages implies an increase in their employment share,

$$\frac{\partial \ln M/N}{\partial \ln w_{MW}} = -\eta \frac{\partial \ln w_M/w_L}{\partial \ln w_{MW}}. \quad \square$$

Intuitively, the minimum wage implies a rise in the relative costs for low- relative to medium-skilled workers (Proposition 2.a), which induces an increase in the share of relatively cheaper medium-skilled workers (Proposition 2.b). The effect is stronger the larger the elasticity of substitution between worker types η and the stronger the minimum wage bite. The reason is that a higher elasticity of substitution between worker types implies that it is easier for firms to replace the relatively more expensive low- by medium-skilled workers. In contrast, the ratio of the high-skilled labour input to the variable labour input (of medium- and low-skilled workers) remains constant – there is no substitution towards high-skilled workers in our model, as their tasks are no close substitutes to those of low-skilled workers.⁷ This is in line with the empirical literature which typically finds positive wage spillovers only for workers who earn slightly above the minimum wage, but not for top-earners (see introduction).

Proposition 3 (Net Effect). *The introduction or rise of a minimum wage*

a) raises (reduces) medium-skilled workers' wages, and

b) raises (reduces) medium-skilled employment

if the elasticity of substitution between workers η exceeds (is lower than) the industry product demand elasticity $\tilde{\epsilon}$.

Irrespective of the relative size of these two elasticities, the introduction or rise of a minimum wage

c) reduces wages of high-skilled workers $\frac{\partial \ln w_H}{\partial \ln w_{MW}} < 0$, and

d) reduces employment of high-skilled workers $\frac{\partial \ln H}{\partial \ln w_{MW}} < 0$.

Proof. We derive $\frac{\partial \ln w_M}{\partial \ln w_{MW}} = \frac{\eta - \tilde{\epsilon}}{\theta + \eta} \frac{(1-\alpha)(\theta + \eta)}{\theta + \eta - \alpha(\eta - \tilde{\epsilon})}$. For $0 < \alpha < 1$, $\theta > 0$, $\eta > 0$, $\tilde{\epsilon} > 0$, this is positive (negative) if $\eta > \tilde{\epsilon}$ ($\eta < \tilde{\epsilon}$). The employment effect is analogous due to $\frac{\partial \ln M}{\partial \ln w_{MW}} = \theta \frac{\partial \ln w_M}{\partial \ln w_{MW}}$.

⁷This is due to the fixed high-skilled labour input assumption jointly with homogeneous firms and free entry.

We take the first derivative of high-skilled equilibrium wages (1) w.r.t. $\ln w_{MW}$, which yields $\frac{\partial \ln w_H}{\partial \ln w_{MW}} = -\frac{\tilde{\varepsilon} (1-\alpha)(\theta+\eta)}{\theta+(1-\alpha)\eta+\alpha\tilde{\varepsilon}}$. This is strictly negative for $0 < \alpha < 1$, $\tilde{\varepsilon} > 0$ and $\eta > 0$. High-skilled labour supply strictly increases in wages, which implies that high-skilled employment declines in the minimum wage. \square

The introduction or rise of a binding minimum wage for low-skilled workers thus might raise or reduce wages (Proposition 3.a) and employment (Proposition 3.b) of medium-skilled workers, depending on whether the substitution or scale effect dominates. The net effect is governed by the relative size of the elasticity of substitution between worker types η and the price elasticity of industry product demand $\tilde{\varepsilon}$. The net effect on high-skilled workers' wages (Proposition 3.c) and employment (Proposition 3.d) is always negative – they suffer from the negative scale effect but do not gain from compensating substitution effects.⁸

Corollary 1 (Returns to Skills and Skill Supply). *The introduction or rise of a minimum wage*

- a) *raises the entrance of medium- relative to low-skilled workers,*
- b) *reduces high-skilled workers' wages relative to medium-skilled workers' wages $\frac{\partial \ln w_H/w_M}{\partial \ln w_{MW}} < 0$, and*
- c) *reduces employment and entrance of high-skilled workers relative to medium-skilled workers.*

Proof. In the long run, the effect on the ratio of the entrance of medium- to low-skilled workers is analogous to the effect on the ratio of medium- to low-skilled employment and thus directly follows from Proposition 2.

We use the results from Proposition 3 jointly with the results from Proposition 1 to derive $\frac{\partial \ln w_H/w_M}{\partial \ln w_{MW}} = -\frac{\eta (1-\alpha)(\tilde{\varepsilon}+\theta)}{\theta+(1-\alpha)\eta+\alpha\tilde{\varepsilon}} < 0$.

The results for the effects on the high-to-medium-skilled employment ratio are proportional to the relative wage effects, $\frac{\partial \ln H/M}{\partial \ln w_{MW}} = \theta \frac{\partial \ln w_H/w_M}{\partial \ln w_{MW}} < 0$. The effects on the corresponding entrants ratio are analogous. \square

The effects on skill supply are analogous to the employment effects in the long run. As firms employ a larger share of medium-skilled workers, in the long-run flow equilibrium, also the entrance of medium- relative to low-skilled workers rises. Moreover, wages of high-skilled workers decline relative to those of medium-skilled workers, as the former do not profit from substitution effects unlike the latter – the

⁸The lack of substitution towards high-skilled workers is an assumption of our model that is guided by our empirical results where we do not find such substitution and it is broadly in line with DIDES types of models where spillover effects of minimum wages fade out at the top if the wage distribution, see e.g. Teulings (2000).

returns to skills decline. This is associated with a decline in the supply of high-skilled workers relative to medium-skilled workers. It is getting harder for the industry to attract high-skilled workers.

Overall, our model provides two main contributions. First, we extend the labour-labour substitution model to include a scale effect. By doing so, our model not only explains why only medium-skilled workers profit from positive substitutions effects, whereas high-skilled do not (similar to the continuous version of Teulings 2000, where spillovers fade out with workers earnings). It also explains how the net spillovers can turn negative through a minimum wage-induced decline in product demand and a net overall employment decline in the industry. The latter scale effect is a missing link that may be of particular importance when studying minimum wages with a large bite in a context of an economic downturn with falling revenues. Second, our model is also able to explain how a minimum wage can reduce returns to skills and, ultimately, hamper skill supply. So far, we are not aware of any framework to study such adjustments.⁹

3 The German Roofing Industry

3.1 Minimum Wage Regulations

Until the introduction of the national minimum wage in 2015, the German minimum wage regulations were organised on an industry level. The first industry-specific minimum wages were introduced in 1997 in three industries of the construction sector, including the main construction industry, the roofing industry and the electric trade industry. After 1997, further industries within and beyond the construction sector decided to implement a minimum wage. The industry-specific minimum wages typically differ between East and West Germany, reflecting the large wage difference between the two parts of the country. According to the association of employers (National Association of Roofers, ZVDH), there are two main reasons for the introduction of a minimum wage: first, to protect the traditional craft in Germany against the increasing cost pressure from cheap East European labour; and, second, to reduce the large wage differences, especially between East and West Germany.

Not all industries in the construction sector agreed on implementing a minimum wage in the mid 90s because tariff agreements are negotiated on an industry level in Germany. In particular, the introduction of

⁹Several authors study the role of minimum wages for training, reporting mixed evidence (see above). There are two opposing mechanisms (Acemoglu and Pischke, 1999): On the one hand, minimum wages hinder workers to temporarily compensate firms for the training costs via lower wages, reducing incentives to form skills. On the other hand, minimum wages lead to wage compression, which induces substitution towards trained workers whose wages decline relative to untrained workers. We complement this literature by showing that there is a scale- and substitution-effect which differs between skill-groups, explaining why the minimum wage has heterogeneous effects for differently skilled workers.

industry-specific minimum wages depends on the industry-specific negotiations between the respective trade unions and employment associations. In addition to differences in the negotiation processes, industries also differ in their spatial organization. Regulations are adopted on a national level in some industries, including the roofing industry, the main construction industry, as well as in the electric trade industry. In other industries, including the plumbing industry, the collective-bargaining competence needs to be delegated from the regional to the national level first. This makes policy implementation more difficult for some industries, explaining why minimum wages were introduced only in some industries. The evaluation of the minimum wage at an industry-level thus provides the opportunity to compare similar industries within a quasi-experiment.¹⁰ Among these, the roofing industry comprises a particularly interesting case for two reasons: (1) The minimum wage was among the first to be introduced in Germany, allowing us to study its effects over a long time period. (2) Additionally, the minimum wage level was exceptionally large by international standards, as discussed in Section 4.2. For all these reasons, we focus on roofing for our quasi experiment.

The minimum wage in the roofing industry was introduced in October 1997. The responsible trade union (Trade Union for Building-Agriculture-Environment, IG BAU) and the ZVDH agreed as part of a general collective bargaining agreement on a minimum wage of 8.2 € in West and 7.7 € in East Germany. All blue-collar workers in the roofing industry, including minor employment, are covered by the minimum wage regulation. Apprentices, cleaning staff and white-collar workers are exempted from the regulations. Since 1997, the minimum wage has been raised subsequently (see Figure 6 in Appendix A.2). The strongest increase occurred in March 2003 for East Germany, where the trade unions and employers agreed on a national minimum wage of 9 €. Periods with no minimum wage regulations are the result of tariff agreements that expired before the new regulations came into force. The interruptions were short, and the continuation of the minimum wage expected, so that firms did not adjust wages downward during this period.¹¹

3.2 Selection of Control Industries

Roofing is an industry (or sub-sector) of the construction sector and constitutes a traditional craft that provides services including the installation of roofs on new buildings for public and private clients,

¹⁰Note that the differences in the spatial organization of negotiations did not change over time. Hence, if these differences would matter for trends in our outcome variables, then they would affect the trends in our outcome variables already before the introduction of the minimum wage. We therefore check whether trends in our outcome variables differ between treated and our control industries before the introduction of the minimum wage.

¹¹Inspections of hourly wages on a monthly basis (LAK data, see Section 4.1) for these periods by quantile of the hourly wage distributions show no downward adjustments of hourly wages for either of the quantiles 0.1, 0.25, 0.5, 0.75 and 0.9, see Appendix A.6 for details.

repairing of roofs including energy-efficient upgrading, and the installation of solar collectors. To identify potential control industries, we build on a previous evaluation study by Aretz et al. (2011) that provides an extensive and systematic analysis in search for similar industries. The main criteria guiding the selection of potential control industries was that they should (1) not be subject to any minimum wage regulation, (2) conduct similar tasks, (3) depend on similar ways on the business cycle of the wider construction sector, (3) have a similar market structure and (4) should not be vulnerable to spillovers to and from the roofing industry.

The main construction industry as well as electric trade can be ruled out as potential control industries, as they also introduced a minimum wage in 1997. The remaining industries with similar tasks include plumbers, glaziers and painters (for details, see Aretz et al., 2011). Since painters introduced a minimum wage in 2003, they cannot provide a counterfactual for the evaluation of long-run effects. Overall, we choose plumbers and glaziers as preferable control industries for our Difference-in-Differences analyses for the following main reasons:¹²

First, both are, similar to the roofing industry, part of the same construction sector and therefore share many basic characteristics of which some important ones are discussed below. In contrast to the roofing industry, the control industries did not introduce a minimum wage in the early 90s for mainly political reasons. This makes these industries generally suitable to reflect the counterfactual situation in the roofing industry, had the minimum wage not been introduced.

Second, with smaller exceptions, both control industries experienced very similar business cycle trends (see Figure 2), namely a severe and long-lasting economic downturn in the aftermath of the boom period in the 90s. Decreasing investments in housing and industrial buildings resulted in decreasing sales and revenues that led firms to increasingly lay off workers, especially in East Germany.

Third, the plumbing and glazier industry are very similar to the treated roofing industry in terms of their market structure. Building on Aretz et al. (2011), Table 1 contrasts some important indicators for the selected industries for the year before the policy reform. Overall, the comparison shows a very similar market size of roofers and plumbers in terms of firm counts and revenues. Most firms operating in these industries are relatively small. Compared to other industries, our treated and control industries are highly regulated, as reflected by the master craftsman's diploma that is required for offering services on the market.¹³ Moreover, with a share of craftsmen and skilled workers of around 70%, roofing firms

¹²The following industry coding identifies the industries: roofers (WZ93/WZ03: 45.22.1), plumbers (WZ93: 45.33.1 and 45.33.2/WZ03: 45.33.0), glaziers (WZ93/WZ03:45.44.2). Note that building construction including building bridges and tunnels, was generally also among the potential control industries, but it turned out to show a very different economic trend.

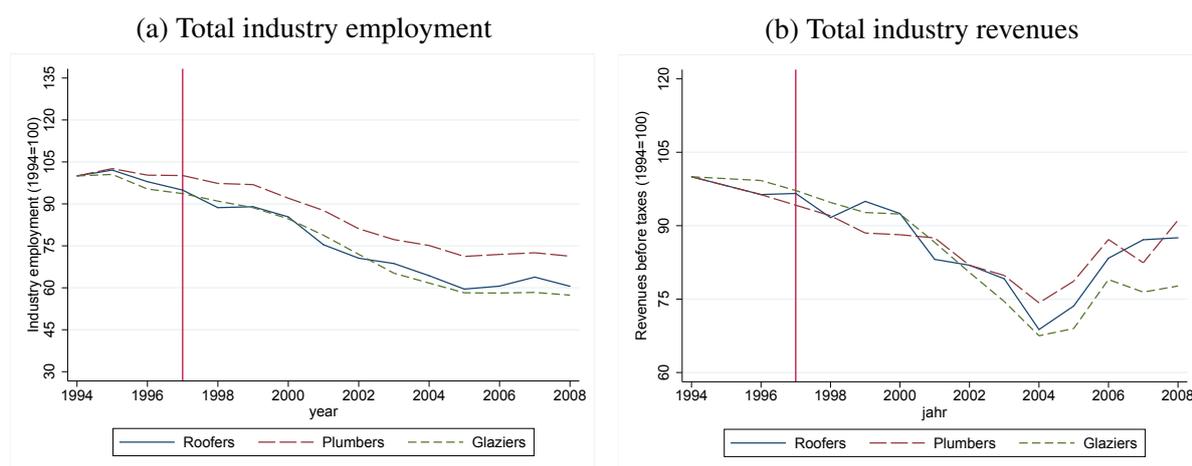
¹³The Master craftsman ("Meister") is the highest professional qualification in crafts. The requirements to become a master craftsman are usually an education in the crafts in which the examination should be taken (a successfully completed

Table 1: Various Economic Indicators for Roofers and Selected Control Industries

	Treated	Untreated		Source, year (4)
	Roofers (1)	Plumbers (2)	Glaziers (3)	
Number of firms	10,958	34,650	3,305	A, 1996
Number of employees	87,170	235,070	16,065	A, 1996
Avg. number of employees per company	7.9	6.7	4.8	A, 1996
Avg. gross daily wage/fulltime employee (in €)	66.2	68.6	66.3	A, 1996
Share of covered blue-collar workers: (in %)				A, 1996
unskilled	29.3	11.1	19.3	
skilled	66.7	83.4	73.9	
master craftsmens	3.7	5	6.1	
part-time workers	0.2	0.2	0.4	
Share of firms by revenues (in 1,000):				B, 1996
< 100 DM	6.8	8.8	13.6	
100-500 DM	24.6	33.7	42.8	
500-1,000 DM	26.1	23.5	21.5	
1,000-2,000 DM	25.1	19.3	13.5	
> 2,000 DM	17.4	14.6	8.5	
Number of companies/1 Mio. industry revenue	1.4	1.5	2.2	B, 1996
Value added in € per employee	37,195	35,949	32,931	C, 2001
Share of labour costs (in %)	36	32.5	49	C, 2001
Investments/employee (in €)	1,472	1,229	2,482	C, 2001

Notes: A - BA data, see Section 4.1, subsamples projected to 100%; B - German sales-tax statistics of the German Federal Statistical Office (Umsatzsteuerstatistik); C - Cost Structure Survey of the German Federal Statistical (Kostenstrukturerhebung).

