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# DISCUSSION PAPER

// TERRY GREGORY AND ULRICH ZIERAHN

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

# WHEN THE MINIMUM WAGE REALLY BITES HARD: IMPACT ON TOP EARNERS AND SKILL SUPPLY*

TERRY GREGORY† ULRICH ZIERAHN‡

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We investigate minimum wage spillovers by exploiting the first-time introduction of a minimum wage within a quasi-experiment in a context with an extraordinary large bite: the German roofing industry. We find positive wage spillovers for medium-skilled workers with wages just above the minimum wage, but negative effects for high-skilled top earners in East Germany, where the bite was particularly pronounced. There, the minimum wage lowered both returns to skills and skill supply. We propose a theoretical model according to which negative spillovers occur whenever a negative scale effect dominates a positive substitution effect and provide empirical support for our theory.

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

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

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†Terry Gregory (corresponding author), Team Leader at the Institute for Labor Economics (IZA), Bonn, Germany, e-mail: gregory@iza.org, and Senior Researcher at the ZEW – Leibniz Centre for European Economic Research, Mannheim, Germany, e-mail: terry.gregory@zew.de.

‡Ulrich Zierahn, Assistant Professor at Utrecht University, the Netherlands, e-mail: u.t.zierahn@uu.nl, and Senior Researcher at the ZEW – Leibniz Centre for European Economic Research, Mannheim, Germany, e-mail: ulrich.zierahn@zew.de.

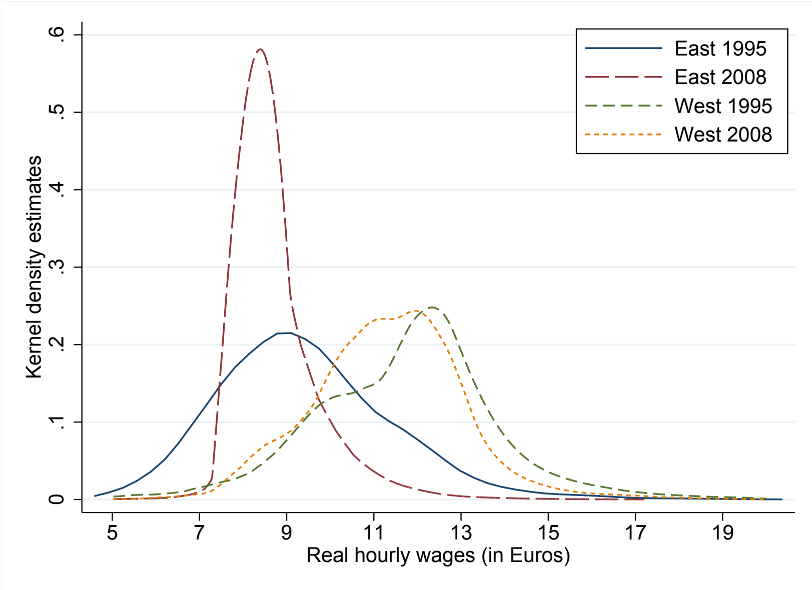
# 1 Introduction

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, and Cengiz et al. 2019). 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 but higher paid jobs, reducing the supply for the latter. The decline in supply raises wages for the undesirable higher paid jobs, 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, some empirical studies indicate the existence of negative spillovers for top-earners as well. 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

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




*Notes:* The figure shows kernel density estimates of real hourly wages based on a full sample of all roofers using the LAK data (see Section 4.1). Hourly wages are adjusted to prices in 1994.

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 clear in case of the German roofing industry, where the bite was particularly strong. As Figure 1 illustrates, the minimum wage coincided with a compression of hourly wages not only at the bottom of the distribution, as one would expect, but also at the top in East Germany. 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 both positive and negative minimum wage spillovers, nor a study which analyzes the implications for employment, wages, returns to skills and skill supply.

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 6 in Appendix A.2), 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. For robustness, we additionally consider a Changes-in-Changes estimator proposed by Athey and Imbens (2006). 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. 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 the industry leads to a decline of employment in the industry, as higher costs and prices induce a reduction in demand

[1] While this quasi-experiment has been used by Aretz et al. (2013) to study the effect of the minimum wage on the probability to remain employed, we are the first to analyze wage spillovers and their implications.

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 for Germany (Apel et al., 2012; Aretz et al., 2013).

Third, we empirically test our models' predictions for minimum wage spillovers, employment and skill supply. In particular, we empirically quantify the scale and substitution effects within a regional labour market approach, which is designed to capture aggregate effects, and assess the resulting net effects on workers with different skills.[2] We thereby contrast West and East Germany, which were affected very differently, thus providing insights into the role of the minimum wage bite in explaining our findings. This is particularly relevant, as the bite of minimum wages is on the rise in many countries (see Figure 6 in Appendix A.2). 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 positive real wage effects of up to 11% for lower-quantile workers between 1997 and 2008 that ripple up to the 60th quantile in East Germany. However, the minimum wage also caused a reduction in real wages by up to 5% in East Germany (stagnation

[2] A 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.

[3] While 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).

of nominal wages) among firms' highest paid employees, who mostly comprise high-skilled workers. We show that the observed upper-tail wage-compression effect in East Germany is solely driven by a reduction in between-group inequality, suggesting deteriorating returns to observable skills in the East as a result of the policy reform. In West Germany, where the minimum wage bite was lower, we find much weaker wage effects at the lower tail (4%) and no compression at the top.

In line with our theoretical framework, we show that positive wage spillovers for medium-skilled workers were driven by a positive substitution effect that overcompensated a negative scale effect (i.e. positive net employment effect). In contrast, the negative wage spillovers on high-skilled workers are the result of negative scale effect without any substitution towards these workers (i.e. negative net employment effect). The latter negative wage spillovers on top earners were, however, only found for East and not for West Germany, suggesting that a strong bite promotes such unfavorable adjustments. In line with deteriorating returns to skills in East Germany, we further find a negative minimum wage effect on skill supply measured by a less favorable selection of trainees.

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 both conditional and unconditional quantile treatment effects of the minimum wage on the distribution of earnings together with several robustness checks. In Section 6, we quantify the scale and substitution effect as well as its net effects in order to test whether the mechanisms proposed by our theory can indeed explain the observed distributional impacts of the minimum wage. 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 $\eta$, whereas high-skilled workers provide no close substitute for low- and medium-skilled labour. This assumption is similar to DIDES models, where low-skilled tasks are more easily substituted by medium compared to high-skilled tasks and it is in line with the empirical literature on spillover effects, which finds substitution only towards workers who earn slightly above the minimum wage. 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.

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 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.[4]

We solve the model as a flow equilibrium, where at each time instant $t$, a share $\delta$ of each type of worker exogenously retires. The supply of low-skilled workers greatly exceeds demand.[5] This implies that they earn their reservation wage $\underline{w}$, unless there is a minimum wage $w_{MW}$ that exceeds their reservation wage, $w_L = \min(\underline{w}, w_{MW})$. 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 $\theta$. 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.

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

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

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

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

**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*

[4] We assume free entry to keep the analysis as simple as possible. Introducing Melitz (2003)-type entrance costs and firm heterogeneity does not change the main results.

[5] This assumption is motivated by the high unemployment rate among low-skilled workers.

*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 $\alpha$ 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, $\frac{\partial \ln N}{\partial \ln w_{MW}} = -\tilde{\varepsilon}\frac{\partial \ln \bar{w}}{\partial \ln w_{MW}}$. □

The intuition of the scale effect is as follows: The minimum wage for low-skilled workers is a cost-shock, raising average wages (1.a). This implies that the industry shrinks due to the negative slope of industry product demand, i.e. output and net employment decline (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) $\frac{\partial \ln w_M/w_L}{\partial \ln w_{MW}} = -\frac{\tilde{\varepsilon}+\theta}{\theta+(1-\alpha)\eta+\alpha\tilde{\varepsilon}}$. This is strictly negative for $0 < \alpha < 1$, $\theta > 0$, $\eta > 0$, $\tilde{\varepsilon} > 0$, 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, $\frac{\partial \ln M/N}{\partial \ln w_{MW}} = -\eta\frac{\partial \ln w_M/w_L}{\partial \ln w_{MW}}$. □

Intuitively, the minimum wage implies a rise in the relative costs for low- relative to medium-skilled workers (2.a), which induces an increase in the share of relatively cheaper medium-skilled workers (2.b). The effect is stronger the larger the elasticity of substitution between worker types $\eta$ 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.[6] 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 $\eta$ exceeds (is lower than) the industry product demand elasticity $\tilde{\varepsilon}$.*
*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 $\frac{\partial \ln w_M}{\partial \ln w_{MW}} = \frac{\eta - \tilde{\varepsilon}}{\theta + \eta} \frac{(1-\alpha)(\theta+\eta)}{\theta+\eta-\alpha(\eta-\tilde{\varepsilon})}$. For $0 < \alpha < 1$, $\theta > 0$, $\eta > 0$, $\tilde{\varepsilon} > 0$, this is positive (negative) if $\eta > \tilde{\varepsilon}$ ($\eta < \tilde{\varepsilon}$). The employment effect is analogous due to $\frac{\partial \ln M}{\partial \ln w_{MW}} = \theta \frac{\partial \ln w_M}{\partial \ln w_{MW}}$.

We take the first derivative of high-skilled equilibrium wages (1) w.r.t. $\ln w_{MW}$, which yields $\frac{\partial \ln w_H}{\partial \ln w_{MW}} = -\frac{\tilde{\varepsilon}}{\theta} \frac{(1-\alpha)(\theta+\eta)}{\theta+(1-\alpha)\eta+\alpha\tilde{\varepsilon}}$. 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. □

The introduction or rise of a binding minimum wage for low-skilled workers thus might raise or reduce wages (3.a) and employment (3.b) of medium-skilled workers, depending on

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

whether the substitution or scale effect dominates. The net effect is governed by the relative size of the elasticity of substitution between worker types $\eta$ and the price elasticity of industry product demand $\tilde{\varepsilon}$. The net effect on high-skilled workers' wages (3.c) and employment (3.d) is always negative – they suffer from the negative scale effect but do not gain from compensating substitution effects.

**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 employment ratio and thus directly follows from Proposition 2.

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

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. □

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 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, but not high-skilled (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 net overall employment 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.[7]

# 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. Since tariff agreements are negotiated on an industry level in Germany, not all industries in the construction sector agreed on implementing a minimum

[7] Several 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.

wage in the mid 90s.[8] The evaluation of the minimum wage at an industry-level provides the opportunity to compare similar industries within a quasi-experiment. 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.

