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How is the Minimum Wage Shaping the Wage Distribution: Bite, Spillovers, and Wage Inequality

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Abstract

Over the last three decades, wage inequality and the importance of the minimum wage presented an interesting negative correlation in Portugal. Using a semiparametric approach, counterfactual decomposition methods, and an extremely rich matched employer-employee dataset of all employees in the country, this paper presents significant visual and quantitative evidence of how the minimum wage structurally reshaped the wage distribution. The remarkable rise in the real minimum wage of 2006-2019 fully explained the sharp decline in wage inequality, and 40% of average wage growth - for women, who benefited the most, that was 60%. Spillover effects reached up to 40% above the minimum, being at times more important than the bite itself. The minimum wage reduced within and between wage in-equality in several fronts, cutting the gender wage gap by a quarter, potentially decreasing the returns to education, and raising wages of workers at less productive firms. While the minimum wage bite was felt in workers' base wages, spillovers predominantly manifested in total wages.

JEL Classification: C14, D31, J31, J38
Keywords: minimum wage, spillover effects, wage inequality, counterfactual decomposition

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1. Introduction

Mounting wage inequality starting around the 1980s was a phenomenon experienced by most advanced economies (Milanovic, 2016; Hoffmann et al., 2020). It was primarily driven by labour supply and demand dynamics, like skill-biased technological change (Card and DiNardo, 2002), globalisation (Feenstra and Hanson, 1996), and the general polarisation of the labour market (Autor et al., 2008), but the decay of labour market institutions in several countries, like the minimum wage and unionisation, has also been implicated (DiNardo et al., 1996; Koeniger et al., 2007).

Over a period where inequality in the upper half of the wage distribution follows a clear, positive trend across developed economies, the behaviour of inequality in the lower half of the distribution was much more diverse. Over the same period, the minimum wage, a policy that specifically targets the lower end of the distribution, also exhibited large cross-country heterogeneity, frequently in negative correlation with lower tail wage inequality. For instance, the real value of the federal minimum wage declined continuously in the United States, during the 1980s, and wage inequality rose dramatically (DiNardo et al., 1996; Lee, 1999), while the UK (Stewart, 2012) and Germany (Bossler and Schank, 2020) both saw wage inequality declining at the bottom of the distribution following the introduction of national minimum wages in 1999 and 2015, respectively. That is good reason to give it particular attention in research of inequality and the shaping of the wage distribution.

In Portugal, wage inequality was high and rising between the 1980s and the mid-2000s, and that increase was mostly due to a widening of the wage distribution at the top (Cardoso, 1998; Alvaredo, 2009; Centeno and Novo, 2014). After that, inequality actually decreased through a compression of the lower half of the wage distribution. In fact, the behaviour of wage inequality in Portugal since the mid-1980s can be well divided into three very distinct periods: between 1986 and 1994 inequality increased sharply, especially in the middle and upper-tail of the distribution; between 1994 and the mid-2000s changes in wage inequality were positive but small; and since the mid-2000s it decreased significantly, with an emphasis on the lower-half of the distribution. This is clearly illustrated in figure 1 and quantified in table C.6 of the appendix.