Figure 2: Business Cycle Trends for Treated and Control Industries



Notes: Revenues are taken from the German sales-tax statistics provided by the Federal Statistical Office. Employment figures are based on the BA data (see Section 4.1). The vertical lines represent the introduction of the minimum wage in October 1997.

apprenticeship) and experience of at least 3 to 5 years as a journeyman (Geselle). Only then can training courses for the Master's examination ("Meisterprüfung") be followed. The duration of the courses depends on the craft and can take 4 to 6 years.

operate with a relatively skilled staff. This share is also very high in our control industries. The number of companies per 1 million industry revenues, as a measure of competition, is the same in roofing and plumbing. Also, value added, investments per employee, as well as labour cost shares among roofing firms are very similar to those figures of plumbing.

Fourth, the potential for spillovers between these industries is low. Among others, these industries are highly regulated and have very specific skill requirements so that workers cannot simply switch jobs between them. This is particularly true for qualified workers. However, even for unqualified workers, opportunities for roofers to find a better local employment in one of the control industries were low during the investigated time period due to the severe economic downturn in the entire construction sector. In fact, we find only few worker transitions between these industries (see Section 5.2). Moreover, it is very unlikely that East German roofers took advantage of the more stable West German economy due to the generally low degree of residential mobility of roofers.

Overall, the evidence suggests that our selected control industries are generally very similar to our treated industry in terms of market conditions. In fact, we find that our main outcome variables follow common trends in the treatment and control industries before the introduction of the minimum wage, as we show in Section 5.3 after introducing our main data sources in the next section. Note that we take both plumbing and glaziers as control industries in our baseline specification, but we test the robustness of our results to using plumbing separately as control industry.

4 Data and Descriptives

4.1 Administrative Linked Employer-Employee Data

We use Linked Employer-Employee Data from the Institute for Employment Research (IAB) as our main data source. This data matches firm data from the IAB Establishment History Panel (BHP) with personal data from Integrated Employment Biographies (IEB). Both are generated via labour administration and social security data processing. The data contains all workers subject to social security contributions by their employers. We have access to IEB subsamples of roofers (75%), plumbers (30%) and glaziers (75%).¹⁴ The data include individual employment histories for these workers on a daily basis, including several worker characteristics such as age, sex, occupational status, gross daily wages, education of workers and a firm identifier. The firm-level BHP data consists of information on the firm's workforce

¹⁴The data generally also includes painters, which we do not further exploit here, as they introduced a minimum wage in 2003, which precludes any long-term analyses.

structure, including the number of workers in certain educational groups. For the analysis, we use annual cross sections at the cut-off date June 30th. We focus on male workers above 19 years of age and drop minor employment, apprentices and white-collar workers that are not covered by the minimum wage regulations. In total, we are left with 788,611 yearly observations for 171,190 roofers as well as 1,059,475 observations for 233,024 workers from uncovered control industries (plumbers, glaziers) for the time period 1994-2008.

The advantage of the BA data is that they allow us to conduct comparisons of daily wage developments between treated and untreated industries. Since the BA data do not include information on hours worked, we further exploit a full sample of all roofers provided by the Central Pay Office (Lohnausgleichskasse, LAK) of the roofing industry. The LAK data collects, among others, monthly information from firms on the number of actual working hours for each worker as well as their gross wages from the year 1995 onwards. Since the reporting is mandatory for firms, and may impose a penalty for non-compliance, the information is highly likely to comprise all blue-collar roofers. In total, we are able to exploit 1,055,137 June observations for 206,753 roofers across the period 1995-2010. The reason why we do not choose the LAK data as the main data source is that it is only available for roofers, which precludes comparisons between treated and untreated industries. However, we use the LAK data to calculate the minimum wage bite, hourly wages and hours worked in the roofing industry. In particular, we use the East-West specific minimum wage bite (see next section) in our regional regressions in Section 6. Details of this data set are reported in Appendix A.4.

4.2 Minimum Wage Bite and Trends in Earnings

In the following section, we provide descriptive facts on the bite and trends in earnings. The bite of the minimum wage was relatively high in this industry (see Table 2, more details in Appendix A.3): In East Germany, the Kaitz-Index was 82% in 1997 and rose to 100% in 2006. That is, the minimum wage equals the median wage in 2006. These figures are large by international standards, as demonstrated by a comparison to the average bite among OECD countries that is around 50% (see Figure 7 in Appendix A.3). The figures also exceed those of Machin et al. (2003), who describe a strongly affected low-wage industry in the UK.¹⁵ With a Kaitz-Index of 65% in the year of its introduction (rising to 73% in 2006), the bite was much lower in West Germany.

We expect the minimum wage to explain the significant changes in the earnings distribution that we

¹⁵Machin et al. (2003) find that 32 percent of the workers were paid below the (age-specific) minimum wage before it was introduced. Our corresponding indicator shows that up 55 percent of workers in East Germany earned an hourly wage below the minimum wage in 2006, where the indicator reached its peak (see Table 2 in Appendix A.3).

Table 2: Indicators of the Minimum Wage Bite

Date of next minimum wage regulation	West Germany		East Germany	
	Hourly minimum wage level in € (1)	Kaitz Index in % (2)	Hourly minimum wage level in € (3)	Kaitz Index in % (4)
01.10.97	8.2	65	7.7	82
01.09.01	8.9	67	8.4	89
01.03.03	9.0	67	9.0	95
01.04.04	9.3	68	9.3	98
01.05.05	9.6	70	9.6	99
01.01.06	10.0	73	10.0	100
01.01.07	10.0	73	10.0	100
01.01.08	10.2	73	10.2	101
01.01.09	10.4	73	10.4	100

Notes: The Kaitz-Index is defined as the minimum wage level divided by the median hourly wage. Figures are calculated in June Prior to the next minimum wage regulation. Figures based on LAK data.

see in Figure 1. The strong compression at the bottom and top of the East German earnings distribution are thereby not driven by adjustments in hours worked. To demonstrate this, we inspect trends in monthly wages and hours worked for selected quantiles of the hourly wage distribution (see Figure 8 in Appendix A.6). Whereas wages (both hourly and monthly) show a compression comparable to Figure 1, monthly hours worked rather follow comparable patterns across the wage quantiles.

The wage compression at the top thereby reflects wage restraints among skilled workers. To show this, we display average yearly wage changes and other worker characteristics for selected wage quantiles (see Table 7 in Appendix A.5). In line with our expectations, top earners have higher formal skills, more tenure, are older and work in larger firms in both parts of Germany.

5 Minimum Wage Effects on Wages and Returns to Skills

5.1 Estimation Approach

In this section, we estimate the causal impact of the minimum wage at each quantile of the earnings distribution. By studying the effects along the earnings distribution, we are not only able to analyze the minimum wage effect on earnings of low-skilled workers, but also spillovers to medium and high-skilled workers. For identification, we exploit a quasi-experiment: For institutional reasons, the minimum wage was introduced only in parts of the construction sector, including the roofing industry. We compare the wage distributions of treated workers (roofers) with the counterfactual distributions of control workers

(plumbers and glaziers) before and after the minimum wage introduction.¹⁶ For a detailed discussion on the selection process and comparability of the control industries, see Section 3.2.

For the estimation, we apply an unconditional quantile regression technique developed by Firpo et al. (2009). The advantage of unconditional quantile regression compared to more traditional conditional quantile regression procedures is that it allows to estimate quantile treatment effects on the overall earnings distribution. In traditional approaches, conditional quantiles do not average up to their population counterpart as in mean regression analysis, since the Law of Iterated Expectations cannot be applied to quantiles. We therefore implement Firpo et al. (2009)'s method to estimate the effect of the minimum wage on the unconditional (marginal) distribution of wages, holding time-varying observable as well as time-constant unobservable factors constant. The method consists of two steps. In a first step, we define the Influence Function $IF(y; q^\tau)$ of our wage outcome Y at sample quantile q^τ , which is then transformed (recentered) such that it aggregates back to the overall wage distribution Y . The so called Recentered Influence Function (RIF) can be expressed as the weighted probability that workers' wage Y lies above a certain quantile:

$$\begin{aligned} RIF(Y; q^\tau) &= q^\tau + IF(Y; q^\tau) \\ &= q^\tau + \frac{\tau - \mathbb{1}\{Y \leq q^\tau\}}{f_Y(q^\tau)} \end{aligned} \quad (3)$$

where $f_Y(q^\tau)$ is the density at that point. Equation 3 essentially transforms conditional to unconditional quantiles before running the regressions. In a second step, we regress the RIF on the explanatory variables, using a fixed effects panel model. Our panel model of daily wages¹⁷ Y of worker i at time t is thereby defined as follows:

$$Y_{it} = \alpha + \gamma Post_t + \delta(Post_t \times D_i) + \eta \mathbf{X}_{it} + v_i + \varepsilon_{it} \quad (4)$$

where D_i refers to the treatment variable that takes the value one for treated roofers and zero for untreated plumbers and glaziers. $Post_t$ takes the value one for the post-reform period (t_1 : years 1998-2008) and zero for the pre-reform period (t_0 : years 1994-1997). The term \mathbf{X}_{it} includes a large set of individual and firm

¹⁶For a graphical illustration of the Differences-in-Differences (DiD) approach applied to quantiles see Havnes and Mogstad (2015).

¹⁷Since we use daily wages from our cross-industry BA data as a dependent variable (compare Section 4.1), we can not rule out that our estimates are driven by adjustments in hours worked rather than hourly wages. Previous research has reached mixed conclusions about the minimum wage effect on hours worked (Couch and Wittenburg, 2001; Neumark et al., 2004; Zavadny, 2000). Nevertheless, descriptive inspections of roofers' hourly wages, monthly hours worked and monthly wages based on the roofing-specific LAK data suggest that adjustments in wages work mainly through hourly wages (compare Section A.6).

level covariates, including age, tenure in industry, educational attainment (6 categories), occupational status (3 categories), a part-time dummy, firm's qualification structure (3 categories) and firm size (4 categories).¹⁸ In addition, v_i controls for time-constant unobservable effects, including also baseline D_i . The coefficient δ^τ gives us the Unconditional Quantile Treatment Effect (UQTE) of the minimum wage introduction (and subsequent increases) at the τ th quantile of the earnings distribution. Following Bertrand et al. (2004), we cluster our standard errors by individuals to account for serial correlation.

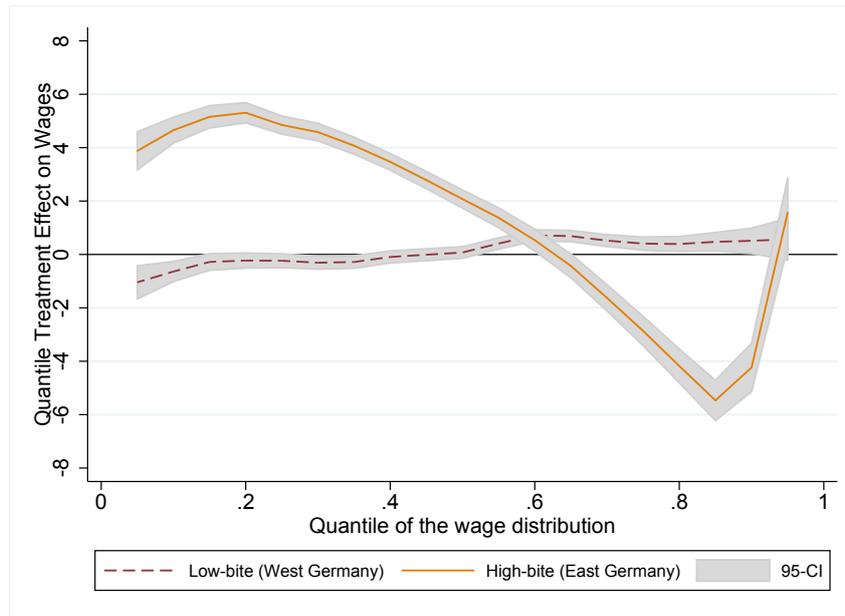
Identifying Assumptions. The following main assumptions are needed for identification:

First, we assume that differences in outcomes between treated and control workers would have stayed the same in the absence of the policy reform (common trends assumption). As outlined in Section 3, the fact that roofing sector could introduce a minimum wage whereas plumbers and glaziers could not lies in differences in the spatial organization of negotiations, which did not change over time. If these differences would directly matter for trends in our outcome variables, then they would affect the outcome variables already before the introduction of the minimum wage. However, our evidence in Section 3.2 shows that both treated roofers and untreated plumbers and glaziers have very comparable market structures, experienced similar trends in several important economic indicators and are in general very comparable regarding other regulations. We further provide several placebo tests and robustness checks with a dynamic specification in Section 5.3 to demonstrate common trends in pre-treatment years, despite smaller exceptions. Our results are also robust to a changes-in-changes estimator proposed by Athey and Imbens (2006), which relies only on the assumption of common changes rather than common trends. Overall, our evidence supports our assumption that our control industries well mimic the counterfactual situation in the treated industry, had the minimum wage regulations not been implemented, conditional on covariates.

Second, there should not be any indirect effects from treated to untreated workers (Stable Unit Treatment Value Assumption, SUTVA), such as worker transitions between both industries. Mobility between our industries is highly unlikely because industry regulations imply large differences in the skill requirements between those industries, creating hurdles that prevent workers from switching between industries. Indeed we find that only 0.35% of our observations in our entire data set show a change in the industry coding between 1994 and 2008, there is hardly any labour mobility between roofers and our

¹⁸Educational attainment: 1 low-level qualification without vocational training (reference), 2 low-level qualification with vocational training, 3 Abitur without vocational training, 4 Abitur with vocational training, 5 University of Applied Sciences degree, 6 University degree; occupational status: 1 unskilled worker (reference), 2 skilled worker, 3 master craftsmen or foremen (whether manual or clerical); firm's qualification structure: 1 share of workers without vocational training (reference), 2 with vocational training, 3 with university or college degree; firm size: less than 6 workers (reference), between 6 and 10; between 11 and 20; more than 20.

Figure 3: Minimum Wage Effects on the Unconditional Real Daily Wage Distribution



Notes: The figures show estimates an unconditional quantile regression estimator (RIF-FE) outlined in Equation 4 by East and West Germany. All models include individual fixed effects, post-year dummies as well as several individual and firm-specific covariates. 95% confidence intervals are based on robust standard errors clustered by individuals. Detailed regression estimates for selected quantiles are shown in Table 3. Quantile treatment effects reflect the impact of the minimum wage introduction on wages (in percent).

control industries (plumbers and glaziers). Moreover, as the entire construction sector experienced an economic downturn during the observation period, it is unlikely that demand effects in the plumbing and glazier industry indirectly affected the roofing industry.

Third, we assume no anticipation behaviour. To test this assumptions, we use our dynamic specification to identify potential anticipation effects. We then conduct robustness checks where we re-assign critical years to show that our main results still hold (see Section 5.3).

Finally, note that it might generally be the case that observed wage changes over time between treatment and control industry reflect compositional changes rather than changes due to the minimum wage. For instance, if low productivity workers drop out of the workforce or if smaller firms stop operating, this might bias the estimates. However, our rich set of time-varying individual- and firm-level covariates as well as time-unvarying individual unobservables largely control for such selection effects.