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 Table 4 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.[9]

## 3.2 Selection of Control Industries

The roofing industry is a 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, repairing of roofs including energy-efficient upgrading, and the installation of solar collectors. Potential control industries for the treated roofing industry should (1) not be

[8]The introduction of 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 between industries, 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 wage were not uniformly introduced.

[9]Inspections 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.

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

| | Roofers (1) | Plumbers (2) | Glaziers (3) | Source, year (4) |
|---|---|---|---|---|
| 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 craftmens | 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 | |
| $500\text{-}1,000$ DM | 26.1 | 23.5 | 21.5 | |
| $1,000\text{-}2,000$ 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 and Sources:* 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).

subject to any minimum wage regulation, (2) depend on the same business cycle as the roofing industry, (3) have a similar market structure and (4) should not be vulnerable to spillovers to and from the roofing industry. Although focusing on earnings rather than employment, we exploit the same quasi-experiment as Aretz et al. (2013), which builds on extensive analysis of potential control industries (see more detailed tests in Aretz et al. (2011)). Building on their work, we choose plumbers (and alternatively glaziers) as preferable control industries for our Difference-in-Differences analyses for four reasons:[10]:

First, the control industries 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

[10]The following industry coding identifies the industries: roofers (WZ93/WZ03: 45.22.1), plumbers (WZ93: 45.33.1 und 45.33.2./WZ03: 45.33.0), glaziers (WZ93/WZ03:45.44.2). Note that painters and vanishers, as well as building construction including building bridges and tunnels, were generally also among the potential control industries. However, as painters and vanishers introduced a minimum wage in 2003, they cannot provide a counterfactual for the evaluation of long-run effects. Building construction turned out to show a very different economic trend.

below. In contrast to the roofing industry, the control industries however did not introduce a minimum wage in the early 90s for mainly political reasons. This makes the industries generally suitable to reflect the counterfactual situation in the roofing industry in case of no minimum wage introduction.

Second, both control industries experienced very similar business cycle trends (see Figure 7 in Appendix A.4), namely a severe and long-lasting economic downturn in the aftermath of the boom period in the early 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. In fact, the number of employed blue-collar workers subject to social security contributions decreased from 70,000 to 40,000 between 1994 and 2004 (see Figure 7 in Appendix A.4). After 2004, the construction industries almost fully recovered in West Germany, while the recovery in East Germany was rather marginal.

Third, the plumbing and glazier industry are very similar to the treated roofing industry in terms of their market structure before the introduction of the minimum wage. 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.[11] Moreover, with a share of craftsmen and skilled workers of around 70%, roofing firms 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. Value added, investments per employee as well as labour cost shares of roofing companies are more similar to those figures for plumbing firms as compared to glaziers. The evidence suggests that the plumbing and glazier industries are comparable in terms of market conditions.

[11] The 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 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.

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 5.1.1). Moreover, it is very unlikely that roofers took advantage of the more stable West German economy due to the generally low degree of residential mobility of roofers.

# 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 subsamples of roofers (75%), plumbers (30%) and glaziers (75%).[12] 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 and education of workers. The firm-level data consists of information on the workforce 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

[12] We drop painters, which are generally also available in our data set, but which also introduced a minimum wage in 2003 so that control group comparisons for long-term analyses are ruled out.

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 they 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 for descriptive analyses on the developments of the minimum wage bite, hourly wages and hours worked in the roofing industry. Details of this data set are reported in Appendix A.3.

## 4.2 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 high with a Kaitz-Index of 63% in West Germany in the year of its introduction (see Appendix A.2 for details). That is, the minimum wage reached 63% of the median wage in the industry in 1997. It rose to 73% in 2006, where it remained until 2009. The figures for East Germany are even higher, where the Kaitz-Index was 82% in 1997 and rose to 100% in 2006, remaining at that level until 2009. These figures are large by international standards, as the average bite among OECD countries is around 50% (see Figure 6 in Appendix A.2).

We expect the minimum wage to explain the significant changes in the earnings distribution. The strong compression at the bottom and top of the earnings distribution in Figure 1 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 Table 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 reflects wage restraints among skilled workers. We show this in Table 5 in Appendix A.5, which displays average yearly wage changes and other worker characteristics for selected wage quantiles. Real wages decline at the top, while nominal wages stagnate. 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.

Wage compression and stagnating top-earners' wages are not only driven by new roofers entering the labour market with lower entry wages, but rather reflect pay restraints among skilled workers that have been working in the roofing industry and for the same firm ever since.[13] The latter speaks for a decline in the returns to observable skills.

# 5 Minimum Wage Effects on Earnings 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 able to analyze minimum wage spillovers also for 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 roofers (treatment industry) with the counterfactual distributions of plumbers (control industry) before and after the minimum wage introduction.[14] Note that our results are robust when using glaziers as an alternative control industry (see Section 5.3). For the estimation, we apply an unconditional quantile regression technique developed by Firpo et al. (2009) to shed light on the quantile treatment effects on the overall earnings distribution. We contrast these results to a conditional quantile regression approach first proposed by Koenker and Bassett (1978). The differences between both approaches reveal additional insights into the quantile treatment

[13]In order to check whether results are driven by new entrants, we restricted the data to all roofers that we observe across the entire 16-year time period (thus comprising a balanced panel) and who worked for the same firm. The results are very similar to the results from the full sample.

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

effects on the returns to observable skills. Below, we explain both approaches together with our identifying assumptions.

### 5.1.1 Conditional Quantile Regression

With the conditional quantile regression, we estimate the effect of the minimum wage on the conditional distribution of wages, holding other factors such as compositional changes constant. In particular, we estimate the conditional log daily wage of workers at the $\tau$th quantile as follows[15]:

$$Q(w_{it}|X_{it})^{\tau} = \alpha^{\tau} + \beta^{\tau} D_i + \gamma^{\tau} Post_t + \delta^{\tau}(Post_t \times D_i) + \eta^{\tau}\mathbf{X}_{it} + \varepsilon_{it}^{\tau} \tag{3}$$

where $D_i$ refers to the treatment variable that takes the value one for treated roofers and zero for untreated plumbers. $Post_t$ 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).[16] $\mathbf{X}_{it}$ is a set of individual and firm 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).[17] The coefficient $\delta^{\tau}$ gives us the Quantile Treatment Effect (QTE) of the minimum wage introduction (and subsequent increases) at the $\tau$th quantile of the earnings distribution.

[15]Since 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; Zavodny, 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.2).

[16]We also test a specification controlling for additional year-specific effects, which yields very similar results.

[17]Educational 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.

### 5.1.2 Unconditional Quantile Regression

Conditional quantile regression estimates capture the impact on the wage distribution within worker groups with similar observable characteristics (within-group inequality). For instance, a positive compression effect at the top (bottom) of the conditional wage distribution implies that within each group of low-, medium- or high-skilled workers, those workers at the top (bottom) have been squeezing together in terms of wages. One cannot make any statements on changes in overall wage inequality with this method, as it neglects how the policy reform affects between-group inequality. In the above case, overall wage inequality at the top (bottom) can even increase, despite lower within-group inequality if, for instance, the wage returns to education increases strong enough.

Technically speaking, 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 the method proposed by Firpo et al. (2009) to estimate the effect of the minimum wage on the unconditional (marginal) distribution of wages, holding other factors constant. The method consists of two steps. In a first step, we define the Influence Function $IF(y;q^\tau)$ of our outcome variable $y$ at sample quantile $q^\tau$, which is then transformed (recentered) such that it aggregates back to the overall distribution of $y$. The so called Recentered Influence Function (RIF) can be expressed as the weighted probability that the outcome variable $y$ lies above a certain quantile:

$$
\begin{aligned}
RIF(y;q^\tau) &= q^\tau + IF(y;q^\tau) \\
&= q^\tau + \frac{\tau - \mathbb{1}\{y \leq q^\tau\}}{f_y(q^\tau)}
\end{aligned}
\tag{4}
$$

where $f_y(q^\tau)$ is the density at that point. Equation 4 essentially transforms conditional to unconditional quantiles before running the regressions. In a second step, we regress the RIF on the explanatory variables, similar to Equation 3, using Ordinary Least Squares (OLS)[18]. By doing so, we compare the unconditional wage distributions of treated and untreated workers both

[18] Firpo et al. (2009) compare their results to other specifications including a Logit and a nonparametric specification. Since the results do not differ much between the RIF-OLS and the alternative specifications, we stick to the first.

before and after the policy reform. We thus receive Unconditional Quantile Treatment Effects (UQTE), which we contrast to our Conditional Quantile Treatment Effects (CQTE).

#### 5.1.3 Identifying Assumptions and Robustness

Three main assumptions are needed for identification. First, the differences in wages between roofers and plumbers would have stayed the same in the absence of the policy reform (common trends assumption). Our evidence in Section 3.2 shows that the plumbing industry has a comparable market structure, experienced similar trends in several important economic indicators and is in general very comparable. This supports our assumption that the roofing industry would have experienced a similar wage development, had the minimum wage regulations not been implemented in the roofing industry, conditional on covariates. Our industries are comparable unconditionally, but we include a large set of covariates to control for remaining differences. We further conduct robustness checks by re-estimating the model using glaziers as an alternative control industry. Moreover, we apply the changes-in-changes method proposed by Athey and Imbens (2006), a nonlinear method which identifies the quantile treatment effects under the assumption that changes in wages between roofers and plumbers would have stayed the same in the absence of the policy reform (common changes). The method essentially relaxes the assumption that the results are invariant to a monotonic transformation of the outcome variable such as taking log wages, i.e. the effects of time and group on the outcome are additively separable. Finally, the introduction of the free mobility of labour in the European Union affects could have affected the treated industry. However, our control industries are subject to the same policy, such that we can identify the effect of the minimum wage by comparing the two industries. Furthermore, free mobility of labour became effective only in 2004. We therefore restrict the time period to years before 2004 as another robustness check. Our key results are robust to all these extensions (see Section 5.3).

Our second assumption is that there are no indirect effects of the minimum wage regulations in the roofing industry on the plumbing industry (Stable Unit Treatment Value Assumption, SUTVA). In order to check this, we calculate transition rates of roofers into the plumbing industry. Since we find that only 0.35% of our observations in our entire data set shows a change in the industry coding between 1994 and 2008, there is hardly any labour mobility between roofers and our 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 industry indirectly affected the roofing industry.

Our third assumptions is the absence of anticipation behaviour. To test this assumptions, we conduct several placebo tests and re-estimate the model dropping the critical years (see Section 5.3). These robustness checks confirm our overall findings, as well.