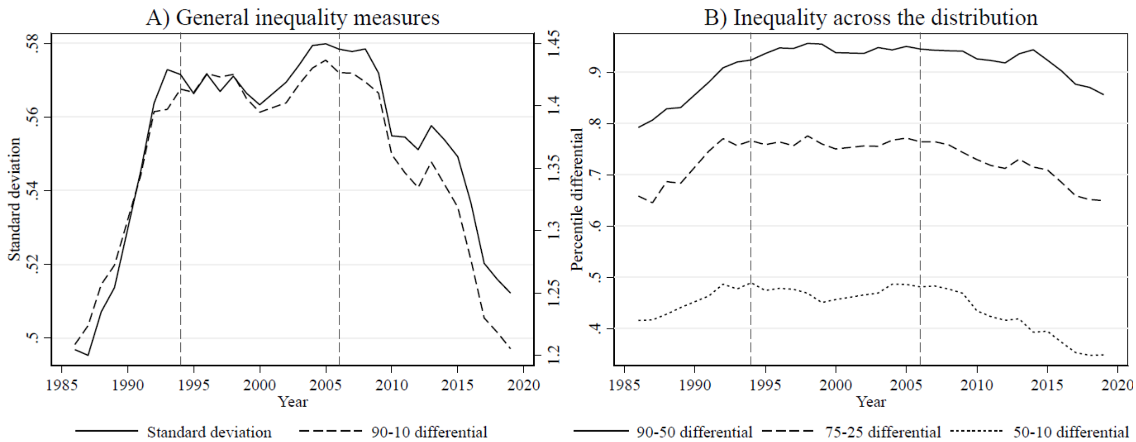

Figure 1: Measures of wage inequality. Panel A depicts wage inequality measures for the entire distribution. Panel B depicts measures of inequality at different parts of the distribution. Both standard deviation and the wage percentile differentials use the logarithm of total monthly wages. The two dashed vertical lines, in 1994 and 2006, divide the three periods of analysis.

The relatively short economic literature aiming to explain the changes in the Portuguese wage distribution over the last decades has naturally focused on the labour market dynamics side of the equation, which does explain a substantial part of those changes. Skill-biased technological changes and the overall modernisation of the labour market had a major impact in the widening of the wage distribution since the 1980s (Cardoso, 1997, 1998; Centeno and Novo, 2014), especially in what regards the growing disparity in returns to education throughout the wage distribution (Cardoso, 1998; Martins and Pereira, 2004; Machado and Mata, 2005) together with a remarkable increase in the education levels of Portuguese workers (Machado and Mata, 2005; Pereira, 2020), and also the rising share of women in the workforce (Cardoso, 1999; Pereira, 2020).

Still, after 1994 the widening of the wage distribution moderated and literature is yet to fully explain that phenomenon, aside from a possible excess of supply of skilled workers relative to unskilled ones that narrowed the lower tail of the distribution (Centeno and Novo, 2014), and a fading association between high-paying firms and high-wage workers (Portugalet al., 2018). Furthermore, wage inequality plummeted since the mid-2000s, especially for lower-wage workers - over a period where the nominal minimum wage almost doubled andthe share of workers on a base wage equal or lower than the minimum went from 8% up to23% - and that remarkable phenomenon is yet to be studied.

With that in mind, this paper contributes to the literature by investigating a side of thestory acknowledged in no more than a handful of articles: the role of the minimum wage. Applying a semiparametric approach that bridges the distribution regression (Chernozhukov et al., 2013) and the rank regression framework (Fortin and Lemieux, 1998), explored in Fortin et al. (2021), and exploiting the extremely rich longitudinal administrative data of the individual records of *Quadros de Pessoal*, this paper presents estimates of the Portuguese wage density over three different time periods - 1986-1994, 1994-2006 and 2006-2019 - as well as a series of counterfactual scenarios that allow us to decompose changes in the distribution into the underlying change and the change attributed to the variation in the minimum. The effect of the minimum wage can then itself be decomposed into minimum wage "bite" effects and spillover effects. More, these results are not only presented in a visually clear way, but they are also quantified in several statistics of interest.

The results unambiguously show that the minimum wage was a crucial factor in theshaping of the Portuguese wage distribution when its relative importance increased. That is to say, while in the first period of analysis the minimum wage barely changed and its impacton the distribution was negligible, in the last period, a hike of 30% in its real value over 13years was enough to structurally reshape the wage distribution, which would be much wider today had the minimum not risen. For instance, the 90-10 percentile differential decreased by 22 log points between 2006 and 2019, and all of that decline can be attributed to the increase in the minimum wage, while the 50-10 differential would have actually increased by 9 points instead of decreasing by 13. Between 2006 and 2019 the rise in the minimum wage was responsible for almost 40% of the average real wage growth of Portuguese workers. For workers at the lowest percentiles of the distribution, which were the ones who saw their wages increase the most out of everyone in the workforce in reality, wages were stagnant in the counterfactual. The results also suggest that, in many cases, spillovers effects, which reached up to 40% above the minimum, can be even higher than the minimum wage "bite".