5.2 Results

Figure 3 displays the UQTE for 19 different quantiles (from 5th to 95th). Table 3 in the next section shows detailed figures together with several robustness checks for selected quantiles $\tau=0.1, 0.25, 0.5, 0.75,$

0.9 (Panels C and E, baseline model). The results for the UQTE reveal a large degree of heterogeneity in the minimum wage effects across quantiles as indicated by the deviations of the RIF-FE coefficients from the coefficients of a Fixed Effects (FE) estimation of Equation 4. In particular, real wages at the lowest quantiles increased by up to 5-6% in East Germany as a result of the minimum wage. Figure 3 shows that the positive wage effects extend to above the median worker. These effects coincide with a location shift of the entire distribution (positive effect on the median). However, these favorable effects were accompanied with real wage losses at a similar magnitude among workers with high wages in East Germany (up to more than 5%). In contrast, we do not find any larger wage effects for West Germany, which is not surprising given that the minimum wage bite was relatively low there. Note that we find small pre-existing differences in trends between industries in West Germany (Section 5.3), which may bias our results for this part of the country. We thus do not find clear evidence on whether the minimum wage affected the West German wage distribution. As we show in Section 5.3, the results for East Germany are not affected by differences in pre-trends.

Whereas the wage compression at the bottom and middle of the distribution in East Germany is in line with existing minimum wage theories on minimum wage spillovers, the compression at the top remains unexplained. In Section 6, we show that these results can be explained by our substitution-scale model laid out in Section 2. According to this, a high-bite minimum wage can induce a negative net labor demand effect on high-wage skilled workers whenever the negative scale effects dominates the positive substitution effect, such as during an economic downturn.

Within or Between-group Compression Effect? Unconditional quantile regressions look at the overall distribution of earnings. In contrast, traditional conditional quantile regression estimates are restricted to the impact on the wage distribution within worker groups with similar characteristics (within-group inequality). Comparing results from both methods thus allows us to shed light on the role of within vs. between-group inequality in driving the observed shifts in the overall wage distribution. For this, we re-estimate Equation 4 using conditional quantile regression approach first proposed by Koenker and Bassett (1978). We refer to these as Conditional Quantile Treatment Effects (CQTE). The results are shown in Figure 11 in Appendix A.7. The CQTE show almost equal effects across quantiles, that is within groups of workers with different characteristics, wages have actually emerged quite similar across wage groups. Thus, the bulk part of the compression effects both at the lower and upper tail can be explained by a between-group compression effect. This means that workers with lower and higher skills have squeezed together in terms of wages, indicating that returns to skills decreased in reaction to the policy reform. The

result is in line with our theoretical predictions according to which a strong minimum wage bite lowers the returns to skills and, hence, depresses skill supply in a context where the negative scale effect dominates the positive substitution effect for skilled workers (see Sections 6 and 7).

Results Based on a Balanced Sample. Our findings might be driven by workers dropping out of employment and potentially re-entering employment in lower paid jobs. To rule out such explanations, we re-estimate our model in two versions: First, we restrict the sample to workers who stay in the same industry throughout the entire observation period. Second, we further restrict the sample to workers who stay in the same firm throughout. The results are shown in Table 11, Panels C.II-III and F.II-III in Section 5.3). The almost unchanged results (only slightly less significant for the highest quantile) suggest that our observed wage changes are not or only partly driven by workers re-entering from other industries. When restricting the sample to stayers within firms, the effects at the top decile become more insignificant, indicating that the overall negative effects on top-earners are partly driven by worker switching between firms within the industry.

5.3 Robustness

Placebo Tests. To test whether our UQTE in Figure 3 are contaminated by heterogeneous trends in treatment and control industries before the policy change, we conduct a placebo test. We restrict the data to the pre-reform years 1994-1995 and replace the $Post_t$ -dummy in Equation 4 with a linear time trend. The $Post_t \times D_i$ interaction effect informs us on potential differences in pre-treatment trends between treated and control industries (Panels A.I and D.I in Table 3). We do not find any differences in East Germany. The interactions are very close to zero and insignificant. In West Germany, instead, we do find significant but small differences in pre-trends. They point towards a worse trend in roofers' wages, indicating a downward bias in our estimated effects for West Germany. When extending the time-period to 1994-1996 and re-estimating the same model with a linear time trend, some of the effects in the East turn significant, although they remain very small (Panel A.II). Even if extrapolated to a time period of 10 years, these differences are still smaller than the estimated treatment effects by at least one order of magnitude in the East, whereas these differences are about the same order of magnitude as the estimated treatment effects in the West (Panel D.II).

These results indicate two things: Firstly, results for West Germany are biased by pre-trends and we likely underestimate the treatment effect in the West, which might explain the lack of wage increases at the bottom of the West-German wage distribution in our estimations, where the minimum wage should

Table 3: Robustness Checks for Unconditional Quantile Regressions in Figure 3

Dependent variable: log real daily wage							
	N	FE	Quantile Regression Estimates (RIF-FE)				
	(1)	(2)	$\tau = 0.1$	$\tau = 0.25$	$\tau = 0.5$	$\tau = 0.75$	$\tau = 0.9$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
High-bite (East Germany)							
A. Placebo tests on pre-reform years:							
I. Sample 1994-1995	91096	-0.00 (-2.46)	-0.01 (-1.30)	-0.00 (-0.61)	0.00 (1.58)	-0.01 (-1.20)	-0.01 (-0.90)
II. Sample 1994-1996	137635	0.00*** (5.14)	0.00 (1.06)	0.01*** (3.83)	0.01*** (8.93)	0.00 (1.72)	-0.00 (-0.45)
B. Dynamic specification (pre-reform year interactions):							
Interaction with 1995 dummy	471122	-0.00 (-2.03)	-0.01 (-2.20)	-0.00 (-0.72)	0.00 (1.50)	0.01 (2.54)	-0.01** (-3.02)
Interaction with 1996 dummy		0.01*** (5.59)	0.00 (0.51)	0.01*** (4.62)	0.02*** (8.97)	0.02*** (6.02)	-0.01 (-1.54)
C. Robustness of baseline model:							
Baseline model	471122	1.49*** (10.28)	4.66*** (18.80)	4.85*** (28.06)	2.07*** (12.00)	-2.87*** (-10.28)	-4.23*** (-9.16)
I. Assign 1996 to post-period	471122	2.16*** (11.64)	5.49*** (17.72)	6.32*** (29.20)	2.65*** (12.09)	-3.41*** (-9.54)	-4.31*** (-7.33)
II. Only stayers in industry	44096	2.04*** (4.75)	9.61*** (15.08)	6.75*** (13.43)	-0.13 (-0.23)	-6.39*** (-7.97)	-3.47* (-2.75)
III. Only stayers in firm	33703	2.43*** (4.69)	8.90*** (12.85)	7.63*** (13.25)	0.85 (1.20)	-7.88*** (-7.77)	-1.80 (-1.06)
IV. Only plumbers in control group	439460	1.98*** (13.28)	5.36*** (20.56)	5.42*** (30.50)	2.54*** (14.15)	-2.36*** (-8.28)	-4.05*** (-8.53)
Low-bite (West Germany)							
D. Placebo tests on pre-reform years:							
I. Sample 1994-1995	181405	-0.01*** (-13.19)	-0.01** (-2.84)	-0.01*** (-6.27)	-0.01*** (-5.74)	-0.01*** (-6.29)	-0.01*** (-3.77)
II. Sample 1994-1996	267343	-0.00*** (-8.05)	-0.00 (-2.03)	-0.01*** (-4.91)	-0.00 (-0.71)	-0.00*** (-4.40)	-0.01*** (-3.53)
E. Dynamic specification (pre-reform year interactions):							
Interaction with 1995 dummy	1141076	-0.01*** (-8.80)	-0.01*** (-3.45)	-0.01*** (-5.78)	-0.01*** (-6.86)	-0.01*** (-7.79)	-0.01*** (-4.36)
Interaction with 1996 dummy		-0.01*** (-4.65)	-0.00 (-1.64)	-0.00 (-1.71)	-0.00 (-1.93)	-0.01*** (-3.47)	-0.01* (-2.66)
F. Robustness of baseline model:							
Baseline model	1141076	-0.11 (-1.19)	-0.64*** (-3.34)	-0.24 (-1.78)	0.07 (0.66)	0.41** (3.22)	0.51 (2.11)
I. Assign 1996 to post-period	1141076	-0.17 (-1.11)	-0.63 (-1.96)	-0.23 (-1.05)	0.15 (0.85)	0.36 (1.80)	0.02 (0.05)
II. Only stayers in industry	216750	0.52*** (3.51)	1.05*** (3.31)	0.66** (3.11)	1.00*** (6.35)	0.26 (1.25)	-0.43 (-1.06)
III. Only stayers in firm	176896	0.36 (2.20)	0.71 (2.00)	0.52 (2.18)	0.90*** (4.99)	0.18 (0.76)	-0.40 (-0.86)
IV. Only plumbers in control group	1042950	-0.38*** (-3.89)	-1.02*** (-5.07)	-0.76*** (-5.56)	-0.18 (-1.60)	0.31 (2.35)	0.67* (2.61)

Notes: t-statistics in parentheses. Significance levels: * 5%, ** 1%, *** 0.1%. All models include individual fixed effects as well as several individual and firm-specific covariates (see Equation 4) and are estimated with robust standard errors clustered by individuals. Placebo tests in Panels A and D show regressions of the outcome variable on treatment status, time trend and their interaction, based on pre-treatment years 1994-1995 (Placebo I) and 1994-1996 (Placebo II). Panels B and E present a dynamic specification of Equation 4 with treatment, year dummies and their interactions and where only the coefficients of the pre-treatment years are reported here (all relative to 1994). Coefficients reflect the impact of the minimum wage introduction on wages (in percent).

bite. Secondly, there are no differences in the Eastern pre-trends but there is anticipation behavior – firms slightly adjusted wages already in the year before the actual introduction of the minimum wage in 1997.

We therefore test the robustness of our results to defining 1996 as a treatment year – all results remain robust in the East and effect sizes remain very similar (Panel C.I). This is not surprising, given that the adjustments in 1996 were tiny. Accordingly, the results for East Germany are not contaminated by these anticipation effects.

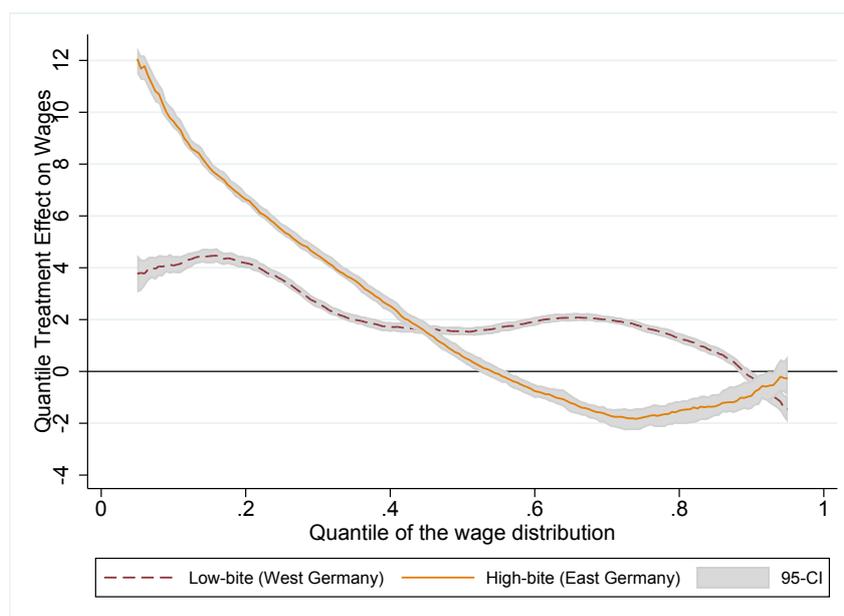
Dynamic Treatment Effects. As an alternative test for pre-trends, we estimate dynamic UQTEs by replacing our $Post_t$ variable and treatment interaction in Equation 4 with a full set of year dummies and year-treatment-interactions. The results are depicted until 1996 in Table 3, for the full set of interactions see Figure 9 in the appendix. All effects are estimated relative to our starting year 1994.¹⁹ In East Germany, there are no differences in 1995 (except for a small difference in the top quantile), but we again find indications for anticipation behavior in 1996, the year before the introduction of the minimum wage (Panel B). Firms apparently adjusted wages upward already before the minimum wage was formally in place, but these differences are small: extrapolated over a time period of 10 years, they are smaller by at least one order of magnitude compared to the estimated treatment effects. This is reflected in the fact that our results are remarkably robust to defining 1996 as a treatment year (Panel C.I).

In West Germany, we find significant differences in pre-treatment year 1995 (Panel E), although these are small compared to the estimated treatment effects. A closer inspection of the year-treatment-interactions for West Germany (see Figure 9 in the Appendix) reveals that there is no clear break in these interactions after the introduction of the minimum wage – the interactions fluctuate around zero across the whole time period for all quantiles. Accordingly, we do not find a clear effect of the minimum wage on the West German wage distribution, in line with the relatively small bite of the West German minimum wage (see Table 2). For East Germany, the interaction effects in Figure 9 in the Appendix instead reflect the results from Table 3. This assures us that the compression effect at upper wage quantiles in East Germany reflects the causal impact of the minimum wage reform, whereas the reform had no clear effect on the West German wage distribution.

Alternative Control Industry. Generally, the selection of our control industries is based on a detailed preliminary analysis where initially no industry was excluded. Both plumbers and glaziers turned out to show large commonalities to the roofing industry (compared to any other untreated industry, see Section 3.2). In our preferred baseline specification, we thus pool both plumbers and glaziers to a control industry. Nevertheless, the main findings are also robust whenever comparing roofers to plumbers (see Robustness

¹⁹Appendix Figure 10 illustrates wage gaps between treatment and control industries across the quantiles and years.

Figure 4: Minimum Wage Effects on the Unconditional Real Daily Wage Distribution Based on the Changes-in-Changes (CiC) Model



Notes: The figures show estimates from Athey and Imbens (2006)'s Changes-in-Changes estimator by East and West Germany. All models include several individual and firm-specific covariates. 95% confidence intervals are based on bootstrapped standard errors using 100 replications. Quantile treatment effects reflect the impact of the minimum wage introduction on wages (in percent). Only estimates for quantiles between $\tau \geq 0.05$ and $\tau \leq 0.95$ shown.

IV in Table 3), with few exceptions:²⁰ For East Germany, our results are robust to using plumbers, only. The effect sizes change slightly, but the results remain robust. For West Germany, results are more sensitive to the choice of the control industry, reflecting the potential problems discussed before (placebo tests, dynamic treatment effects). In line with our previous findings, there is no clear evidence on the effects of the minimum wage on the West German wage structure, whereas results for East Germany are clear and robust. Note that the main results are also largely confirmed when using the painters as an alternative control industry.²¹

Changes-in-Changes. As a further check, we estimate the QTE based on the changes-in-changes model proposed by Athey and Imbens (2006). Besides other, the main advantage over our unconditional quantile regression estimator is that it allows to identify unconditional quantile treatment effects under the less stricter assumption that treated and control industry experienced common changes as composed to common trends. The results in Figure 4 report, in contrast to our UQTE estimations, positive wage effects at lower quantiles in West Germany (4% at $\tau=0.1$) reinforcing the indications from our placebo

²⁰We do not use glaziers separately as a control group because they are too small.

²¹We do not show the results here, as painters introduced a minimum wage in 2003, which might have contaminated the results. Nevertheless, this gives further assurance that our results are robust to alternative control industries.

tests towards a downward bias in the baseline estimations in the West. For East Germany, however, the results confirm our baseline findings of the UQTE, despite some differences in magnitudes: the negative wage effect at the top of the wage distribution in East Germany is somewhat smaller (1.8% at $\tau=0.75$ and 1% at $\tau=0.9$), whereas the positive effect is larger (9.6% at $\tau=0.1$).