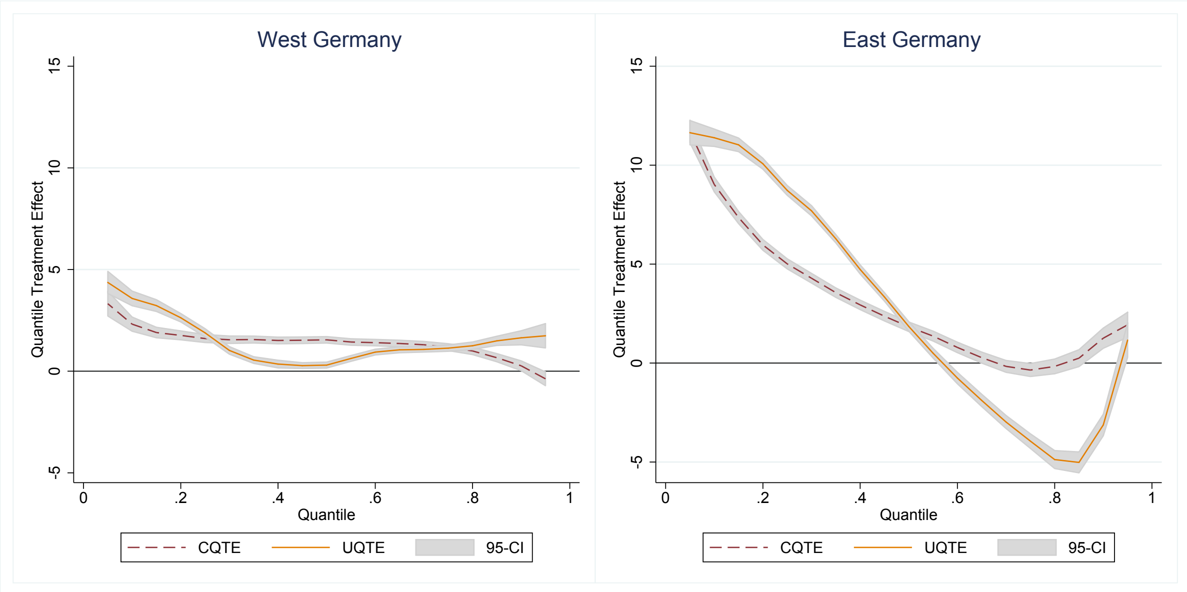
In addition, there are two alternative explanations that must be ruled out. The first one is sample selection. In particular, it might be the case that observed wage changes over time between treatment and control industry reflect compositional changes, rather than changes due to the minimum wage. For instance, if low productivity workers drop out of the workforce or if smaller firms stop operating, this might bias the estimates. Our rich set of time-varying individual and firm-level covariates controls for such selection effects based on observable characteristics, although we cannot fully rule out compositional changes with respect to unobservable characteristics.[19] To further test whether our findings are driven by workers dropping out of the sample, we re-estimate our model based on a balanced sample of roofers (for corresponding tests see Section 5.3). The other alternative explanation is that wage changes might be driven by interfirm mobility such as fired workers that re-enter employment in lower paid jobs. Corresponding estimates based on a balanced sample of roofers, who stay employed in the same firm during the entire time period, suggest that our observed wage changes are driven by firm-specific wage policies among experienced workers rather than changing salaries for new hires.

## 5.2 Results

Figure 2 displays both UQTE and CQTE for 19 different quantiles (from 5th to 95th). Table 2 shows corresponding figures for quantiles $\tau$=0.1, 0.25, 0.5, 0.75, 0.9 (Columns 2-6) as well as for two inequality measures (the variance of the wage and the Gini coefficient, Columns 7-8). The results for the UQTE reveal a large degree of heterogeneity in the minimum wage effects across

[19] To our knowledge, there does not exist yet an unconditional quantile regression model for panel data with fixed effects which is suitable for our purposes.

Figure 2: Minimum Wage Effects on the Unconditional and Conditional Daily Wage Distribution




*Notes:* This figure shows CQTE and UQTE estimates including their 95% confidence intervals based on bootstrapping with 100 replications; Corresponding figures for selected quantiles are shown in Table 2.

quantiles as indicated by the deviations of the RIF-OLS coefficients from the OLS coefficients. In particular, real wages at the lowest quantiles increased by more than 11% in East Germany as a result of the minimum wage (Column 3, Basic Model). Figure 2 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, see Column 5). However, in contrast to these favorable effects, workers with high wages in East Germany experienced real wage losses of up to 5% (Figure 2). These real wage losses mostly reflect wage restraints among skilled workers already working in the industry and within the same firm ever since (for corresponding tests see Table 5 in Appendix A.5 as well as Section 5.3). Whereas the wage compression at the bottom and middle of the distribution 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 the negative scale effect dominating the positive substitution effect for high-skilled workers.

In contrast, the effects for West Germany are small. Workers at the lowest quantiles experienced minimum wage-induced real wage increases of up to 4%. The effects fade out at about the 40th quantile (Figure 2). For higher earning groups, the wage effects increase slightly (above 1%). Despite the reduction in lower tail inequality, overall wage dispersion did not change much in this part of the country, also reflected in the small negative effect on the Gini coefficient. The fact that we find much weaker positive wage effects at the bottom of the wage distribution and no wage losses among upper tail workers reflects the lower bite of the minimum wage in this part of the country (see Section A.2).

Comparing UQTE (solid line) to CQTE (dashed line) in Figure 2 for East Germany reveals further insights into the wage compression effects in East Germany. Generally, conditional estimates refer to within-group inequality, whereas unconditional estimates refer to overall inequality. The difference between both estimates is informative about between-group inequality. In our case, unconditional estimates (solid line) are much higher than conditional estimates (dashed line) for workers below the median and unconditional estimates are much lower than conditional estimates for workers with earnings above the median in East Germany. These differences can be attributed to the between-group effect. At lower quantiles, the between- and within group effect are both positive. This suggests that the minimum wage decreased wage inequality at the lower rank both within groups with similar observable characteristics as well as between these groups. More interesting is the pattern for upper quantiles. Here, within-group inequality remained unchanged (zero treatment effect), while between-group inequality decreased (negative treatment effect). The result, that the wage compression effect at the upper tail in East Germany is driven solely by the between-group effect, indicates that returns to observable skills decreased in reaction to the policy reform there. 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).

## 5.3 Robustness

**Anticipation effects.** To test whether our UQTE in Figure 2 are contaminated by anticipation behaviour before the policy change, we conduct several placebo tests (Table 2). We restrict the sample to the pre-reform years (1) 1994-1997, (2) 1994-1996 and (3) 1994-1995 and assume the subsequent year to be the post-reform period. If there were no anticipation effects, we would observe QTE of zero at each quantile. The results suggest positive anticipation effects in

1997 (see Placebo I in Table 2) and to a lesser degree in 1996 (Placebo II), meaning that firms started to adjust wages upwards prior to the minimum wage during these years. This implies a downward bias for our main estimates. We do not find such effects for the year 1995 in the East, and only weak effects in the West (Placebo III). To make sure the results are not driven by these anticipation effects, we re-estimate the basic model in two versions: In a first version, we declare the 1997 to be part of the post-reform period (Robustness I) since there are only 3 months between the data point in June 30th 1997 and the minimum wage introduction in October 1st of the same year. In a second version, we drop all observations of the years 1996 and 1997 (Robustness II). The slightly higher coefficients of the latter models suggest that the basic model underestimates the wage effects. Nevertheless, the negative wage effects for top-earners in East Germany remain significant. Overall, the estimates change only slightly, suggesting that our estimates are robust.

**Restricting the sample to stayers.** The minimum wage caused a compression at the top of the East German real wage distribution. This compression effect might either result from lower entry wages of new workers or from wage restraints among incumbent workers. To test this, we restrict the sample to workers who we observe in every year in the sample, creating a balanced sample (Robustness III). The effects decrease in West Germany, indicating that wage changes in Western Germany are partly driven by new entrants to the industry. In contrast, the effects stay almost unchanged for East German roofers, which implies that our estimates for East Germany are not driven by lower entry wages of new workers. Instead, real wages of incumbent top earners declined in East Germany. We further restrict the balanced sample to all workers that were employed in the same firm during the entire observation period (Robustness IV). Again the results are stable for East German workers, suggesting that the effects are also not driven by workers that lost their job and returned to work with a lower salary in a different firm.

**Alternative control industries.** Finally, we re-estimate the basic model using glaziers instead of plumbers as a control industry (Robustness V). The results largley confirm our findings, which is not surprising given the high comparability of glaziers and plumbers to roofers, as suggested in Section 3.2.

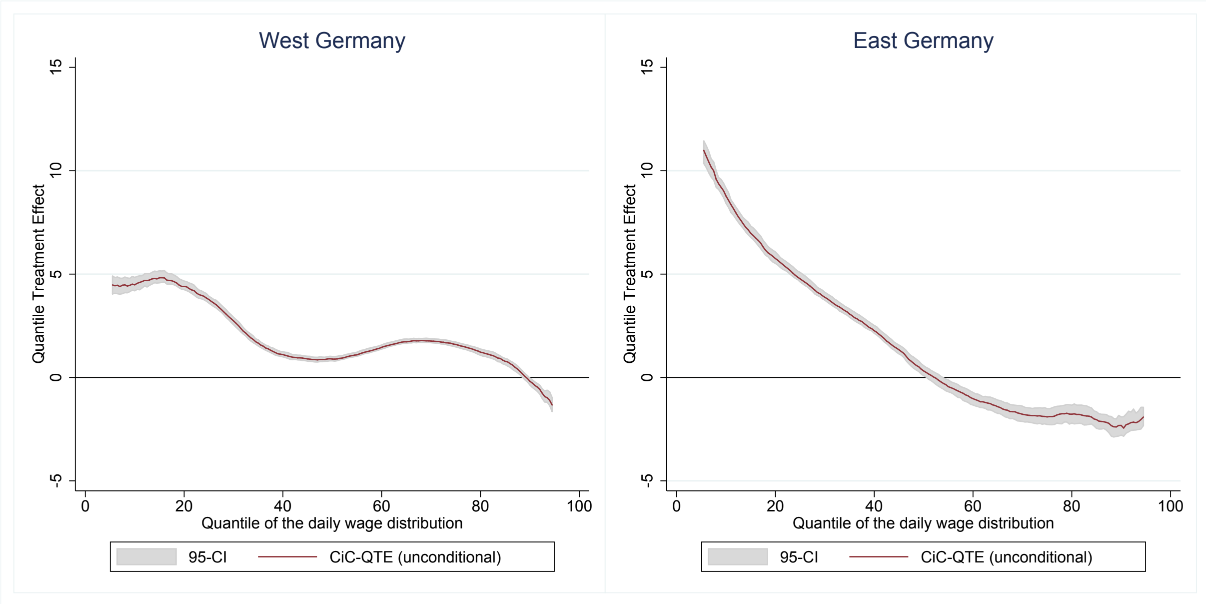
Table 2: Placebo Tests and Robustness Checks for UQTE in Figure 2

| Dependent variable: log real daily wages | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | OLS | Quantile Regression Estimates (RIF-OLS) | | | | | | |
| Post-reform period | N | | $\tau = 0.1$ | $\tau = 0.25$ | $\tau = 0.5$ | $\tau = 0.75$ | $\tau = 0.9$ | Variance | Gini |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| **West Germany** | | | | | | | | | |
| Basic model | | | | | | | | | |
| 1998-2008 | 1,055,400 | 1.33*** | 3.58*** | 1.89*** | 0.30*** | 1.13*** | 1.64*** | 0.14 | -0.05** |
| | | (14.66) | (18.90) | (18.79) | (3.91) | (13.31) | (8.57) | (1.14) | (-2.84) |
| Placebo tests | | | | | | | | | |
| I. 1996-1997 | 323,405 | 0.81*** | 1.84*** | 1.50*** | 1.00*** | 0.33* | 0.66* | 0.51* | -0.03 |
| | | (5.47) | (7.15) | (7.90) | (8.04) | (2.17) | (2.28) | (2.41) | (-1.08) |
| II. 1995-1996 | 245,291 | -0.07 | 0.78* | 0.10 | -0.01 | -0.65*** | -0.73* | -0.34 | -0.08** |
| | | (-0.39) | (2.54) | (0.43) | (-0.06) | (-3.46) | (-2.05) | (-1.21) | (-2.66) |
| III. 1995 | 166,420 | -0.54** | -0.14 | -0.79** | -0.67*** | -0.96*** | -0.93* | -0.60 | -0.06 |
| | | (-2.68) | (-0.38) | (-2.74) | (-3.45) | (-5.38) | (-2.56) | (-1.77) | (-1.67) |
| Robustness of basic model | | | | | | | | | |
| I. without year 1996 | 1,055,400 | 1.57*** | 3.84*** | 2.24*** | 0.63*** | 1.27*** | 2.10*** | 0.32* | -0.04* |
| | | (15.99) | (19.94) | (19.98) | (7.57) | (12.93) | (11.56) | (2.40) | (-2.03) |
| II. without years 1996 | 898,415 | 1.81*** | 4.52*** | 2.80*** | 0.82*** | 1.37*** | 2.19*** | 0.40* | -0.06** |
| and 1997 | | (15.71) | (20.25) | (21.17) | (8.24) | (11.71) | (8.68) | (2.36) | (-3.01) |
| III. only stayers | 196,217 | 0.22 | 0.22 | -0.04 | 0.85*** | 0.17 | -0.52 | -0.29* | -0.06** |
| | | (1.50) | (0.91) | (-0.23) | (6.96) | (0.94) | (-1.42) | (-2.21) | (-2.70) |
| IV. only stayers | 158,894 | 0.09 | 0.13 | -0.14 | 0.70*** | -0.09 | -0.88 | -0.32* | -0.06* |
| in same firm | | (0.51) | (0.44) | (-0.71) | (4.53) | (-0.42) | (-1.93) | (-2.34) | (-2.51) |
| V. Glaziers | 559,508 | 2.15*** | 5.02*** | 3.85*** | 1.36*** | 1.08*** | 0.96*** | -0.24 | -0.17*** |
| | | (13.31) | (16.42) | (21.14) | (9.24) | (8.52) | (3.58) | (-1.32) | (-6.41) |
| **East Germany** | | | | | | | | | |
| Basic model | | | | | | | | | |
| 1998-2008 | 451,241 | 3.07*** | 11.39*** | 8.73*** | 1.85*** | -3.94*** | -3.13*** | -1.17*** | -0.70*** |
| | | (22.18) | (61.03) | (61.44) | (15.04) | (-19.31) | (-11.84) | (-5.53) | (-31.25) |
| Placebo tests | | | | | | | | | |
| I. 1996-1997 | 174,675 | 1.74*** | 3.81*** | 3.12*** | 2.18*** | -0.59 | -0.65 | -0.41 | -0.19*** |
| | | (7.72) | (11.91) | (14.85) | (9.60) | (-1.93) | (-1.63) | (-1.14) | (-5.32) |
| II. 1995-1996 | 131,337 | -0.17 | 0.83** | 0.62* | 0.61* | -1.50*** | -0.65 | 0.11 | -0.02 |
| | | (-0.60) | (2.62) | (2.01) | (2.20) | (-4.17) | (-1.63) | (0.28) | (-0.43) |
| III. 1995 | 86,752 | -0.91** | -0.61 | -0.39 | -0.24 | -1.77*** | -1.16 | 0.35 | 0.05 |
| | | (-2.75) | (-1.20) | (-1.12) | (-0.79) | (-3.76) | (-1.96) | (0.69) | (0.83) |
| Robustness of basic model | | | | | | | | | |
| I. without year 1996 | 451,241 | 3.47*** | 11.36*** | 8.73*** | 2.54*** | -3.15*** | -3.12*** | -1.09*** | -0.67*** |
| | | (22.72) | (48.42) | (64.97) | (18.40) | (-13.60) | (-8.46) | (-4.96) | (-25.68) |
| II. without years 1996 | 363,318 | 3.86*** | 12.72*** | 9.81*** | 3.17*** | -3.51*** | -4.65*** | -1.26*** | -0.77*** |
| and 1997 | | (20.90) | (49.64) | (64.06) | (21.54) | (-14.90) | (-10.29) | (-5.62) | (-25.91) |
| III. only stayers | 41,518 | 2.64*** | 11.63*** | 7.26*** | -0.33 | -6.52*** | -2.99** | -1.25*** | -0.60*** |
| | | (6.24) | (25.32) | (22.77) | (-0.65) | (-9.07) | (-2.82) | (-3.33) | (-9.83) |
| IV. only stayers | 31,115 | 2.67*** | 10.90*** | 8.13*** | 0.23 | -7.82*** | -1.41 | -1.78** | -0.64*** |
| in same firm | | (5.07) | (21.70) | (21.13) | (0.48) | (-8.85) | (-1.01) | (-2.95) | (-8.55) |
| V. Glaziers | 251,694 | -0.80** | 8.91*** | 3.53*** | -2.83*** | -6.18*** | -4.68*** | -1.06** | -0.63*** |
| | | (-2.64) | (15.69) | (13.58) | (-13.97) | (-18.54) | (-8.22) | (-2.86) | (-14.63) |

*Notes:* robust t-statistics in parentheses. Significance levels: * 5%, ** 1%, *** 0.1%. Standard errors are bootstrapped with 100 replications.

**Alternative estimation procedures.** As a final check, we estimate the QTE based on the changes-in-changes model proposed by Athey and Imbens (2006). The alternative estimation

Figure 3: Quantile Treatment Effects based on Changes-in-Changes (CiC) Model




procedure tackles two problems: First, the effect of time might be heterogenous. For instance, despite our evidence on the general commonalities, one might worry that treatment and control industries experienced different time trends in the aftermath of the minimum wage introduction, thus violating the common trends assumption. Second, the common trend assumption may not be invariant to a monotonic transformation. In our case, the results may be different depending on whether we use wages in level of logs. The CiC model solves these shortcomings by assuming that our treatment and control industry experienced common changes (rather than common trends). The results in Figure 3 confirm the findings of the UQTE based on the estimator by Firpo et al. (2009), although the negative wage effect at the top of the wage distribution is somewhat smaller (up to 2%).

# 6 What Explains the Wage Compression at the Top?

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, 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 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 induced 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 low-skilled employment ($L$) (net effect) into the effect on the low-skilled employment share (substitution effect) and the effect on total employment (scale effect) as follows:

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

We proceed analogously for medium- ($M$) and high- ($H$) skilled workers. We estimate the respective effects within a regional DiD approach since we are interested in aggregate rather than individual-level outcomes here. 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 IAB micro 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 treated/untreated industry and define three equal-sized tertiles, representing low-, medium- and high-skilled workers. In a second step, we compute figures on employment and average wages for the total workforce and each skill group.[20] We compute these figures at the level of 412 regional labour markets (NUTS-3) for each industry and year between 1994-2008. Note that this is only possible because our sample covers a large fraction of the population (see Section 4.1).

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

$$\ln Y_{jrt} = \alpha + \beta D_j + \delta (Post_t \times D_j) + \nu_{rj} + \varepsilon_{jrt} \quad (6)$$

where $D_j$ represents the treatment status (roofing vs. plumbing industry) and $Post_t$ captures the post-treatment phase. The term $\nu_{rj}$ represents industry-region fixed effects. The parameter $\delta$ captures the effect of the minimum wage. 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 the same (see Section 5.1.3).