6 Minimum Wage Effects on Total and Skill-Specific Employment

6.1 Empirical Approach

The positive wage effects at the bottom of the wage distribution as well as the positive wage spillovers for workers with earnings just above the minimum wage in East Germany can be explained by existing minimum wage theories outlined in the introduction. However, existing theories leave the negative minimum wage effects at the top of the East German wage distribution unexplained. Section 2 introduces a labour market model with labour-labour substitution and a scale effect to explain how spillover effects can turn negative at the top of the distribution. In particular, our theory predicts that a minimum wage driven increase in labour costs for low-skilled workers induces a cost-shock that causes the industry to shrink – with negative effects on all workers (Proposition 1). The increase of low-skilled workers' wages induces firms to substitute low- for medium-skilled workers due to the change in relative input prices (Proposition 2). High-skilled workers do not benefit from substitution effects, as their tasks are not suitable substitutes to low-skilled workers' tasks, in line with the existing literature which finds spillover effects to fade out quickly with rising earnings. On net, employment of high-skilled workers decreases, whereas the employment effect on medium-skilled workers is ambiguous, depending on the relative size of the scale and substitution effect (Proposition 3).

To test these predictions, we decompose the minimum wage effect on high-skilled employment (H) (net effect) into the effect on the high-skilled employment share (substitution effect) and the effect on total employment (scale effect) as follows:

$$\underbrace{\frac{\partial \ln H}{\partial \ln w_{MW}}}_{\text{net employment effect}} = \underbrace{\frac{\partial \ln \left(\frac{H}{L+M+H} \right)}{\partial \ln w_{MW}}}_{\text{substitution effect}} + \underbrace{\frac{\partial \ln(L+M+H)}{\partial \ln w_{MW}}}_{\text{scale effect}} \quad (5)$$

We proceed analogously for low- (L) and medium- (M) skilled workers. To estimate the respective effects, we follow a regional DiD approach, since we are interested in aggregate rather than individual-level outcomes here. To prepare the data, we proceed in two steps:

First, we create a continuous skill measure to classify workers. Similar to other studies (e.g. Combes

et al. 2008), we define skills as all fixed individual attributes which are rewarded on the labour market. To estimate these, we use the individual-level BA data and conduct an individual-level regression of the log daily wages on a set of dummies for year, industry, east, industry-year and east-year interactions as well as individual-level fixed effects. From this regression, we extract the time-constant individual fixed effect for each individual, which we define as an individuals' skill level. We then rank individuals based on this skill distribution by East/West and industry and define three equal-sized tertiles, representing low-, medium- and high-skilled workers. Note that our core findings are robust to using different skill measures including education levels (see Section 6.3).

In a second step, we compute figures on employment and average wages for the total workforce and each skill group.²² We compute these figures at the level of local labour markets (henceforth referred to as regions) for each industry and year between 1994-2008. We use the definition of 150 local labour market proposed by Eckey et al. (2006), which defines regions as places where people live and work, based on commuting patterns (see Appendix A.8 for a corresponding spatial map).

Based on this region-industry panel, we then estimate the minimum wage effect on our outcome variable (Y_{jt}) in region r , industry j , and year t as follows:

$$\ln Y_{jrt} = \alpha + \beta \text{Bite}_{ejt} + \eta_t^{\text{post}} + \theta_{e \times t}^{\text{post}} + \nu_{rj} + \varepsilon_{jrt} \quad (6)$$

where Bite_{ejt} is our treatment measure. As treatment, we use the Kaitz-Index that equals the minimum wage level w_{ejt}^{MW} divided by the median wage w_{ejt}^{p50} for individuals from the treated industry during the post-reform period (years 1997-2008) and zero otherwise, see Table 2. We further control for post-reform year dummies η_t^{post} as well as as interactions with East and West Germany $\theta_{e \times t}^{\text{post}}$ to control for any other trends related to both parts of the country. The term ν_{rj} represents industry-region fixed effects. The parameter β then captures the effect of an increase in the minimum wage bite (including its largest increase from zero after the minimum wage introduction). We use skill-specific employment shares, overall employment as well as skill-specific net employment as outcome variables to estimate the substitution, scale and net effects from Equation 6. To account for size differences between regions, regressions are weighted by (skill-specific) regional employment in pre-treatment years.²³ Following Bertrand et al. (2004), we report robust standard errors clustered by region in our results tables to account for serial correlation.

Note that for the treated industry, the bite varies only between East and West Germany (index e) as

²²We also conducted regressions based on a sample of only full-time workers, which yields comparable results.

²³Our dependent variable is in logs, which implies that our treatment effect represents effects on change rates or growth rates. We weight by regions' initial sizes to take into account size differences between regions.

well as by post-reform years (we essentially take the values from Table 2).²⁴ This way we exploit the institutional differences in the minimum wage reform while precluding any endogenous regional variation in the bite. Using the bite instead of a post-reform dummy further allows us to pool East and West Germany into a single regression and exploit the differences in the size of the bite to estimate the effects of the reform. Pooling the data also helps prevent small sample sizes, especially in East Germany.²⁵ However, we test the robustness of our approach to splitting the sample into East and West Germany and using a dummy-treatment instead of a continuous treatment, as before, see Section 6.3.

Identification comes from comparing local outcomes between treated and control industry before and after the minimum wage. The main difference to the approach in Section 5 is that we compare industries across regions and time instead of individuals (by quantile), since we are interested in aggregate industry effects here. Otherwise, the identification assumptions are similar (see Section 5.1). In particular, we assume that treated roofers and untreated plumbers and glaziers would have experienced the same changes in outcomes on a local labour market level, had the minimum wage not been introduced. In Section 6.3, we show that treatment and control industries follow largely the same trends before the reform.

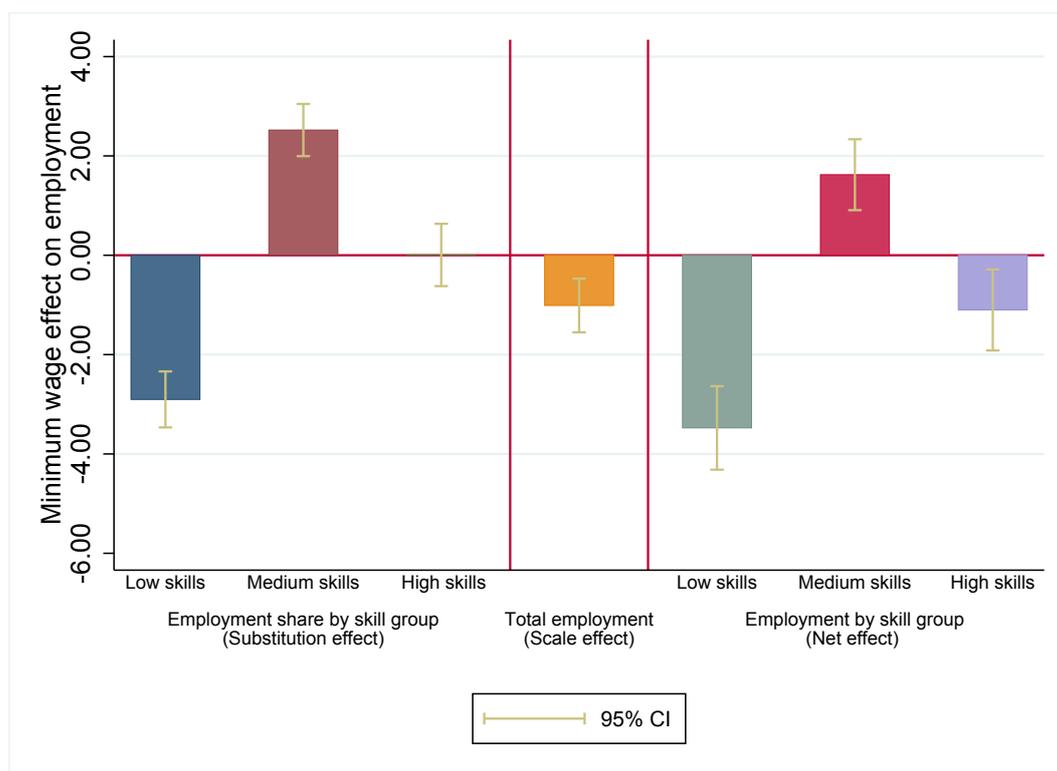
6.2 Results

The results for the substitution and scale effect are shown in Figure 5 and can be interpreted as percentage changes in employment (shares) as a result of a 10 percentage points increase in the minimum wage bite. Our regional regressions suggest a substantial substitution of low- (-2.9%) by medium-skilled workers (+2.5%), whereas the share of high-skilled workers is unaffected by the minimum wage. The finding is in line with our theoretical predictions (and other minimum wage studies, see introduction) according to which medium-skilled workers provide close substitutes for low-skilled ones, whereas high-skilled workers do not. The relatively large substitution effect among medium-skilled workers potentially reflects the strong minimum wage bite in the industry, which required substantial adjustments within firms in order to cope with minimum wage induced cost increases. However, these positive substitution effects are counteracted by the negative scale effect, which has so far been largely neglected in other studies. In particular, we find a substantial decline in overall employment (-1%) resulting from overall increased labour costs (and falling firm revenues, see Appendix A.11), such that the net impact on high-skilled

²⁴Note that by dividing the next subsequent minimum wage by the contemporaneous median wage, we also receive values for periods with a gap (where the minimum wage was shortly suspended, see Figure 6 in Appendix A.2).

²⁵We do not pool East and West Germany in our quantile regressions for two main reasons. First, the wage structures significantly differ between East and West Germany, which creates large obstacles for quantile regressions. Differences in wages structures do not matter at the regional level as we focus on the overall level of employment (and wages) as well as skill-specific regional outcomes, where the definition of skills takes account of the level differences. Second, we do not face any challenges with sample size in the quantile regression approach that relies on the individual-level version of our data.

Figure 5: Minimum Wage Effects on Total Employment (Scale Effect) and Skill-Specific Employment Share (Substitution Effect)



Notes: The figures show regional estimates of skill-specific employment shares, total employment and skill-specific absolute employment based on region-industry-year cells between 1994-2008 according to Equation 6. All models include industry-region fixed effects, post-reform year dummies and interactions with East/West Germany. Regressions are weighted by regional (skill-specific) employment in pre-treatment years. Whiskers mark the 95 percent significance interval. Robust standard errors clustered by region. Figures reflect the impact of a 10 percentage points increase in the minimum wage bite. Detailed regression tables are shown in Table 4.

workers is negative (-1.1%). For medium-skilled workers, the positive substitution effects suffices to overcompensate the negative scale effect, resulting in a net positive employment effect for these workers (+1.6%). For low-skilled workers, the scale effect even enforced the negative substitution effect (on net, -3.5%).

The above findings are in line with our labour-labour substitution-scale model and are able to explain the compression of wages at the highest quantiles in East Germany that we demonstrated in the previous section. In particular, it is the substitution of workers away from low- to higher skilled workers that fades out with rising skills. Since the scale effect is negative and large enough, the resulting net labour demand effect on high-skilled workers is negative, causing, ultimately, the downward pressure on wages of top earners. These adjustments are only effective whenever the bite of minimum wage is sufficiently large, as in the case of East Germany.

Firm Revenues. To provide more evidence on the negative scale effect, which is crucial in explaining our findings, we estimate the minimum wage effect on regional revenues (firm averages, industry totals as well as firm averages per worker) based on Equation 6. The data on firm revenues is calculated from separate micro data for all active firms in Germany. The details of the data set together with the results are presented in Appendix A.11. Accordingly (compare Table 8), a 10 percentage points increase in the minimum wage bite caused lower total industry revenues (-2.8%), average firm revenues (-3.1%) as well as revenues per worker (-3.6%). Overall, the results confirm a negative aggregate demand shock.

6.3 Robustness

Placebo tests. To test for differences in trends between treatment and control industries before the introduction of the minimum wage, we follow the approach analogous to Section 5.3. That is, we restrict the sample to pre-reform years and regress our regional outcomes on a time trend, its interaction with treatment D_i – which takes the value one for treated roofers and zero for untreated plumbers and glaziers– as well as region-industry fixed effects. Panel A.I in Table 4 shows the results when focusing on the pre-treatment years 1994-1995, Panel A.II for the years 1994-1996. For some of the outcome variables, particularly for the substitution effects, we find some evidence for differences in pre-trends, although these are small compared to the treatment effects: Even when extrapolating these trends to a time-period of 10 years, these differences are still smaller by one order of magnitude than the treatment effects. In addition, the effects – similar to the effects along the wage distribution – point towards anticipation effects in 1996. The effects mostly disappear when treating 1996 as a treatment year, and our estimated treatment effects are robust to assigning 1996 as a treatment year (Panel C). Firms apparently adjusted before the official introduction of the minimum wage, although these adjustments are small.

Dynamic treatment effects. As an alternative test for differences in trends before the introduction of the minimum wage in the regional approach, we proceed analogous to our placebo tests, but replace the time trend (baseline and interactions with treatment) with a full set of year dummies and extend the regression to the entire observation period again. If there are no pre-treatment trends, the interaction effects for pre-treatment years should be zero. Results are shown in Panel B of Table 4 for our three skill groups (for a visualization of the full set of interactions, see Figure 13 in the appendix). The results confirm our placebo tests: There is evidence for anticipation behavior in 1996, whereas in 1995 most interactions are zero (all relative to 1994). Any deviations are small, especially when compared to the estimated treatment effects – if differences in pre-trends bias our results, these biases are small compared

to the size of the estimated effect. Figure 13 in the appendix further highlights that effects are close to zero before the reform, but grow thereafter, and in particular the effects jump whenever there was a significant increase in the minimum wage. To test the robustness of our results to the indication of anticipation behavior, we re-assign 1996 as a treatment year, similar to the quantile regressions in Section 5.3. Our results are robust to re-assigning those years to the post-reform period (see Panel C in Table 4).

Estimates by East and West Germany. Although we pool East and West Germany in our regional-level estimations for reasons of sample size and to stress the role of the bite, we test the robustness of our results to splitting the data into East and West Germany (see Figure 14 in the Appendix A.9). Standard errors increase due to the smaller samples for East and West, as expected, but the overall picture remains, particularly for East Germany, where the bite was large.

Alternative control industries. Similar to Section 5.3, we also test our results against using only plumbers as a control industry. Results in Table 13 confirm our baseline findings when using only plumbers (Panel C). We do not use only glaziers as a control industry because the aggregate regional employment figures would be based on partly very few observations due to the small sample size, inducing potentially large biases.

Wage effects by skill group. To test whether the regional level approach resembles the quantile regression estimates for wages in Section 5, we estimate Equation 6 using skill-specific average regional wages as the dependent variable. The results in Figure 15 in the appendix resemble the quantile regression results in Section 5. In particular, they demonstrate that an increase of the minimum wage bite (Kaitz index) by 10 percentage points led to a wage increase among low-skilled workers by 0.48%, whereas high-skilled workers experienced wage reductions of 0.28%. Note that the minimum wage bite in the East increased up to 100 percentage points, which corresponds to wage increases for low-skilled workers of 4.8% and real-wage reductions of 2.8% for high-skilled workers. These numbers are remarkably close to the corresponding findings from our quantile regressions for East Germany, which again strengthens the robustness of the quantile regressions in Section 5.