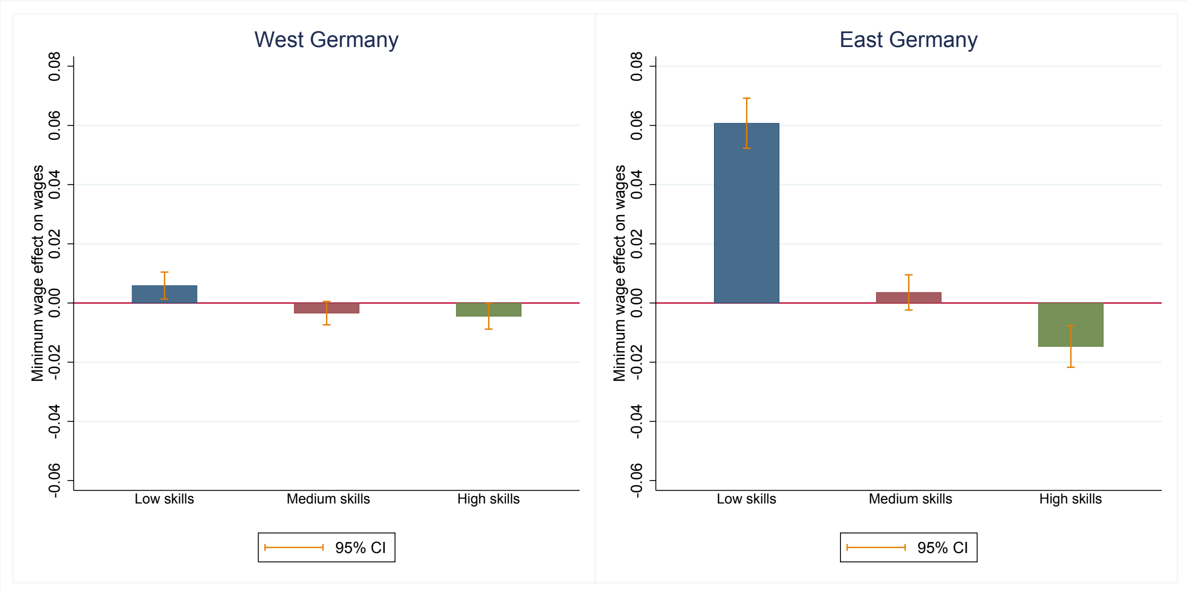
We use skill-specific employment shares, overall employment and skill-specific net employment as outcome variables to estimate the substitution effect, scale effect and net effect from Equation 6. To test whether the regional level approach resembles the quantile regression estimates for wages in Section 5, we estimate Equation 6 using skill-specific average regional wages as the dependent variable. To account for size differences between regions, regressions are weighted by (skill-specific) regional employment in pre-treatment years (for estimates without weights, see Apendix A.7).[21]

Figure 4 shows the minimum wage effects on wages based on the approach described above. Corresponding figures are shown in Appendix Table 6. Overall, the results resemble the quantile regression results in Section 5. In particular, they demonstrate that the minimum wage led to a substantial wage-increase among low-skilled workers (around 6%) in East Germany, whereas high-skilled workers experienced minimum wage-induced wage-reductions (around 1%). For West Germany, we find only very small positive wage effects for low-skilled workers (around 1%)

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

[21] Our 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.

Figure 4: Minimum Wage Effects on Wages by Skill Group



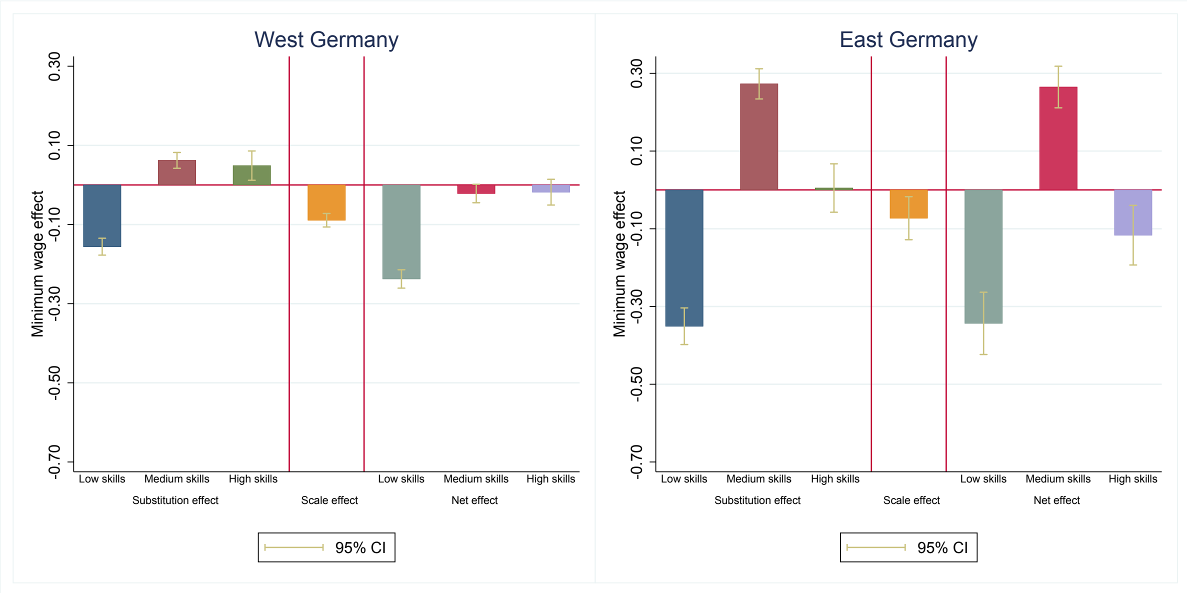

*Notes:* Corresponding estimates are shown in Table 6 in the appendix. All regressions are weighted by regional (skill-specific) employment in pre-treatment years. Whiskers mark the 95 percent significance interval.

and no impact on high-skilled workers. The findings confirm our results in Section 5, although our estimates are smaller. The smaller effects likely reflect the fact that, by focussing on three broad skill groups, we average out some of the spikes seen in the quantile treatment plots.[22]

The results for the substitution and scale effect are shown in Figure 5. For East Germany, we see a substantial substitution of low- (-35%) by medium-skilled workers (+27%), 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 East, which required substantial adjustments within firms in order to cope with minimum wage induced cost increases. However, these positive (and neutral) 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 (-7%) resulting from overall increased labour costs (and falling firm revenues, see Appendix A.8), such that the net impact on high-skilled workers is negative (-12%). For medium-

[22]We refrain from differentiating workers in more skill groups, as the number of observations in our region-industry-year cells would become too small.

Figure 5: Scale and Substitution Effects by Skill Group




*Notes:* Corresponding estimates are shown in Table 8 in the appendix. All regressions are weighted by regional (skill-specific) employment in pre-treatment years. Whiskers mark the 95 percent significance interval.

skilled workers, the positive substitution effects suffices to overcompensate the negative scale effect, resulting in a net positive employment effect for these workers (+26%). For low-skilled workers, the scale effect even enforced the negative substitution effect (on net, -34%).

In West Germany, where the minimum wage bite was much lower, we see a much smaller substitution away from low- (-16%) to medium-skilled workers (+6%). Surprisingly, we also find substitution towards high-skilled workers, although the effect is smaller (+5%). The latter might suggest that low-skilled workers' tasks are partly substitutable with high-skilled workers' tasks in the West, but not in the East. This could be due to smaller differences between low- and high-skilled tasks in West Germany, rooted in differences in the training systems for historical reasons.[23] The decline in overall employment is similar to East Germany (-9%). On net, the positive substitution effects can just about compensate for the negative scale effect, so that the net effects are close to zero for both groups (-2%). The net effect on low-skilled workers was -24%.

Overall the results demonstrate that negative employment and wage responses to a minimum wage for high-skilled workers may occur in situations where two circumstances come together:

[23]We abstract from substitution towards high-skilled workers to keep the model traceable and because we are mostly interested in East Germany where no such substitution occurs.

First, the minimum wage is introduced in an environment where the response of output to prices is particularly negative, namely, during an economic downturn with falling revenues. Note that we provide further evidence in Appendix A.8 suggesting negative minimum wage effects on regional revenues (average firm, industry total and average firm per worker) in East and West Germany. The findings are based on separate micro data for all active firms in Germany and confirm a negative aggregate demand shock in both parts of the country. Second, the minimum wage bite must be particularly high, while high-skilled workers are not close substitutes to low-skilled workers. This situation leads to a large increase in wages of low relative to medium-skilled workers, thus inducing a strong substitution away from low-skilled to medium-skilled workers, while there is no substitution towards high-skilled workers. This is what we see in East Germany, where the minimum wage level was set relatively high compared to lower wage levels. In contrast, the bite was less severe in West Germany, explaining why we find more muted results there.

# 7 Implications for Skill Supply

Our results from previous sections show that the minimum wage policy led to a wage compression at both ends of the wage distribution and reduced the returns to skills in East Germany. In West Germany, the effects on the wage distribution were much more muted, suggesting only slight declines in the returns to skills. We explain these findings with our model of minimum wage-induced scale and substitution effects. In the present section, we turn to the minimum wage effects on skill supply.

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 changes 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 and suffer from declining returns to skills (Corollary 1). Moreover, as before, we expect differences between East and West Germany due to the difference in the bite of the minimum wage.

To test these predictions, we follow a similar regional DiD approach as described in Section

Table 3: Minimum Wage Effects on Industry Skill Supply

| | West Germany | | East Germany | |
|---|---|---|---|---|
| | (A) Share of apprentices among entrants | (B) Skills of apprentices | (A) Share of apprentices among entrants | (B) Skills of apprentices |
| | (1) | (2) | (3) | (4) |
| Treat × post | 0.07*** | -0.01 | 0.03*** | -0.03*** |
| | (13.43) | (-1.44) | (3.32) | (-2.62) |
| Post | 0.00 | 0.02*** | -0.01 | 0.06*** |
| | (0.97) | (7.06) | (-0.92) | (8.06) |
| Constant | 0.26*** | 0.03*** | 0.18*** | 0.02*** |
| | (115.31) | (19.56) | (51.48) | (4.83) |
| N | 9630 | 8869 | 2598 | 2396 |
| R-squared | 0.037 | 0.007 | 0.006 | 0.035 |
| F | 172.2 | 29.3 | 7.4 | 40.4 |

*Notes:* t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects and are weighted with pre-treatment number of entrants (in case of A), number of apprentices (in case of B).

6. Based on the regional data and in line with our theoretical predictions, we estimate the effect of the minimum wage on the supply of skills to the industry by using as dependent variables: (A) the share of new apprentices among all entrants and (B) the share of apprentices with the highest school degree (i.e. high-school degree) as proxies for medium- and 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. Note 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. Our estimates are weighted to account for differences in the size of regions (see table notes). Appendix A.9 provides unweighted results.

Table 3 shows the results. In East Germany, we find an increase in the share of apprentices among new workers in the industry, reflecting the rise in the relative demand for medium-skilled workers, as expected (A, Column 3). However, the quantitative size of the effect (+3%) is smaller compared to the increase in relative demand (+27%) found in Section 6. One reason for this gap could be that our dependent variable provides only a proxy for medium-skills, leading to an underestimation of medium-skilled entrees' 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. In 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). In line with our predictions, we further find a decline in the share of apprentices with a high-school degree (-3%) in response to the minimum wage (B, Column 4). 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 extensively documented by Aretz et al. (2011).

In West Germany, we also find an increase in the share of apprentices among new employees, as expected (A, Column 1). Here, the effect (+7%) more closely matches the rise in relative demand for medium-skilled workers (+6%) found in Table 6. This suggests that West German firms restructure more strongly through hiring rather than separation. Aretz et al. (2013) indeed find that separation rates for low-skilled workers increased more modestly in West compared to East Germany, where the bite was also lower. Table 3 further shows that the minimum wage had no statistically significant effect on the selection of workers into the West German roofing industry (B, Column 2). This can be explained by the lack of negative wage effects on high-skilled workers in this part of the country. The bite of the minimum wage apparently was too weak to reduce returns to skills and the supply of high-skilled workers.

# 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: the German roofing industry. The minimum wage was introduced in 1997 and 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 6 in Appendix A.2), in combination with an economic downward trend currently observed around the globe. Based on our quasi-experimental case study, we draw four 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 roofing industry, we find significant real daily wage increases of up to 11% for lower-quantile workers that ripple up to the 60th quantile in East Germany between 1997 and 2008, where the Kaitz-index reached values of 100 percent (i.e. minimum wage equals the median wage). In West Germany, where the Kaitz-index "only" reached values of 72 percent, the wage effects are weaker (about 4% at the lower tail). Hence, the policy seems to have met its goal of improving the earnings of low-wage workers (at least for those, who did not loose 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 about 5% in East Germany for the highest quantiles (stagnating nominal wages) that mostly comprise skilled and experienced workers. In turn, the returns to skills declined in the industry. We do not find such negative effects on wages in West Germany, where the bite was considerably smaller, suggesting that the bite needs to be sufficiently large to cause such negative wage spillovers.

Third, negative spillovers may arise if the scale effect dominates the substitution effect. We demonstrate this for the German roofing industry, where the minimum wage caused an overall decline in product and labour demand in the industry. For medium-skilled workers, 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 such substitution effects as their tasks are not suitable substitutes to low-skilled minimum wage workers, leading to a negative net impact on wages and employment. The proposed mechanism may be a missing link in explaining negative spillovers from minimum wage policies, especially in an environment of an economic downturn with falling revenues.

Fourth, a minimum wage may also hamper skill supply. Our results suggest that the minimum wage has worsened the selection of workers into the East German roofing industry. The industry is facing increasing problems in attracting high-skilled workers. We do not find a significant worsening of worker selection in West Germany, where the bite was weaker and had more muted effects on the wage structure. This demonstrates how a minimum wage can affect skill supply.

Finally, a high minimum wage bite seems to be important in explaining our findings. Throughout our paper, we find large effects particularly in East Germany, where the bite was large. Effects in West Germany, where the bite was lower, are by far more muted. This is in line with a large literature which focuses on incremental increases of minimum wages and finds no or only modest disemployment 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 6 in Appendix A.2).

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# 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 $\eta$, $n_i = \left( l_i^{\frac{\eta-1}{\eta}} + m_i^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$. 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

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

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

### 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, $U = \left[ \int_0^I q_i^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}$.[24]

[24] This 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. $\sigma \to \infty$).

Total roofing sales are $R = \int_0^I p_i q_i di$. Utility maximization implies a downward sloping demand curve for each variety,

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

with the CES price index $P = \left[\int_0^I p_i^{1-\sigma}\right]^{1/(1-\sigma)}$. 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:

$$p_i = \frac{\bar{w}}{\varphi} \frac{\sigma}{\sigma - 1} \tag{10}$$

Free entry implies that new firms enter the market until profits decline to zero, from which we derive firm size:[25]

$$q_i = (\sigma - 1)\varphi f \tag{11}$$

Firm size is exogenous. Without loss of generalizability, we normalize $\varphi \equiv \sigma/(\sigma - 1)$ and $f \equiv 1/\sigma$.[26] Using equilibrium firm size (11) and the price markup (10) in the product demand equation (9) then provides

$$\bar{w}^{\sigma} = RP^{\sigma-1} \tag{12}$$

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:

$$Q = \bar{w}^{-\tilde{\varepsilon}} Q_0^{\tilde{\varepsilon}/\varepsilon} \tag{13}$$

[25] We 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.

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

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 $\varepsilon$ and the elasticity of substitution between firms' varieties $\sigma$. Demand for high-skilled workers $H$ is proportional, as there is no firm heterogeneity:

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

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

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

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 $\eta$.

### 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 $L_t^S \geq L_t$,[27] 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, $\delta L_t$ 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 $\theta$. At each time instant, all workers face the exogenous retirement risk $\delta$. 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,

[27] This assumption is motivated by the high unemployment rate among low-skilled workers.

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

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

We proceed analogously for high-skilled workers to get

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

## A.2 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 4 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).[28] 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 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.

[28]Note 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 4: Indicators of the Minimum Wage Bite Measured in June Prior to the Next Minimum Wage Regulations

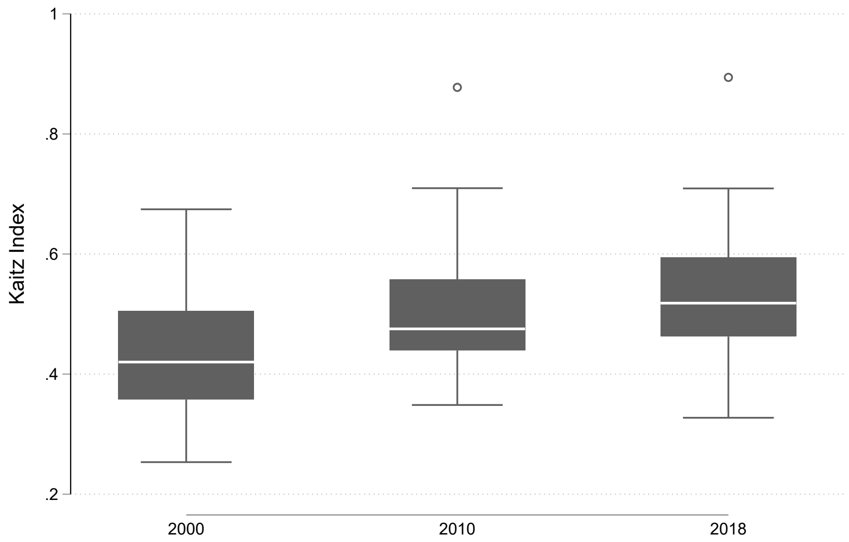
| | | Workers with an hourly wage: | | | | |
|---|---|---|---|---|---|---|
| | | below next minimum wage | | | at/above next minimum wage | |
| Date of next minimum wage regulation (1) | minimum wage (in €) (2) | Share of all workers (in %) (3) | Wage gap[a] (in %) (4) | Annual Wage growth[b] (in %) (5) | Annual Wage growth[b] (in %) (6) | Kaitz Index[c] (7) |
| **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 $wgap_{it} = (w_{MW_{i,t+1}} - w_{it})/w_{it}$.
[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 cacluations based on the LAK data.

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. 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.

Figure 6: 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

## A.3 LAK data

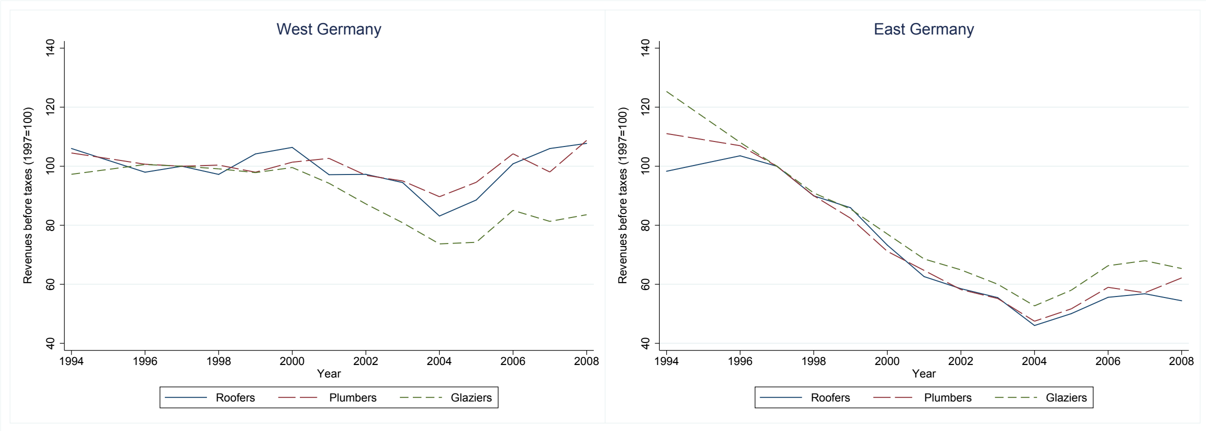
The LAK is a public service institution of the employer association ZVDH and the trade union IG Bau in Germany. The main objective is to help insure employees against several structural disadvantages of the industry. For instance, the agency compensates roofers for earnings losses caused by bad weather, 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.[29]. 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.