Alternative skill groups. We check the robustness of our results to the choice of our skill measure. As our alternative skill measure, we use education defined as follows: without apprenticeship training (low-skills); with apprenticeship training (medium skills); with apprenticeship and at least 6 years of work experience or a master craftsmen degree (high skills). Results of the baseline model with this

Table 4: Substitution and Scale Effect by Skill Group as shown in Figure 5

Skills:	N	Sub effect			Scale effect	Net effect		
	(1)	Low (2)	Medium (3)	High (4)	All (5)	Low (6)	Medium (7)	High (8)
A. Placebotests on pre-reform years								
I. Sample 1994-1995	900	0.01 (0.68)	0.01** (2.43)	-0.01** (-2.08)	-0.00 (-0.18)	0.00 (0.09)	0.01 (1.38)	-0.02* (-1.91)
II. Sample 1994-1996	1350	-0.02*** (-2.94)	0.02*** (4.99)	-0.00 (-0.21)	-0.01 (-1.20)	-0.02 (-1.60)	0.01 (0.79)	-0.01 (-1.47)
B. Dynamic specification (pre-reform year interactions)								
Interaction with 1995 dummy	6750	0.01 (0.68)	0.01** (2.43)	-0.01** (-2.08)	-0.00 (-0.18)	0.00 (0.09)	0.01 (1.38)	-0.02* (-1.91)
Interaction with 1996 dummy		-0.04*** (-2.94)	0.04*** (4.98)	-0.00 (-0.21)	-0.02 (-1.19)	-0.04 (-1.60)	0.01 (0.79)	-0.02 (-1.47)
C. Robustness of baseline model:								
Baseline model	6750	-2.90*** (-10.18)	2.52*** (9.48)	0.01 (0.02)	-1.01*** (-3.69)	-3.48*** (-8.17)	1.62*** (4.49)	-1.10*** (-2.66)
Assign 1996 to post-reform period	6750	-0.08 (-0.16)	1.92*** (8.66)	-2.06*** (-7.93)	-2.55*** (-9.63)	-2.58*** (-7.18)	-0.73 (-1.65)	-4.76*** (-10.38)
Only plumbers in control group	4500	-3.13*** (-11.04)	2.59*** (9.20)	0.07 (0.21)	-1.36*** (-4.92)	-4.15*** (-9.44)	1.31*** (3.45)	-1.39*** (-3.21)
D. Skill groups:								
Alternative skill measure	6648	-3.44*** (-4.50)	0.96*** (8.33)	-0.02 (-0.04)	-1.01*** (-3.69)	-2.37*** (-3.56)	-0.14 (-0.48)	-1.07** (-2.02)

Notes: t-statistics in parentheses. Robust standard errors clustered by region. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects, post-reform year dummies as well as their interactions with East/West. Substitution and scale effects are weighted with pre-treatment regional employment. Net effects are weighted with pre-treatment region-skill-specific employment. Placebo tests in Panels A show regressions of the outcome variable on treatment status, time trend and their interaction, based on pre-treatment years 1994-1995 (Placebo I) and 1994-1996 (Placebo II). Panels B present a dynamic specification of Equation 4 with treatment, year dummies and their interactions and where only the coefficients of the pre-treatment years are reported here (all relative to 1994). Results in Panel C reflect the impact of a 10 percentage points increase in the minimum wage bite. Panel D shows a specification where workers are defined as follows: without education (low-skills); with education (medium skills); with education and at least 6 years of work experience or a master craftsmen degree (high skills).

alternative skill measure are shown in Panel D of Table 4. Overall, they confirm our results, except that the substitution from low- to medium skilled workers is now smaller, so that the net effect of medium skills workers is near zero and insignificant compared to positive baseline effect for this group at baseline.

7 Minimum Wage Effects on Skill Supply

In Section 5, we have shown that the minimum wage introduction led to a wage compression at both ends of the wage distribution in East Germany. We have also demonstrated that the bulk part of this compression is explained by a between- rather than within-group compression effect. This means that workers with lower and higher skills have been squeezed together in terms of wages. This suggests reduced returns to skills in high-bite East Germany, whereas no large changes in low-bite West Germany. In the present section, we now test the wider implications for skill supplies in the industry.

According to our theoretical model, we expect (A) an increase in the entrance of medium- relative

to low-skills (Corollary 1), as firms restructure towards medium-skilled workers due to the minimum wage-induced change in relative wages. Moreover, we expect (B) a decline in the supply of high- relative to medium-skills, as high-skilled workers do not profit from substitution effects, while at the same time suffering from a scale effect and, hence, declining returns to skills (Corollary 1). Moreover, as before, we expect the effects to rise with the minimum wage bite.

To test these predictions, we follow a similar regional DiD approach as described in Section 6. In particular, we estimate the effect of the minimum wage on: (A) the share of new apprentices among all entrants, as a proxy for medium-skilled entrants and (B) the share of apprentices with the highest school degree (i.e. high-school degree) to capture high-skilled entrants. Entrants are defined in our data as workers that have no prior working experience in the industry. Trainees can be identified separately in the data via an indicator on workers' occupational status.²⁶

Table 5 shows the results. Our estimates are weighted to account for differences in the size of regions (see table notes). All effects are percentage changes in reaction to a 10 percentage points increase in the minimum wage bite. Starting with our measure for the entrance of medium-relative to low-skills: We find an increase in medium-skilled entrants in the industry (Column 1), reflecting the rise in the relative demand for medium-skilled workers. However, the quantitative size of the effect (+0.47%) is smaller compared to the increase in relative demand (+2.52%) found in Table 3. One reason for this gap could be that our dependent variable (share of new apprentices among all entrants) provides only a proxy for medium-skills, leading to an underestimation of medium-skilled entrants' increase. Another reason could be that firms restructure towards medium-skilled workers not only via hiring relatively more medium-skilled workers, but also via a higher separation rate among low-skilled workers.²⁷

Turning to our measure for the entrance of high relative to medium skills: In line with our predictions, we find a decline in high-skilled workers entering the industry (-9.09%) in response to the minimum wage (Column 2). This finding reflects the reduced real wages of high-skilled workers and returns to skills, which reduced the incentives for high-skilled workers to enter the industry. This might also explain why the industry faced increasing problems in attracting high-skilled workers in the aftermath of the policy reform, as reported by Aretz et al. (2011), or the observed increase in solo self-employment (in search for alternative income perspectives) found by Ganserer et al. (2021). The effect size is large and suggests that the decline in high-skilled employment in the industry is mostly explained by a sharp decline in

²⁶Note that we would ideally classify entrants into low-, medium-, and high-skilled workers by identifying their skills from individual fixed effects, as before. This is unfortunately not possible, because these workers did not yet work in the industry so that we cannot obtain their skills as fixed effects from a wage regression.

²⁷In fact, complementary work confirms this explanation by showing that the minimum wage significantly increased the separation rate of low-skilled workers in East Germany (Aretz et al., 2013).

Table 5: Minimum Wage Effects on Industry Skill Supply

	Share of all worker entrants to the treated industry:	
	Medium-skilled (1)	High-skilled (2)
Minimum wage bite	0.47*** (4.46)	-9.09** (-2.39)
N	6741	6672

Notes: t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. Figure shows estimates of Equation 6 using the share of apprentices among all entrants (Column 1) and the share of apprentices with high-school degree among all entrants (Column 2) as outcome variables. All estimates include industry-region fixed effects. Model in Column 1 is weighted with pre-treatment number of entrants, whereas Column 2 is weighted by the pre-treatment number of apprentices. Robust standard errors are clustered by region.

high-skilled entrants and less so by the exit of high-skilled workers. This is in line with the fact that skills are highly industry-specific, preventing mobility of workers between industries.

8 Conclusion

We investigate the impact of a minimum wage on workers' wages, returns to skills and skill supply in light of a particular interesting case where the minimum wage really bites hard: For institutional reasons, Germany introduced its first minimum wages in 1997 only in parts of the German construction sector, including the German roofing industry. There, the minimum wage was subsequently raised several times. According to the Kaitz Index, the bite of the minimum wage in East Germany has to be considered exceptionally high by international standards. In addition, the minimum wage was introduced during a long-lasting period of an economic downturn with falling revenues, which tends to require further adjustments among firms. This setting is of particular interest against the background of internationally rising minimum wages (see Figure 7 in Appendix A.3), in combination with an economic downward trend currently observed around the globe. Based on our quasi-experimental setting that allows us to identify the causal impact of the minimum wage on wages and employment along different wage and skill groups, we draw several conclusions for the understanding of minimum wages:

First, a minimum wage may induce positive wage spillovers to workers with wages slightly above the minimum wage. For the investigated industry, we find significant real daily wage increases of up to about 6% for lower-quantile workers that ripple up to the 60th quantile in high-bite East Germany

between 1997 and 2008. We explain these findings within a substitution-scale model that predicts a shift in labour demand towards medium-skilled workers in response to the minimum wage-induced change in relative input prices. Thus, the policy seems to have met its goal of improving the earnings of low-wage workers (at least for those, who did not lose their job due to the minimum wage) and reducing overall wage inequality.

Second, a minimum wage can reduce the earnings of high-skilled workers. According to our estimates, the minimum wage caused a reduction in real daily wages of up to about 5% in East Germany for the highest quantiles (stagnating nominal wages) that mostly comprise skilled and experienced workers. We show that this striking finding is in line with our substitution-scale model that predicts negative spillovers whenever the negative scale effect dominates the positive substitution effect, such as in an economic downturn with falling demand (and revenues) in combination with an increasing minimum wage bite. For medium-skilled workers in our investigated industry, these negative scale effects were overcompensated by positive substitution effects, resulting in a net positive impact on wages and employment. High-skilled workers, however, did not profit from positive substitution effects, as their tasks are not suitable substitutes to low-skilled minimum wage workers, resulting in a net negative impact of employment and wages. The proposed mechanism may be a missing link in explaining negative spillovers from minimum wage policies, especially during an economic downturn.

Third, a minimum wage may hamper skill supply. Our results suggest that the minimum wage has worsened the selection of workers into the industry. In particular, we find a positive effect on medium-skilled entrants, whereas our estimates suggest a negative effect on high-skilled entrants. Our substitution-scale model explains this with deteriorating wage and employment perspectives of high- relative to medium-skilled workers, leading to lowered returns to skills in the industry. Deteriorating returns to observable skills are also reflected by the fact that our observed upper-tail wage-compression effect is solely driven by a reduction in between-group inequality. The results may explain reports by industry insiders according to which the industry is facing increasing problems in attracting high-skilled workers.

Fourth, a high minimum wage level (relative to the median wage) is important in triggering unfavourable adjustments. In East Germany, where the Kaitz-index rose from 0 to 100 between 1997-2008, we find large wage and employment effects across all skill groups. In contrast, we hardly find any such effects for West Germany, where the bite was much lower, i.e. the Kaitz-index reached much smaller values of 72 percent. This is in line with a large literature that focuses on incremental increases of minimum wages and finds no or only modest unemployment effects. Even the first-time introduction of the general

German minimum wage – which had a bite of around 57% and was introduced in a boom-phase – was associated with only moderate disemployment effects (Caliendo et al., 2018). Accordingly, minimum wages appear to have unfavourable side effects only if they are set too high, such as in our case of East Germany. This is particularly relevant against the background of rising minimum wages in many countries (see Figure 7 in Appendix A.3).

Finally, our work may have further implications beyond wages, employment and returns to skills. In particular, our complementary work (see Ganserer et al., 2021) suggests that solo self-employment (as one type of alternative work arrangement that is on the rise worldwide, see Boeri et al., 2020) significantly increased in German industries that introduced a minimum wage in the 1990s (we also show this for the roofing industry). As suggested by our companion work, the increase in solo self-employment, which for institutional reasons in German craft industries is driven by high-skilled workers, could reflect a further consequence of the deteriorating wage and employment perspectives of high-skilled workers in reaction to the minimum wage, as demonstrated here.

References

- Acemoglu, D. and Pischke, J.-S. (1999). The structure of wages and investment in general training. *Journal of Political Economy*, 107(3):539–572.
- Acemoglu, D. and Pischke, J.-S. (2003). Minimum wages and on-the-job training. *Research in Labor Economics*, 22:159–202.
- Apel, H., Bachmann, R., Bender, S., vom Berge, P., Fertig, M., Frings, H., König, M., Paloyo, A., Schaffner, S., Tamm, M., et al. (2012). Arbeitsmarktwirkungen der Mindestlohneinführung im Bauhauptgewerbe. *Journal for Labour Market Research*, 45(3-4):257–277.
- Aretz, B., Arntz, M., Gottschalk, S., Gregory, T., Niefert, M., Rammer, C., Schröder, H., and Schütz, H. (2011). ZEW-Studie zu den Wirkungen eines Mindestlohns in der Dachdeckerwirtschaft. Research report for the Federal Ministry of Labour and Social Affairs.
- Aretz, B., Arntz, M., and Gregory, T. (2013). The minimum wage affects them all: Evidence on employment spillovers in the roofing sector. *German Economic Review*, 14(3):282–315.
- Arulampalam, W., Booth, A. L., and Bryan, M. L. (2004). Training and the new minimum wage. *Economic Journal*, 114:C87–C94.
- Athey, S. and Imbens, G. (2006). Identification and inference in nonlinear difference-in-differences models. *Econometrica*, 74(2):431–497.
- Autor, D. H., Manning, A., and Smith, C. L. (2016). The contribution of the minimum wage to u.s. wage inequality over three decades: A reassessment. *American Economic Journal: Applied Economics*, 8:58–99.
- Baldwin, R., Forslid, R., Martin, P., Ottaviano, G., and Robert-Nicoud, F. (2003). *Economic Geography and Public Policy*. Princeton University Press.
- Bertrand, M., Duflo, E., and Mullainathan, S. (2004). How much should we trust differences-in-differences estimates? *The Quarterly journal of economics*, 119(1):249–275.

- Boeri, T., Giupponi, G., Krueger, A. B., and Machin, S. (2020). Solo self-employment and alternative work arrangements: A cross-country perspective on the changing composition of jobs. *Journal of Economic Perspectives*, 34(1):170–195.
- Caliendo, M., Fedorets, A., Preuss, M., Schröder, C., and Wittbrodt, L. (2018). The short-run employment effects of the german minimum wage reform. *Labour Economics*, 53:46–62.
- Cengiz, D., Dube, A., Lindner, A., and Zipperer, B. (2019). The effect of minimum wages on low-wage jobs. *Quarterly Journal of Economics*, 134(3):1405–1454.
- Combes, P.-P., Duranton, G., and Gobillon, L. (2008). Spatial wage disparities: Sorting matters! *Journal of Urban Economics*, 63(2):723–742.
- Couch, K. A. and Wittenburg, D. C. (2001). The response of hours of work to increases in the minimum wage. *Southern Economic Journal*, pages 171–177.
- Dickens, R. and Manning, A. (2004). Has the national minimum wage reduced uk wage inequality? *Journal of the Royal Statistical Society Series A*, 167(4):613–626.
- Dube, A., Giuliano, L., and Leonard, J. (2018). Fairness and frictions: the impact of unequal raises on quit behavior. *American Economic Review*, 109:620–663.
- Eckey, Kosfeld, and Türck (2006). Abgrenzung deutscher arbeitsmarktregionen. *Raumforschung und Raumordnung*, 64:299–309.
- Fairris, D. and Bujanda, L. (2008). The dissipation of minimum wage gains for workers through labor-labor substitution: Evidence from the Los Angeles living wage ordinance. *Southern Economic Journal*, 75(2):473–496.
- Fairris, D. and Pedace, R. (2004). The impact of minimum wages on job training: An empirical exploration with establishment data. *Southern Economic Journal*, 70(3):566–583.
- Falk, A., Fehr, E., and Zehnder, C. (2006). Fairness perceptions and reservation wage - The behavioral effects of minimum wage laws. *Quarterly Journal of Economics*, 121(4):1347–1381.
- Firpo, S., Fortin, N. M., and Lemieux, T. (2009). Unconditional quantile regressions. *Econometrica*, 77(3):953–973.
- Ganserer, A., Gregory, T., Murmann, S., and Zierahn, U. (2021). Minimum wages and solo self-employment. *Unpublished*.