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

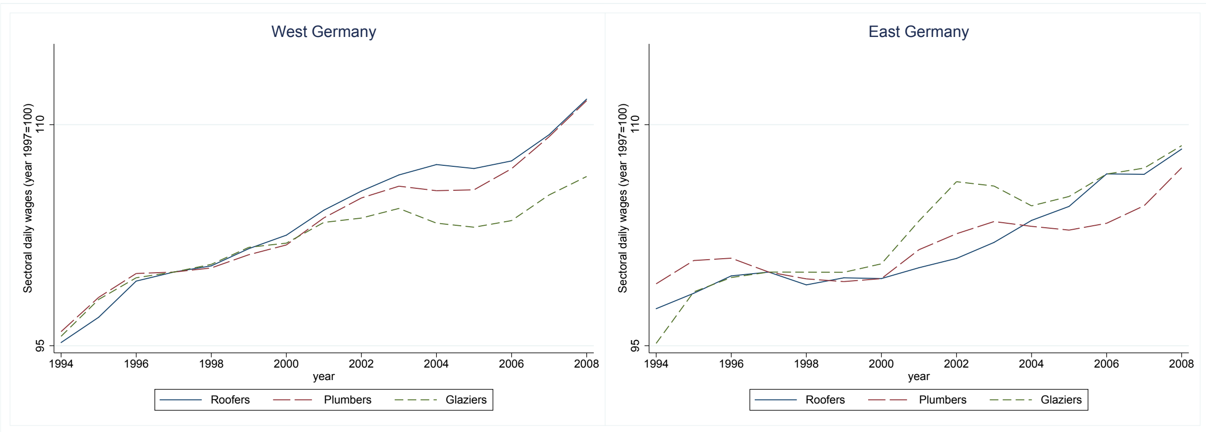
## A.4 Business cycle trends

Figure 7: Business Cycle Trends for Roofers and Selected Control Industries

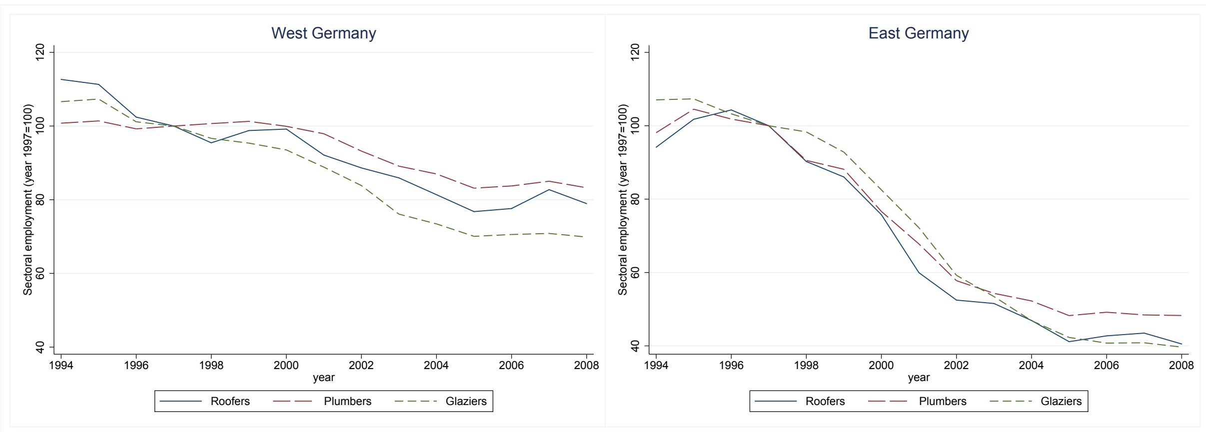
(a) Revenues




(b) Gross daily wages




(c) Employment




*Notes:* Revenues are taken from the German sales-tax statistics provided by the Federal Statistical Office. Gross daily wages and employment figures are based on the BA data (see Section 4.1).

## A.5 Changes in the Earnings Distribution

Table 5: Average Worker Characteristics by Quantiles of the Real Daily Wage Distribution, German Roofing Industry (BA-data)

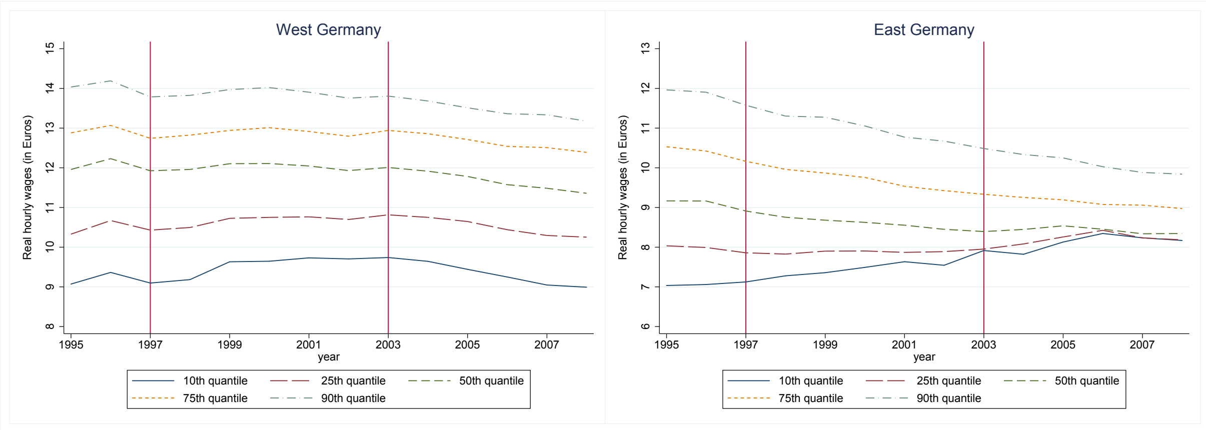
| | Quantile | | | | |
|---|---|---|---|---|---|
| | $\tau = 0.1$ | $\tau = 0.25$ | $\tau = 0.5$ | $\tau = 0.75$ | $\tau = 0.9$ |
| **West Germany** | | | | | |
| real daily wage (in €) | 51.6 | 60.5 | 69.7 | 79 | 90.1 |
| yearly growth of real daily wages (in %) | 3 | 1.2 | .1 | -.6 | -1.1 |
| nominal daily wage (in €) | 57.1 | 67 | 77.2 | 87.5 | 99.8 |
| yearly growth of nominal daily wages (in %) | 4.6 | 2.8 | 1.7 | 1 | .5 |
| share of unskilled workers (non-technicians) | 23.9 | 15.9 | 9.4 | 6 | 5.8 |
| share of skilled workers (technicians) | 74.5 | 82.7 | 88 | 88.8 | 81.8 |
| share of master craftmen | .8 | 1.2 | 2.3 | 4.9 | 12 |
| without vocational traning degree | 11.1 | 7.4 | 3.6 | 2.8 | 3.2 |
| with vocational traning degree | 76.7 | 83.1 | 88.4 | 89.9 | 88.9 |
| with university degree | .2 | .2 | .2 | .3 | .5 |
| tenure in industry (in days) | 1364.1 | 1705.5 | 2090.4 | 2205.4 | 2236.3 |
| average age | 30.2 | 33.1 | 37.7 | 40.5 | 42.5 |
| number of workers | 432 | 432 | 432 | 432 | 432 |
| **East Germany** | | | | | |
| real daily wage (in €) | 37.9 | 42.2 | 47.3 | 54.5 | 65.1 |
| yearly growth of real daily wages (in %) | 1.9 | .4 | -.5 | -1.1 | -1.7 |
| nominal daily wage (in €) | 42 | 46.7 | 52.3 | 60.2 | 71.9 |
| yearly growth of nominal daily wages (in %) | 3.5 | 2 | 1 | .4 | -.1 |
| share of unskilled workers (non-technicians) | 12.5 | 9.3 | 9.3 | 9.4 | 9.5 |
| share of skilled workers (technicians) | 86.5 | 90.1 | 89.2 | 86.6 | 83.2 |
| share of master craftmen | .7 | .6 | 1.3 | 3.9 | 7.3 |
| without vocational traning degree | 2.2 | 1.9 | 1.6 | 1.4 | 2.4 |
| with vocational traning degree | 85.1 | 86.9 | 87.9 | 83.7 | 81.3 |
| with university degree | .3 | .1 | .2 | .5 | .7 |
| tenure in industry (in days) | 1327.6 | 1673.4 | 1853.7 | 1979.3 | 1963.3 |
| average age | 34.6 | 37 | 38.5 | 40 | 40.8 |
| number of workers | 175 | 175 | 176 | 175 | 175 |

*Notes:* All figures shown in the table reflect average yearly values. Real wages are inflation-adjusted to prices in 1994.

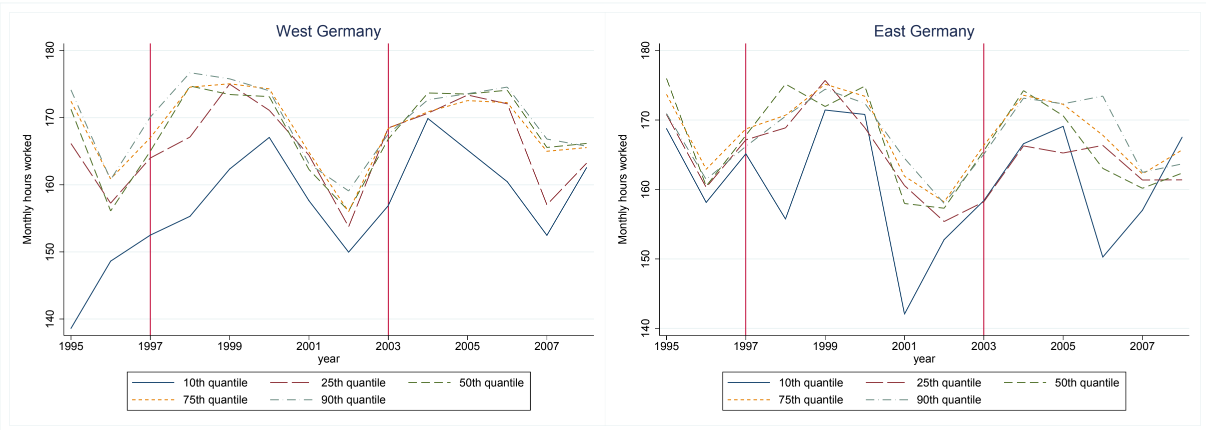
## A.6 Wages and Hours Worked

Figure 8: Development of Real Hourly Wages, Real Monthly Wages and Hours Worked in the German Roofing Industry (LAK data)

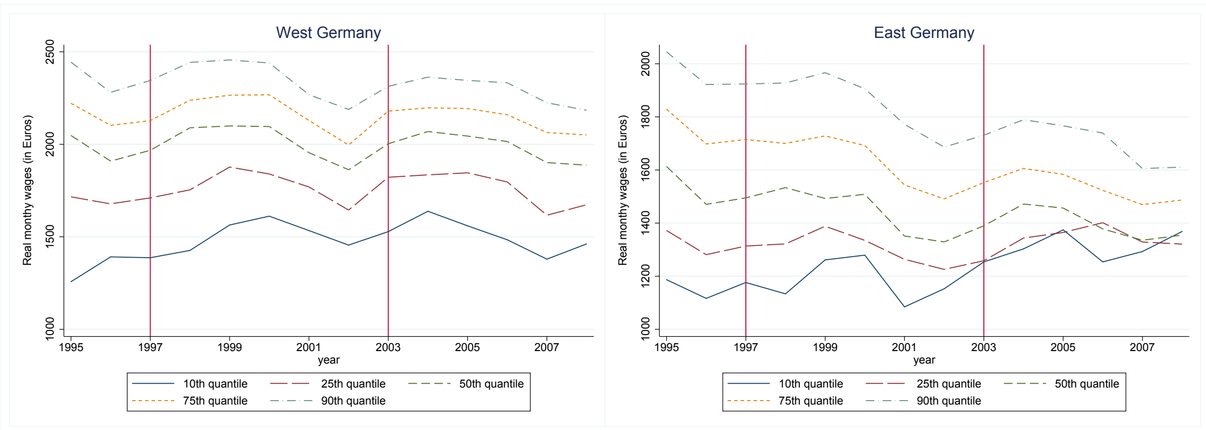
(a) Real hourly wages




(b) Monthly hours worked




(c) Real monthly wages




*Notes:* The vertical lines represent mark the introductions of the minimum wage in October 1997 and the national minimum wage in March 2003.