- Giuliano, L. (2013). Minimum wage effects on employment, substitution, and the teenage labor supply: Evidence from personnel data. *Journal of Labor Economics*, 31(1):155–194.
- Gopalan, R., Hamilton, B. H., Kalda, A., and Sovich, D. (2020). State minimum wages, employment, and wage spillovers: Evidence from administrative payroll data. *State Minimum Wages, Employment, and Wage Spillovers: Evidence From Administrative Payroll Data (Mar 1, 2020)*. *Journal of Labor Economics*, Forthcoming.
- Gramlich, E. M., Flanagan, R. J., and Wachter, M. L. (1976). Impact of minimum wages on other wages, employment, and family incomes. *Brookings Papers on Economic Activity*, 1976(2):409–461.
- Grossberg, A. J. and Sicilian, P. (1999). Minimum wages, on-the-job training, and wage growth. *Southern Economic Journal*, 65(3):539–556.
- Grossman, J. (1983). The impact of the minimum wage on other wages. *Journal of Human Resources*, 18(3):359–378.
- Hashimoto, M. (1982). Minimum wage effects on training on the job. *American Economic Review*, 72(5):1070–1087.
- Havnes, T. and Mogstad, M. (2015). Is universal child care leveling the playing field? *Journal of public economics*, 127:100–114.
- Koenker, R. W. and Bassett, G. W. (1978). Regression quantiles. *Econometrica*, 46(1):33–50.
- Lechthaler, W. and Snower, D. J. (2008). Minimum wages and training. *Labour Economics*, 15:1223–1237.
- Lee, D. S. (1999). Wage inequality in the United States during the 1980s: Rising dispersion or falling minimum wage? *Quarterly Journal of Economics*, 114(3):977–1023.
- Machin, S., Manning, A., and Rahman, L. (2003). Where the minimum wage bites hard: Introduction of minimum wages to a low wage sector. *Journal of the European Economic Association*, 1(1):154–180.
- Manning, A. (2003). *Monopsony in motion: Imperfect competition in labor markets*. Princeton University Press.
- Melitz, M. J. (2003). The impact of trade on intra-industry reallocation and aggregate industry productivity. *Econometrica*, 71(6):1696–1725.

- Neumark, D., Schweitzer, M., and Wascher, W. (2004). Minimum wage effects throughout the wage distribution. *Journal of Human Resources*, 39(2):425–450.
- Neumark, D. and Wascher, W. (2001). Minimum wages and training: Revisited. *Journal of Labor Economics*, 19(3):563–595.
- Neumark, D. and Wascher, W. (2008). *Minimum wages*. MIT Press.
- Pereira, S. C. (2003). The impact of minimum wages on youth employment in portugal. *European Economic Review*, 47(2):229–244.
- Pettengill, J. (1981). The long run impact of a minimum wage on employment and the wage structure. *Report of the Minimum Wage Study Commission*, 6:63–104.
- Phelan, B. J. (2019). Hedonic-based labor supply substitution and the ripple effect of minimum wages. *Journal of Labor Economics*, 37(3):905–947.
- Schumann, M. (2017). The effects of minimum wages on firm-financed apprenticeship training. *Labour Economics*, 47:163–181.
- Teulings, C. N. (2000). Aggregation bias in elasticities of substitution and the minimum wage paradox. *International Economic Review*, 41(2):359–398.
- Teulings, C. N. (2003). The contribution of minimum wages to increasing wage inequality*. *The Economic Journal*, 113(490):801–833.
- Welch, F. and Cunningham, J. (1978). Effects on minimum wages on the level and age composition of youth employment. *Review of Economics and Statistics*, 60(1):140–145.
- Zavodny, M. (2000). The effect of the minimum wage on employment and hours. *Labour Economics*, 7(6):729–750.

A Appendix

A.1 Theory

In this appendix, we show the details of our theoretical framework.

A.1.1 Production

There are I firms in the industry, producing varieties q_i of the industries' final output Q under monopolistic competition. Firms require a fixed high-skilled labour input $h_i = f$ and a variable labour input $n_i = \varphi q_i$. Modeling high-skilled workers as a fix input implies no substitution with lower skilled workers. This is similar to DIDES models, where low-skilled tasks are more easily substituted by medium than by high-skilled tasks. In our case, this is regulated by the master craftsmen requirement, according to which only master craftsmen or vocationally trained workers with sufficient work experience are allowed to lead a roofing firm. Nevertheless, it occurs more broadly in industries where high and low-skilled workers perform substantially different tasks, precluding substitution between them.

The variable labour input is composed of low and medium-skilled workers. Firms can replace low by medium-skilled workers with constant elasticity of substitution η , $n_i = \left(l_i^{\frac{\eta-1}{\eta}} + m_i^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$. Firms' wage costs for low and medium-skilled workers are $\bar{w}n_i = w_L l_i + w_M m_i$, where \bar{w} is the wage resp. factor cost index. Firms optimally choose the composition of low and medium-skilled workers, which implies

$$m_i = n_i \left(\frac{w_M}{\bar{w}} \right)^{-\eta} \quad (7)$$

$$\bar{w} = \left(w_M^{1-\eta} + w_L^{1-\eta} \right)^{\frac{1}{1-\eta}} \quad (8)$$

A.1.2 Consumption

Consumers have Constant Elasticity of Substitution (CES) preferences for the varieties i produced by the firms with elasticity of substitution $\sigma > 1$ between the varieties, $U = \left[\int_0^I q_i^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}$.²⁸ Total roofing sales are $R = \int_0^I p_i q_i di$. Utility maximization implies a downward sloping demand curve for each variety,

$$q_i = \left(\frac{p_i}{P} \right)^{-\sigma} \frac{R}{P} \quad (9)$$

²⁸This implies that the varieties produced by the roofing firms are no perfect substitutes. Note, however, that the results of the paper also hold if varieties are perfect substitutes (i.e. $\sigma \rightarrow \infty$).

with the CES price index $P = \left[\int_0^I p_i^{1-\sigma} \right]^{1/(1-\sigma)}$. The industry sells its output to the rest of the economy and is too small to affect the size of the economy. We assume that demand for the overall output of the industry is price sensitive with the constant price elasticity of demand $\varepsilon < 1$, $Q = Q_0 P^{-\varepsilon}$, where $Q = R/P$ are real sales.

A.1.3 Labour Demand

Due to monopolistic competition, prices are a markup on marginal costs, where \bar{w} are wages:

$$p_i = \frac{\bar{w}}{\varphi} \frac{\sigma}{\sigma - 1} \quad (10)$$

Free entry implies that new firms enter the market until profits decline to zero, from which we derive firm size:²⁹

$$q_i = (\sigma - 1)\varphi f \quad (11)$$

Firm size is exogenous. Without loss of generalizability, we normalize $\varphi \equiv \sigma/(\sigma - 1)$ and $f \equiv 1/\sigma$.³⁰ Using equilibrium firm size (11) and the price markup (10) in the product demand equation (9) then provides

$$\bar{w}^\sigma = RP^{\sigma-1} \quad (12)$$

This equation tells us that the wage, at which firms break even, increases in the size of the market R – the larger the market, the higher the wage that firms can afford. Moreover, firms charge the same prices, so that the price index simplifies to $P = \bar{w}Q^{1/(1-\sigma)}$, where Q is total roofing output. Lower-case letters refer to firm-level variables, upper-case letters refer to industry-level variables. We rearrange equation (12) to receive the industry-level product demand equation:

$$Q = \bar{w}^{-\tilde{\varepsilon}} Q_0^{\tilde{\varepsilon}/\varepsilon} \quad (13)$$

where $\tilde{\varepsilon} \equiv \varepsilon \frac{1-\sigma}{\varepsilon-\sigma}$ is the wage elasticity of total roofing product demand, which depends on the price elasticity of roofing demand ε and the elasticity of substitution between firms' varieties σ . Demand for

²⁹We assume free entry to keep the analysis as simple as possible. Introducing Melitz (2003)-type entrance costs and firm heterogeneity doesn't change the main results.

³⁰See Baldwin et al. (2003, p. 23) for the innocuousness of these normalizations. These normalizations do not affect our key results.

high-skilled workers H is proportional, as there is no firm heterogeneity:

$$H = \frac{1}{\sigma} \bar{w}^{-\tilde{\varepsilon}} Q_0^{\tilde{\varepsilon}/\varepsilon} \quad (14)$$

We derive demand for medium-skilled workers by combining (7) with (13) and the production function.

$$M = \frac{\sigma - 1}{\sigma} Q_0^{\tilde{\varepsilon}/\varepsilon} w_M^{-\eta} \bar{w}^{\eta - \tilde{\varepsilon}} \quad (15)$$

The demand for medium-skilled workers is thus a decreasing function of wages for medium-skilled workers w_M and a de- or increasing function of average wages \bar{w} depending on the relative sizes of the elasticity of demand $\tilde{\varepsilon}$ and the substitution elasticity between low and medium-skilled workers η .

A.1.4 Labour Supply

At each time instant t , there is a huge mass of low-skilled workers L_t^S who are searching for work. Their mass exceeds aggregate demand for low-skilled workers $L_t^S \geq L_t$,³¹ so that they only earn their reservation wage, unless there is a minimum wage that exceeds their reservation wage $w_L = \max(\underline{w}, w_{MW})$. At each time instant, δL_t low-skilled workers retire and are replaced by other low-skilled entrants, $E_t^L = \delta L_t$.

Assume that at each time instant t there is a mass of medium E_M and high-skilled entrants E_H , who supply one unit of labour with an extensive labour supply wage elasticity of θ . At each time instant, all workers face the exogenous retirement risk δ . Labour supply for medium- and high-skilled workers thus is $M_t = (1 - \delta)M_{t-1} + E_M w_{M,e}^\theta$ and $H_t = (1 - \delta)H_{t-1} + E_H w_{H,e}^\theta$. $w_{M,e}$ and $w_{H,e}$ denote expected medium- and high-skilled workers' wages.

In the steady state, the inflow (entrants) of workers equals the outflow (retirement), and expected wages correspond to actual wages. Steady-state labour supply of medium- and high-skilled workers thus is $M = \frac{E_M}{\delta} w_M^\theta$ and $H = \frac{E_H}{\delta} w_H^\theta$. We abstract from any wage setting frictions, which implies no unemployment among medium- and high-skilled workers. We solve the steady state labour market equilibrium by plugging labour demand (15) into steady state labour supply and drop all time indices. In the steady state, medium-skilled workers' wages are

$$w_M = \left(\frac{\delta(\sigma - 1)}{\sigma E_M} \right)^{1/(\theta + \eta)} Q_0^{\frac{\tilde{\varepsilon}/\varepsilon}{\theta + \eta}} \bar{w}^{\frac{\eta - \tilde{\varepsilon}}{\theta + \eta}} \quad (16)$$

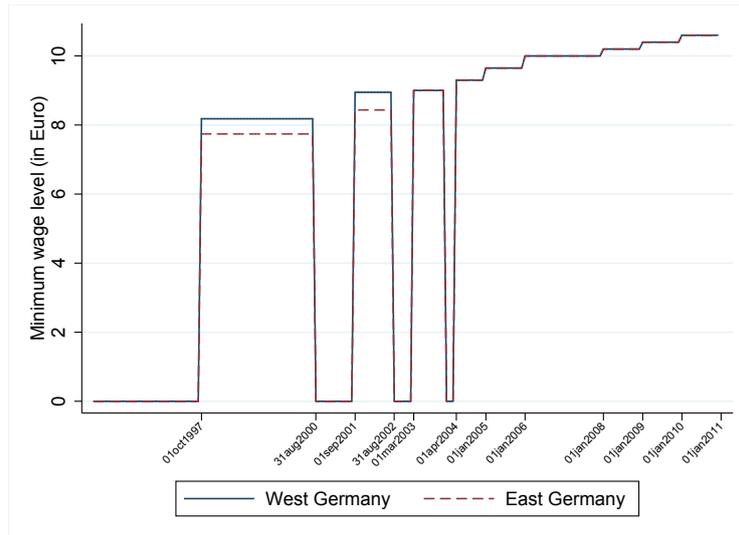
³¹This assumption is motivated by the high unemployment rate among low-skilled workers.

We proceed analogously for high-skilled workers to get

$$w_H = \left(\frac{\delta}{\sigma E_H} \right)^{1/\theta} Q_0^{\frac{\bar{\varepsilon}}{\theta}} \bar{w}^{-\bar{\varepsilon}/\theta} \quad (17)$$

A.2 Minimum Wage Regulations

Figure 6: Minimum wage level in the German Roofing Industry



A.3 Minimum Wage Bite

This appendix builds on Aretz et al. (2011) to analyze the bite of the minimum wage in more detail. Figure 1 indicates a strong bite of the minimum wage, as reflected by the significant compression at the lower tail of the East German wage distribution. Table 2 provides direct evidence on the size of the minimum wage bite using several indicators for East and West Germany, separately. The data refers to the June 30th prior of each new minimum wage regulation. The starting date of each new minimum wage regulation is depicted jointly with the subsequent new minimum wage level in Columns (1) and (2).³² Columns (3)-(5) show statistics for workers with an hourly wage below the next minimum wage including its share among the workforce (Column 3), the average individual wage gap, defined as the difference between individuals hourly wage and the expected hourly wage if firms fully comply with the new regulations (Column 4), as well as the average annual hourly wage growth (Column 5). If actual wage growth of workers below the next minimum wage is smaller than the wage gap, firms do not fully comply with the minimum wage

³²Note that the indicators may slightly underestimate the bite due to the fact that hourly wages may contain overtime compensation that is not subject to the minimum wage. Overtime hours account for 6% of the working hours in June. This may lead to an estimated hourly wage that is up to 1.6% too high depending on the applied overtime compensation scheme ranging from no additional compensation to a markup of 25%. Since we do not know which scheme is applied and since the resulting imprecision appears to be rather marginal, we left the data uncorrected.

Table 6: Indicators of the Minimum Wage Bite Measured in June Prior to the Next Minimum Wage Regulations

Date of next minimum wage regulation (1)	minimum wage (in €) (2)	Workers with an hourly wage:				Kaitz Index ^c (7)
		Share of all workers (in %) (3)	below next minimum wage		at/above next minimum wage	
			Wage gap ^a (in %) (4)	Annual Wage growth ^b (in %) (5)	Annual Wage growth ^b (in %) (6)	
West Germany						
01.10.97	8.2	3.8	16.9	3.6	2.3	65
01.09.01	8.9	1.5	9.6	7.0	1.5	67
01.03.03	9.0	1.5	10.0	5.6	2.5	67
01.04.04	9.3	2.1	9.3	5.9	1.5	68
01.05.05	9.6	2.7	8.6	4.6	0.7	70
01.01.06	10.0	4.1	7.8	5.0	1.2	73
01.01.07	10.0	4.4	8.2	7.0	3.3	73
01.01.08	10.2	5.2	6.9	5.6	2.3	73
01.01.09	10.4	4.6	6.5	8.1	3.1	73
East Germany						
01.10.97	7.7	13.4	12.2	6.7	-0.0	82
01.09.01	8.4	14.0	4.1	4.7	0.7	89
01.03.03	9.0	33.9	4.3	4.2	0.2	95
01.04.04	9.3	43.8	3.9	4.2	0.4	98
01.05.05	9.6	46.7	4.3	4.0	0.2	99
01.01.06	10.0	55.3	4.1	4.1	0.2	100
01.01.07	10.0	45.0	1.6	1.9	1.0	100
01.01.08	10.2	53.2	2.7	3.3	1.4	101
01.01.09	10.4	49.8	2.4	3.3	0.7	100

^a The individual wage gap is calculated as follows $wgap_{it} = (w_{MW_{it+1}} - w_{it})/w_{it}$.

^b Wage growth corresponds to the actual observed percentage nominal wage change $(w_{it+1} - w_{it})/w_{it}$ between the June preceding and the June following the new minimum wage regulation.

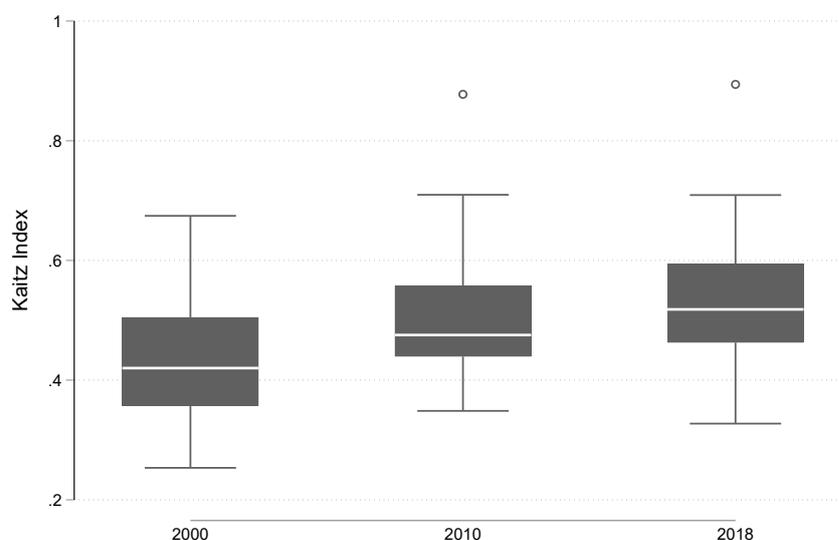
^c The Kaitz-Index is defined as the minimum wage divided by the median wage.

Own calculations based on the LAK data.

regulations. Column (6) shows the annual wage growth for workers with a hourly wage at or above the next minimum wage. Column (7) shows the Kaitz-Index, defined as the ratio between the minimum wage level and the median wage in the industry.

The indicators show large differences between East and West Germany. For West Germany, the share of workers with a binding minimum wage (Column 3) increased moderately from 3.8% to 5.2% between 1997 and 2007, before dropping again slightly in the year thereafter. According to the Kaitz-Index, the bite in West Germany is high and lies in the upper range of what has been found for other countries. The figures for the wage gap and actual wage growth among West German workers (Columns 4 and 5) reveal that actual wage growth lags behind what is necessary to fully comply with the minimum wage regulations. However, this deviation declines towards the end of the observation period. The latter might be explained by stronger controls after 2006, as reported by industry insiders (Aretz et al., 2011). Despite the lack of compliance, the figures for wage growth range between 3.6% and 8.1% for affected workers.

Figure 7: Kaitz Index in OECD Countries



Notes: The figure shows the Kaitz Index (= minimum wage / median wage) for 31 OECD countries for the years 2000, 2010 and 2018. The mean of the Kaitz index is 0.44 (2000), 0.51 (2010) and 0.54 (2018). Own illustration using data from OECD.stat

The salaries of non-affected workers increased only moderately by 0.7-3.3%, which suggests a decline in wage inequality.

For East Germany, we observe a much stronger bite of the minimum wage. According to Column (3), 13.4% of all East German roofers earned a wage below the 1997 wage floor in June 1997. The share increased rapidly after 2002, when the minimum wage was raised to the same level in East and West, which implied a rapid rise in the East. In June 2005, more than half of the workers (55.3%) had a wage below the 2006 minimum wage level. In fact, the Kaitz-Index approached the value of 100 in 2005, that is, the median wage equals the minimum wage. Compared to the findings for a strongly affected low-wage industry in the UK (Machin et al., 2003), the bite in the German roofing industry seems extraordinarily large. Machin et al. (2003) find that 32 percent of the workers were paid below the (age-specific) minimum wage before it was introduced. The mere size of affected workers in East Germany might also explain the higher compliance (i.e. lower deviation of wage gap and actual wage growth, Columns (4) and (5)) compared to West Germany. The more workers earn a minimum wage in a firm, the harder it is to circumvent the regulations. More strikingly, Column (4) shows that East German workers with salaries above the wage floor experienced almost no nominal wage growth or even suffered from wage losses. In the recovery period towards the end of our time series, wages increased only moderately in nominal terms.

A.4 LAK data

The LAK is a public service institution of the employer association ZVDH and the trade union IG Bau in Germany. The main objective is to help insure employees against several structural disadvantages of the industry. For instance, the agency compensates roofers for earnings losses caused by bad weather, ensures a thirteenth monthly income, administrates working-time accounts and old age benefits and promotes vocational education in the industry. For these purposes, the office collects monthly information from firms on the number of actual working hours for each worker as well as their gross wages and the length of their current employment from the year 1995 onwards. Since the reporting is mandatory for firms, and may impose a penalty for non-compliance, the information is highly likely to comprise all blue-collar roofers. The information is complemented with further worker characteristics including the date of birth and sex of workers as well as an establishment identifier to calculate further firm-level characteristics. Since the data does not comprise information on education and training, we drop workers below 19 years of age that should eliminate most apprentices that are not covered by the minimum wage regulations. Furthermore, we focus on men only, since female workers account for only a small fraction in this industry (less than 2%). Moreover, we drop observations where workers are reported to be sick, on vacation, serving in the military, and those with missing and unrealistically high (or low) wages and drop minor employment.³³ Finally, we focus on monthly observations in June to make the data comparable to the BA data and to avoid distortions due to seasonal fluctuations during the months October to April where compensation payments by the LAK are more relevant. In total, we are able to exploit 1,055,137 June observations for 206,753 roofers across the period 1995-2010.

³³In particular, we drop observations where the hourly wages falls below (above) 50% (150%) of the median hourly wage.

A.5 Changes in the Earnings Distribution

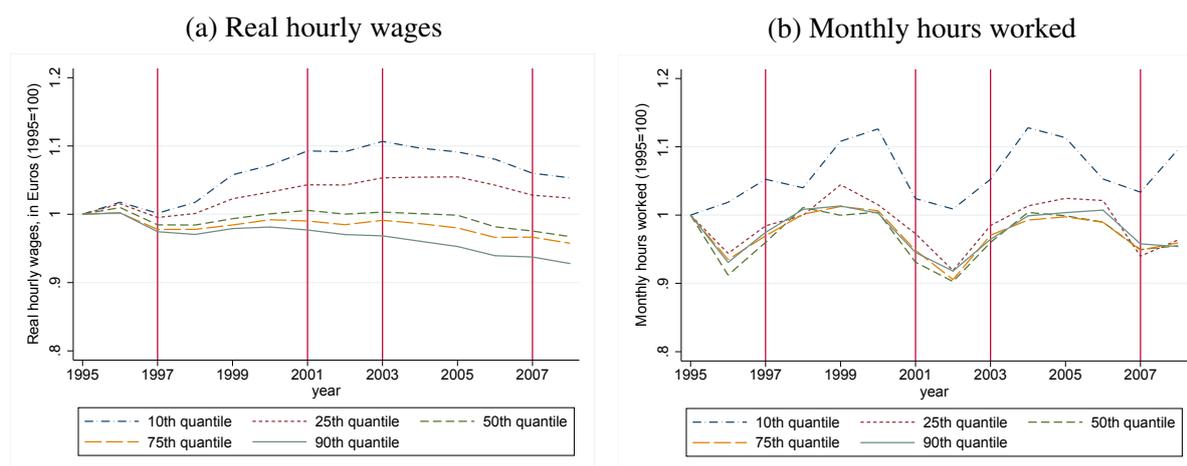
Table 7: Average Worker Characteristics by Quantiles of the Real Daily Wage Distribution

	Quantile of the daily wage distribution				
	$\tau = 0.1$	$\tau = 0.25$	$\tau = 0.5$	$\tau = 0.75$	$\tau = 0.9$
real daily wage (in €)	49.4	56.2	62.9	69	75.8
yearly growth of real daily wages (in %)	3.8	1.2	-.1	-1.2	-2
nominal daily wage (in €)	54.8	62.4	69.7	76.5	84
yearly growth of nominal daily wages (in %)	5.4	2.8	1.5	.4	-.5
share of unskilled workers (non-technicians)	48.9	39.3	25.6	17	16.8
share of skilled workers (technicians)	49.5	59.8	73.4	81.3	77.7
share of master craftsmen	.9	.7	.8	1.6	5.4
without vocational training degree	25	21.8	14.3	9.9	9.9
with vocational training degree	53.3	62.3	73.6	79.8	78.6
with university degree	.1	.1	.1	.1	.3
tenure in industry (in days)	1289.7	1666.9	2004.6	2291.4	2385
average age	32.6	33.6	35.9	38.4	40

Notes: Based on BA-data. All figures shown in the table reflect average yearly values of roofers. Real wages are inflation-adjusted to prices in 1994.

A.6 Wages and Hours Worked

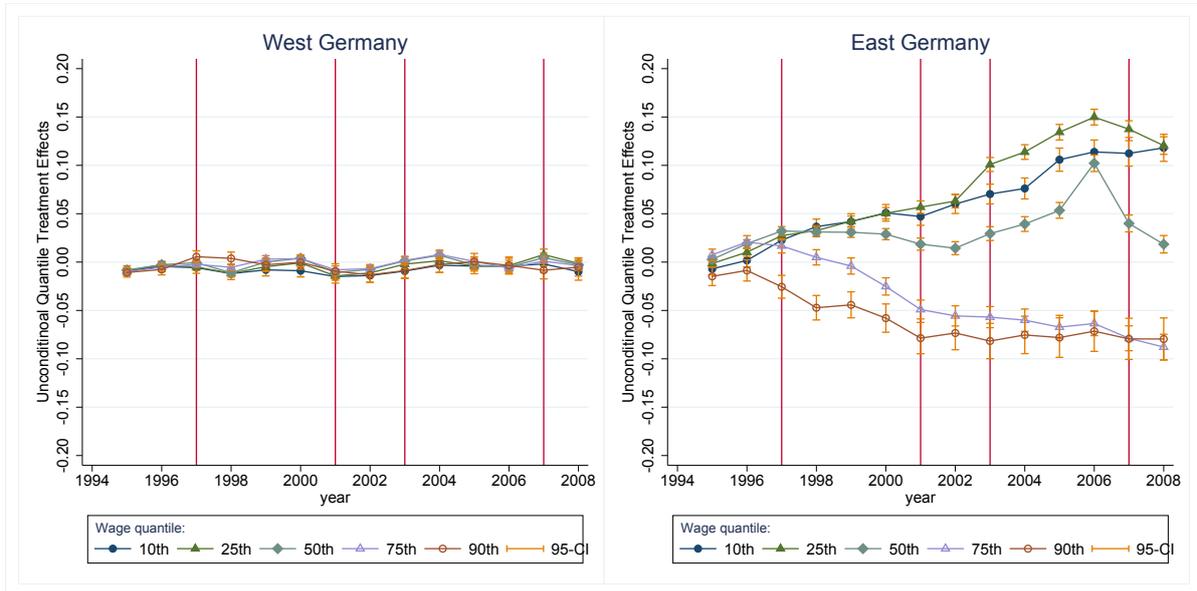
Figure 8: Development of Real Hourly Wages and Hours Worked



Notes: Based on LAK data (roofers only). The vertical lines represent the introduction of the minimum wage in October 1997, the first increase in September 2001, the adjustment of the East German minimum wage level to higher West levels in March 2003 as well as the year 2007 where a regular increase was suspended (compare Figure 6).

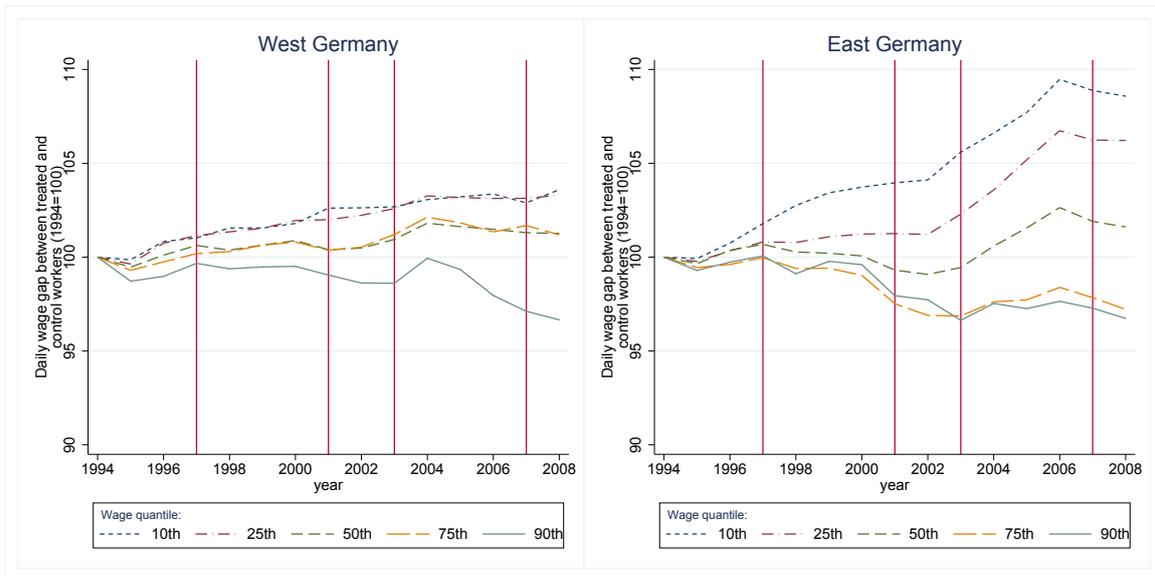
A.7 Quantile Regressions

Figure 9: Minimum Wage Effects on the Unconditional Real Daily Wage Distribution Over Time (Relative to 1994)



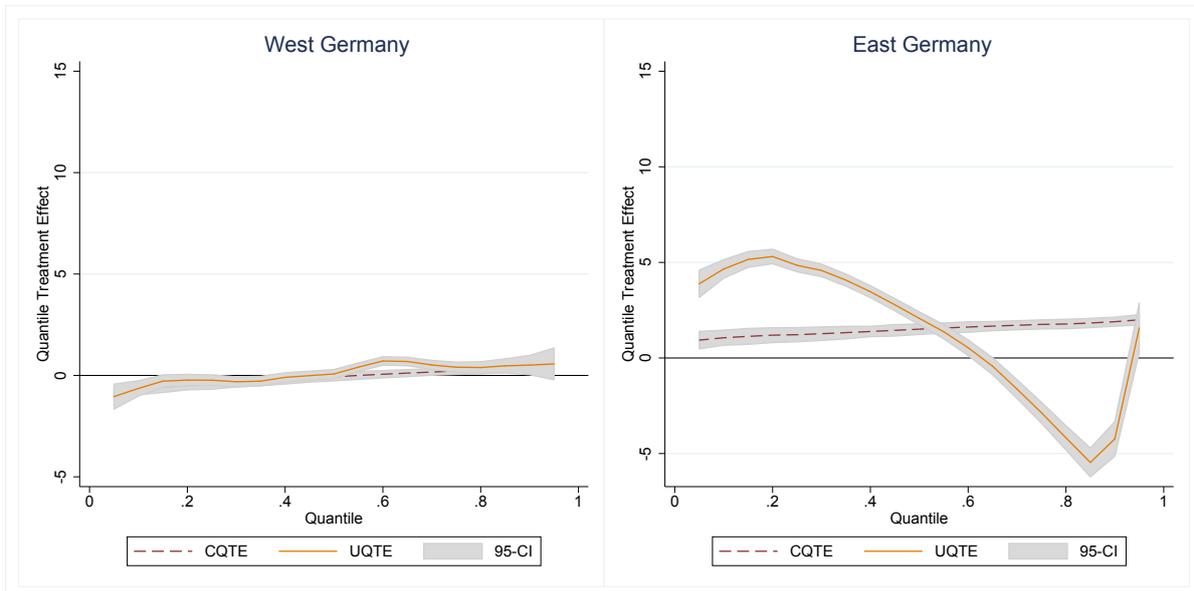
Notes: The figures show unconditional quantile regression estimates of Equation 4 for selected quantiles by East and West Germany, where the term $Post_t$ is replacing by year dummies (baseline dummies and interactions). All effects are relative to starting year 1994. All models include individual fixed effects as well as several individual and firm-specific covariates. Whiskers mark the 95 percent significance interval. Robust standard errors clustered by individuals. The vertical lines represent the introduction of the minimum wage in October 1997, the first increase in September 2001, the adjustment of the East German minimum wage level to higher West levels in March 2003 as well as the year 2007 where a regular increase was suspended (compare Figure 6).