## A.7 Substitution and Scale Effects

Table 6: Wage Effect by Skill Group as shown in Figure 4

| | West Germany | | | East Germany | | |
|---|---|---|---|---|---|---|
| Skills: | Low<br>(1) | Medium<br>(2) | High<br>(3) | Low<br>(4) | Medium<br>(5) | High<br>(6) |
| Treat × post | 0.01** | -0.00* | -0.00** | 0.06*** | 0.00 | -0.01*** |
| | (2.54) | (-1.69) | (-2.04) | (14.07) | (1.18) | (-4.11) |
| Post | 0.09*** | 0.11*** | 0.10*** | 0.05*** | 0.03*** | 0.01*** |
| | (57.59) | (77.18) | (63.44) | (16.36) | (12.97) | (4.67) |
| N | 9664 | 9660 | 9569 | 2607 | 2606 | 2578 |
| R-squared | 0.442 | 0.541 | 0.446 | 0.414 | 0.125 | 0.009 |
| F | 3566.5 | 5318.0 | 3596.6 | 860.1 | 173.9 | 11.5 |

*Notes:* t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects. Regressions are weighted with pre-treatment region-skill-specific employment.

Table 7: Wage Effect by Skill Group as shown in Figure 4 (unweighted)

| | West Germany | | | East Germany | | |
|---|---|---|---|---|---|---|
| Skills: | Low<br>(1) | Medium<br>(2) | High<br>(3) | Low<br>(4) | Medium<br>(5) | High<br>(6) |
| Treat × post | 0.00* | -0.00 | -0.01*** | 0.06*** | -0.00 | -0.04*** |
| | (1.74) | (-1.21) | (-4.11) | (12.45) | (-0.21) | (-8.30) |
| Post | 0.10*** | 0.11*** | 0.10*** | 0.05*** | 0.03*** | 0.04*** |
| | (50.99) | (69.58) | (56.77) | (15.81) | (13.98) | (13.19) |
| N | 9685 | 9669 | 9569 | 2607 | 2606 | 2578 |
| R-squared | 0.376 | 0.510 | 0.393 | 0.360 | 0.136 | 0.068 |
| F | 2715.8 | 4691.6 | 2890.5 | 683.0 | 191.4 | 88.0 |

*Notes:* t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects.

Table 8: Substitution and Scale Effect by Skill Group as shown in Figure 5

| | Sub effect | | | Scale effect | Net effect | | |
|---|---|---|---|---|---|---|---|
| Skills: | Low<br>(1) | Medium<br>(2) | High<br>(3) | All<br>(4) | Low<br>(5) | Medium<br>(6) | High<br>(7) |
| **West Germany** | | | | | | | |
| Treat × post | -0.16*** | 0.06*** | 0.05*** | -0.09*** | -0.24*** | -0.02* | -0.02 |
| | (-14.31) | (6.09) | (2.59) | (-10.25) | (-20.05) | (-1.82) | (-1.10) |
| Post | 0.29*** | -0.02*** | -0.26*** | -0.14*** | 0.12*** | -0.18*** | -0.41*** |
| | (38.73) | (-3.43) | (-20.27) | (-23.48) | (14.42) | (-22.71) | (-36.42) |
| N | 9700 | 9700 | 9700 | 9700 | 9685 | 9685 | 9700 |
| R-squared | 0.165 | 0.004 | 0.068 | 0.172 | 0.043 | 0.105 | 0.222 |
| F | 894.8 | 19.1 | 328.1 | 937.5 | 201.0 | 528.7 | 1291.0 |
| **East Germany** | | | | | | | |
| Treat × post | -0.35*** | 0.27*** | 0.01 | -0.07** | -0.34*** | 0.26*** | -0.12*** |
| | (-14.61) | (13.75) | (0.16) | (-2.57) | (-8.40) | (9.70) | (-2.98) |
| Post | 0.10*** | 0.07*** | -0.13*** | -0.57*** | -0.58*** | -0.54*** | -0.69*** |
| | (6.00) | (4.97) | (-5.94) | (-28.35) | (-19.42) | (-29.55) | (-24.57) |
| N | 2609 | 2609 | 2609 | 2609 | 2609 | 2609 | 2595 |
| R-squared | 0.094 | 0.205 | 0.027 | 0.431 | 0.377 | 0.304 | 0.381 |
| F | 126.0 | 313.5 | 34.3 | 921.9 | 736.2 | 531.6 | 743.2 |

*Notes:* t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects. Substitution und Scale effects are weighted with pre-treatment regional employment. Net effects are weighted with pre-treatment region-skill-specific employment.

Table 9: Substitution and Scale Effect by Skill Group as shown in Figure 5 (unweighted)

| | Sub effect | | | Scale effect | Net effect | | |
|---|---|---|---|---|---|---|---|
| Skills: | Low<br>(1) | Medium<br>(2) | High<br>(3) | All<br>(4) | Low<br>(5) | Medium<br>(6) | High<br>(7) |
| **West Germany** | | | | | | | |
| Treat × post | -0.15*** | 0.10*** | -0.05 | -0.10*** | -0.24*** | 0.00 | -0.12*** |
| | (-6.49) | (3.88) | (-1.16) | (-10.05) | (-11.61) | (0.07) | (-3.33) |
| Post | 0.29*** | -0.10*** | -0.34*** | -0.10*** | 0.18*** | -0.20*** | -0.42*** |
| | (17.50) | (-5.73) | (-11.15) | (-13.78) | (12.04) | (-12.86) | (-16.13) |
| N | 9713 | 9713 | 9713 | 9713 | 9713 | 9713 | 9713 |
| R-squared | 0.040 | 0.004 | 0.031 | 0.096 | 0.018 | 0.035 | 0.071 |
| F | 187.3 | 16.4 | 143.2 | 483.6 | 82.1 | 163.2 | 345.1 |
| **East Germany** | | | | | | | |
| Treat × post | -0.29*** | 0.30*** | 0.05 | -0.11*** | -0.39*** | 0.20*** | -0.08 |
| | (-8.26) | (8.80) | (0.80) | (-3.39) | (-8.07) | (5.22) | (-1.28) |
| Post | -0.04 | 0.03 | -0.19*** | -0.51*** | -0.55*** | -0.48*** | -0.66*** |
| | (-1.63) | (1.25) | (-4.42) | (-22.71) | (-16.18) | (-17.73) | (-14.59) |
| N | 2609 | 2609 | 2609 | 2609 | 2609 | 2609 | 2609 |
| R-squared | 0.069 | 0.072 | 0.012 | 0.343 | 0.296 | 0.148 | 0.165 |
| F | 90.0 | 94.5 | 15.2 | 636.0 | 511.7 | 210.6 | 240.8 |

*Notes:* t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects.

Table 10: Minimum Wage Effects on Industry- and Firm Revenues

| | West Germany | | | East Germany | | |
|---|---|---|---|---|---|---|
| | total industry revenues | average firm revenues | firm revenues per worker | total industry revenues | average firm revenues | firm revenues per worker |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Treat × post | -0.65*** | -0.37*** | -0.58*** | -0.29*** | -0.35*** | -0.51*** |
| | (-9.98) | (-8.05) | (-9.17) | (-4.78) | (-5.74) | (-5.37) |
| Post | 1.99*** | 0.30*** | 0.67*** | -0.01 | -0.00 | 0.96*** |
| | (65.55) | (13.72) | (22.90) | (-0.31) | (-0.16) | (21.62) |
| Constant | 16.94*** | 14.57*** | 13.18*** | 19.27*** | 14.65*** | 12.76*** |
| | (734.26) | (888.92) | (593.13) | (897.01) | (680.86) | (381.19) |
| N | 8876 | 8876 | 8876 | 2609 | 2609 | 2609 |
| R-squared | 0.369 | 0.023 | 0.060 | 0.013 | 0.018 | 0.170 |
| F | 2419.6 | 95.9 | 263.6 | 15.6 | 21.7 | 248.5 |

*Notes:* 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.

## A.8 Minimum Wage Effects on Firm Revenues

To provide further support on negative aggregate demand shocks in response to the minimum wage in East and West Germany (negative scale effects in Section 6), Table 10 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. 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 11 provides unweighted results.

Table 11: Minimum Wage Effects on Industry and Firm Revenues (unweighted)

| | West Germany | | | East Germany | | |
|---|---|---|---|---|---|---|
| | total industry revenues | average firm revenues | firm revenues per worker | total industry revenues | average firm revenues | firm revenues per worker |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Treat × post | -0.50*** | -0.19*** | -0.44*** | -0.16** | -0.24*** | -0.40*** |
| | (-8.66) | (-4.30) | (-7.37) | (-2.41) | (-3.68) | (-4.09) |
| Post | 2.22*** | 0.50*** | 0.86*** | -0.04 | 0.03 | 1.01*** |
| | (58.61) | (17.39) | (21.80) | (-0.81) | (0.56) | (14.71) |
| Constant | 15.70*** | 14.19*** | 12.67*** | 18.11*** | 14.54*** | 12.46*** |
| | (626.53) | (742.70) | (486.90) | (653.20) | (531.96) | (299.47) |
| N | 9225 | 9225 | 9225 | 2609 | 2609 | 2609 |
| R-squared | 0.368 | 0.044 | 0.061 | 0.008 | 0.009 | 0.108 |
| F | 2493.4 | 195.3 | 279.5 | 9.3 | 11.0 | 147.8 |

*Notes:* t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-region fixed effects.

## A.9 Skill Supply

Table 12: Minimum Wage Effects on Industry Skill Supply (unweighted)

| | West Germany | | East Germany | |
|---|---|---|---|---|
| | (A)<br>Share of apprentices among entrants<br>(1) | (B)<br>Skills of apprentices<br>(2) | (A)<br>Share of apprentices among entrants<br>(3) | (B)<br>Skills of apprentices<br>(4) |
| Treat × post | 0.07*** | -0.02*** | 0.03** | -0.01 |
| | (10.31) | (-4.23) | (2.57) | (-0.56) |
| Post | 0.00 | 0.02*** | -0.01 | 0.04*** |
| | (0.42) | (5.58) | (-0.95) | (4.53) |
| Constant | 0.26*** | 0.03*** | 0.19*** | 0.02*** |
| | (88.38) | (15.07) | (42.90) | (3.81) |
| N | 9640 | 8937 | 2598 | 2396 |
| R-squared | 0.024 | 0.004 | 0.003 | 0.015 |
| F | 111.6 | 15.7 | 4.1 | 17.1 |

*Notes:* t-statistics in parentheses. Significance levels: * 10%, ** 5%, *** 1%. All estimates include industry-year fixed effects.

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**ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung GmbH Mannheim**

ZEW – Leibniz Centre for European Economic Research

L 7,1 · 68161 Mannheim · Germany
Phone +49 621 1235-01
info@zew.de · zew.de