Figure 10: Daily Wage Gap Between Treated and Control Workers



Notes: The figure shows the wage gap between treated and untreated workers by quantile of the wage distribution based on the raw data. A positive (negative) value reflects a higher (lower) wage of treated compared to the untreated workers. The vertical lines represent the introduction of the minimum wage in October 1997, the first increase in September 2001, the adjustment of the East German minimum wage level to higher West levels in March 2003 as well as the year 2007 where a regular increase was suspended (compare Figure 6).

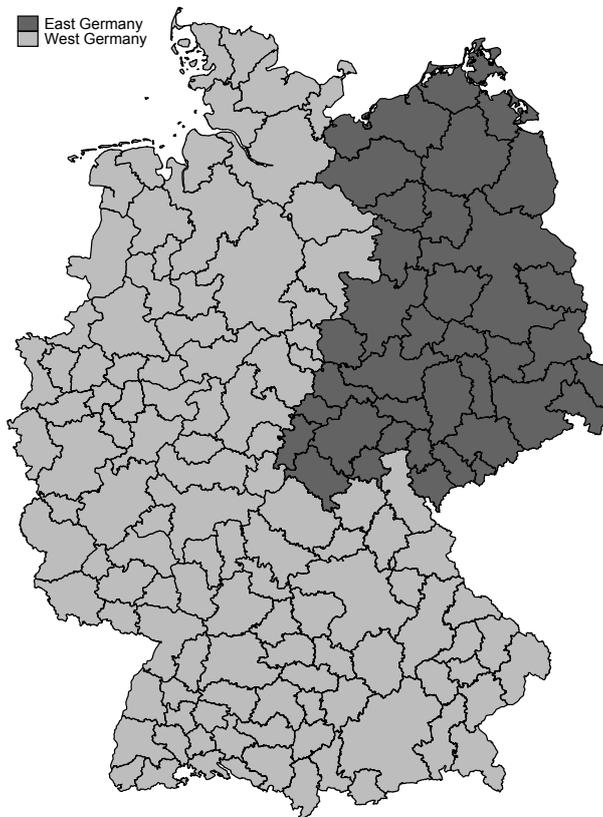
Figure 11: Minimum Wage Effects on the Unconditional and Conditional Daily Wage Distribution



Notes: This figure shows CQTE and UQTE estimates based on Equation 4 by East and West Germany. All models include individual fixed effects, post-year dummies as well as several individual and firm-specific covariates. 95% confidence intervals are based on robust standard errors clustered by individuals. Standard errors for CQTE are bootstrapped with 100 replications. Quantile treatment effects reflect the impact of the minimum wage introduction on wages (in percent).

A.8 Local labour markets

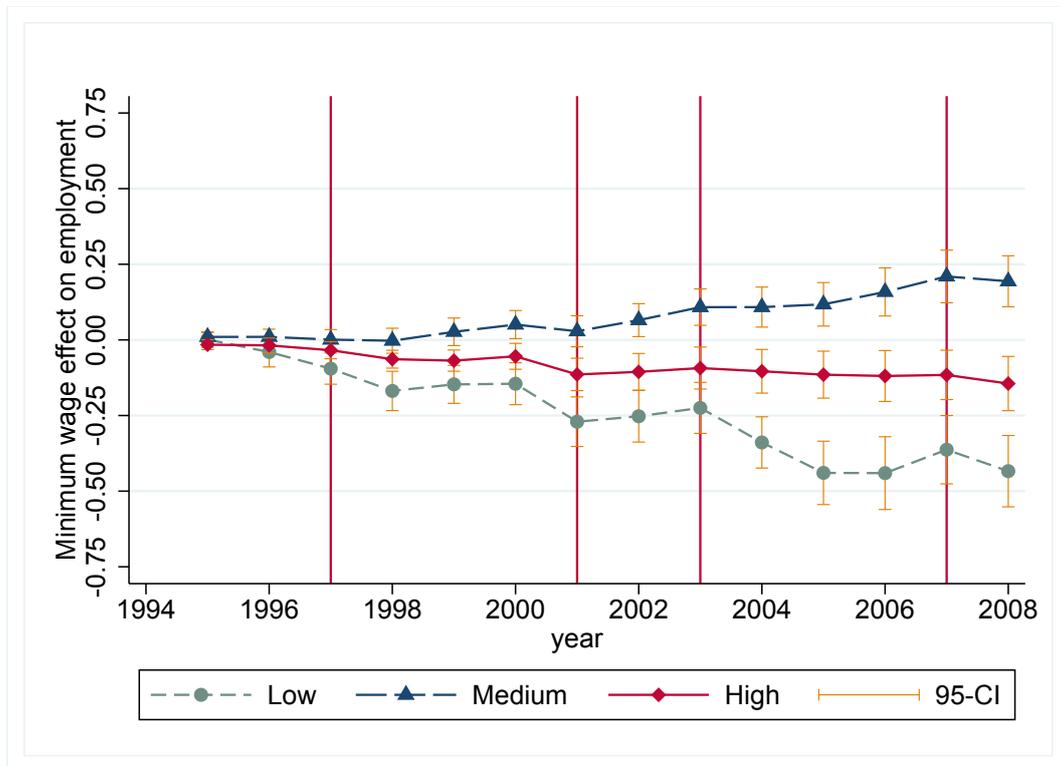
Figure 12: 150 German Local Labour Market



Notes: Following the definition of local labour markets by Eckey et al. (2006).

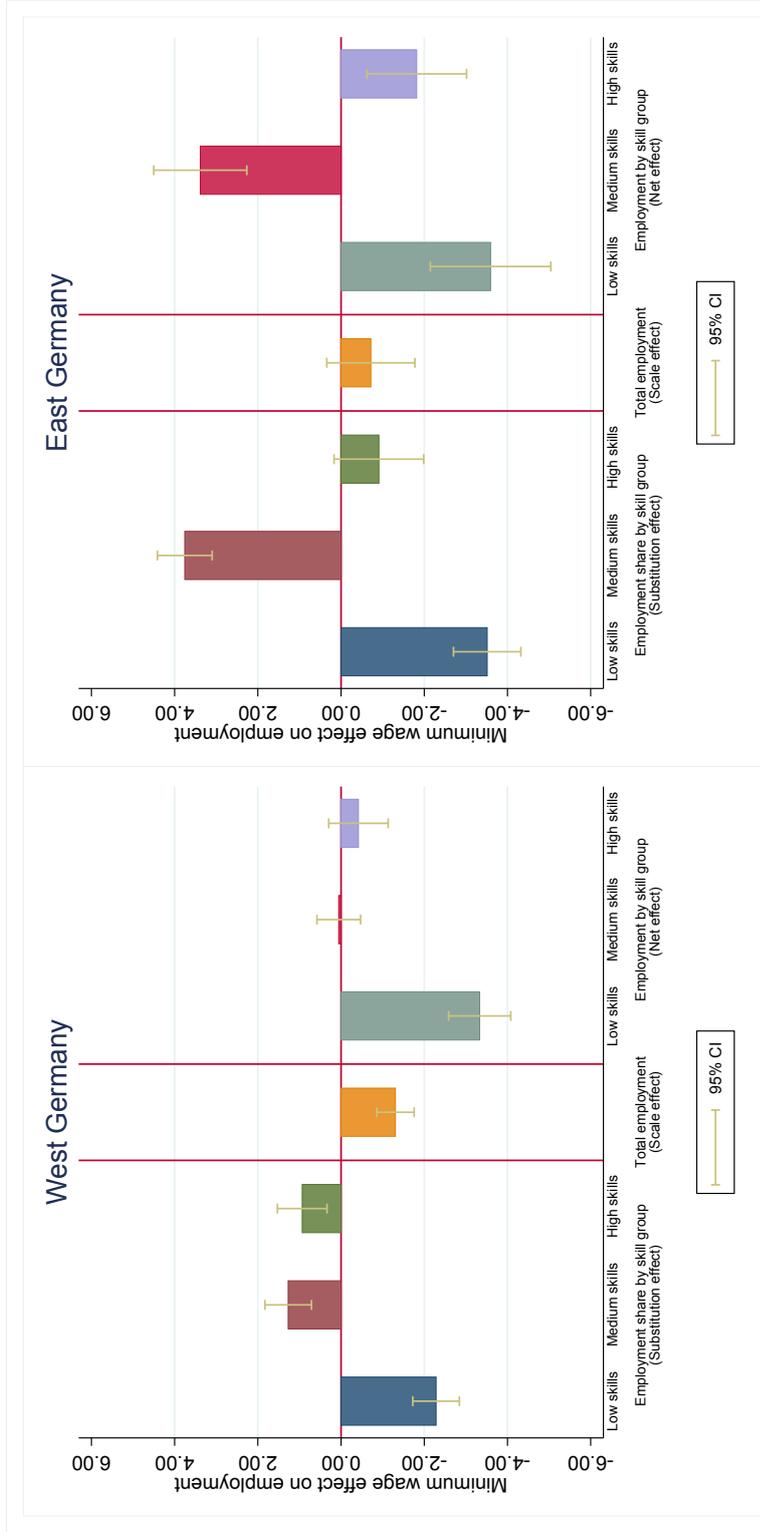
A.9 Substitution- and Scale Effects

Figure 13: Minimum Wage Effects on Net Employment by Skill Group and Year (Relative to 1994)



Notes: The figures show regional estimates of skill-specific net employment by East and West Germany according to Equation 6, where our $Post_t$ variable is replaced by year dummies (baseline dummies and interactions). All effects are relative to starting year 1994. All models include industry-region fixed effects. All regressions are weighted by regional (skill-specific) employment in pre-treatment years. Whiskers mark the 95 percent significance interval. Robust standard errors clustered by region. The vertical lines represent the introduction of the minimum wage in October 1997, the first increase in September 2001, the adjustment of the East German minimum wage level to higher West levels in March 2003 as well as the year 2007 where a regular increase was suspended (compare Figure 6).

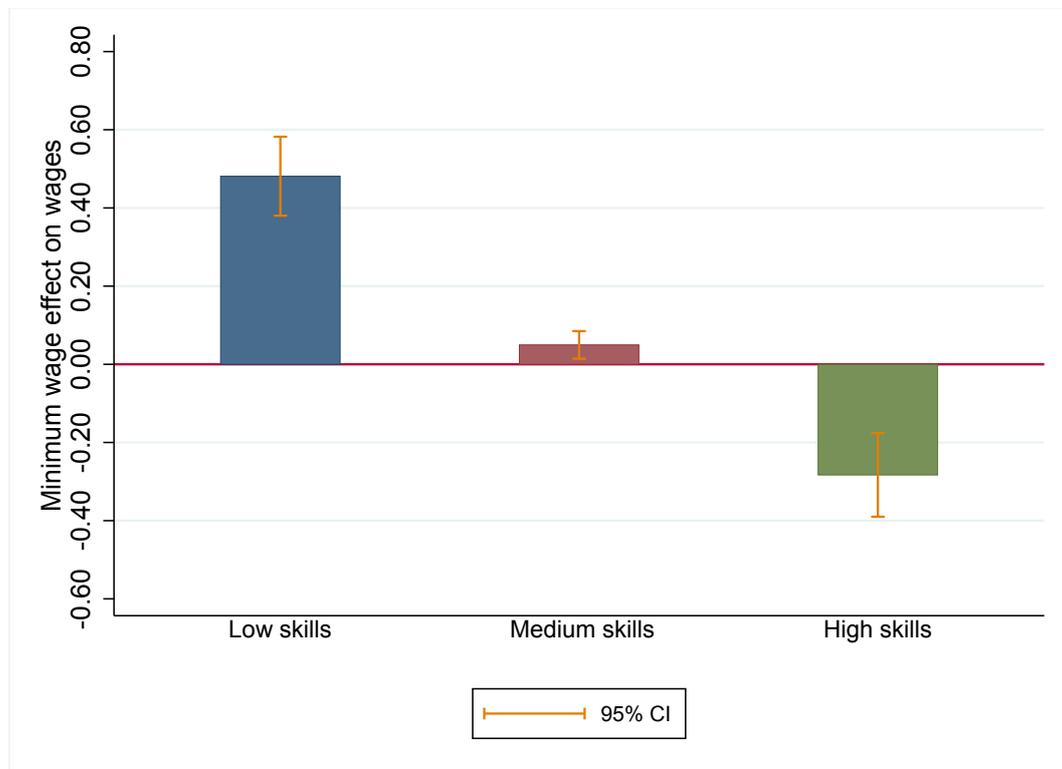
Figure 14: Minimum Wage Effects on Total Employment (Scale Effect) and Skill-Specific Employment Share (Substitution Effect) by East and West Germany



Notes: The figures show regional estimates of skill-specific employment shares, total employment and skill-specific absolute employment based on region-industry year cells between 1994-2008 according to Equation 6. All models include industry-region fixed effects, post-reform year dummies. Regressions are weighted by regional (skill-specific) employment in pre-treatment years. Whiskers mark the 95 percent significance interval. Robust standard errors clustered by region. Figures reflect the impact of a 10 percentage points increase in the minimum wage bite. Detailed regression tables are shown in Table 4.

A.10 Skill-specific wage effects

Figure 15: Minimum Wage Effects on Wages by Skill Group



Notes: The figures show regional estimates of skill-specific employment shares, total employment and skill-specific absolute employment by East and West Germany according to Equation 6. All models include industry-region fixed effects. Regressions are weighted by regional (skill-specific) employment in pre-treatment years. Whiskers mark the 95 percent significance interval. Robust standard errors clustered by region. The vertical lines represent the introduction of the minimum wage in October 1997 and the harmonization of minimum wage levels between East and West Germany in March 2003 (compare Figure 6). Detailed regression tables are shown in Table 4.

A.11 Firm Revenues

To provide further support on negative aggregate demand shocks in response to the minimum wage (negative scale effects in Section 6), Table 8 shows the results using firm revenues on the left hand side of Equation 6. Revenues are taken from the Mannheimer Unternehmenspanel (MUP), a data base that collects information on all active firms in Germany. Data is only available for roofers and plumbers, i.e. we do not have data for glaziers. We look at log total industry revenues, average firm revenues as well as average firm revenues per worker, all defined at the regional level. The regressions are weighted with pre-treatment regional revenues to control for size differences between regions.

Table 8: Minimum Wage Effects on Industry- and Firm Revenues

	log total industry revenues (1)	log average firm revenues (2)	log firm revenues per worker (3)
Minimum wage bite	-2.81*** (-4.00)	-3.13*** (-4.85)	-3.64*** (-4.24)
N	4496	4496	4496

Notes: Revenues based on MUP data. t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects and are weighted with pre-treatment total regional revenues. Robust standard errors clustered by region. Figures reflect percentage changes in the outcome variable in reaction to a 10 percentage points increase in the minimum wage bite.