Breaking down the results by various segments of the population also demonstrated that: the minimum wage was most important for women sharply reducing inequality between females, being responsible for 60% of female average wage growth, and cutting the gender wage gap by 5 p.p., or a quarter; its impact was greater for less educated workers - explaining all of the wage growth of the least educated, and showing signs of a mitigating effect in the returns to education; it benefited more younger and older workers approaching retirement age; and was most influential for workers working at micro and large firms, and at less productive firms, demonstrating a potential productivity enhancing effect.

Finally, this paper uncovers a large discrepancy between the behaviour of base and total wages, which reacted differently to rises in the minimum wage - while the minimum wage bite was felt both in base and total wage, spillover effects were almost entirely reflected in total wages. This phenomenon gains importance knowing that both public debate and academic research frequently focus solely on base wages, overlooking a share of the minimum wage impact that this paper suggests can be as great as the impact of the bite itself.

The remaining of this paper is organised as follows: section 2 presents a review of the literature and relevant information on the minimum wage and wage inequality, section 3 presents the methodology and details on data and estimation, section 4 presents the visual and quantitative results of the paper along with a breakdown of the impact of the minimum wage on other wages, and section 5 concludes the paper with some final remarks.

2. The minimum wage and the wage distribution

The minimum wage allows for a set of margins through which labour markets can adjust, like employment, hours worked, wages and prices, but its impact across the wage distribution stands out in the sense of how structural it can be, depending on its value and the latent distribution.

When analysing the distributional effects of an increase in the real value of the minimum wage on wages – or the introduction of a minimum wage, for that matter – we must consider three main ideas. First, the minimum wage can destroy jobs, leading to reduced incomes for those who would have been able to find a job in the absence of it. Second, and most notably, it allows some people at the bottom of the wage distribution to receive a higher wage. Third, the rise in wages can spillover to workers higher up in the pay-scale who wouldnot apparently benefit from the rise. There are many other mechanisms through which a minimum wage can affect wages, but their effects are either still unsettled in the literatureor just not structural, by affecting only specific segments of the workforce and not the wagedistribution *per se*.[2]

The first concept regards disemployment effects, which ought to raise *income* inequality since the minimum wage can be discarding the left tail of the wage distribution and cutting the incomes of all those workers that cannot find a job with the higher minimum (Stigler, 1946; Mincer, 1976; Neumark et al., 2004). The impact on *wage* inequality, however, will be the exact opposite, as the workers that are "discarded from the distribution" are those at its very end, ironically flattening the distribution (Machin et al., 2003; Teulings, 2003). Still, the empirical literature on these disemployment effects is extensive, and has indicatedthat job losses attributed to the minimum wage are oftentimes negligible (Brown et al., 1982; Machin and Manning, 1994; Card and Krueger, 1994, 1995; Dolado et al., 1996; Dubeet al., 2010). In fact, a suitably chosen minimum wage may even raise wages and employment simultaneously in a labour market with monopsony power (Katz and Krueger, 1992; Rebitzerand Taylor, 1995; Manning, 2003; Portugal and Cardoso, 2006).

While distributional outcomes of disemployment effects can almost be seen as unintended consequences, the two other mechanisms through which the minimum wage can shape the wage structure are distributional by nature. The minimum wage "bite" (Meyer and Wise, 1983a,b; Machin et al., 2003) is the most fundamental, and the most obvious: setting a minimum wage – or raising it – will increase the wages of those workers initially makingless than the minimum to exactly the level of the minimum, pushing those workers' wages at the left-most part of the distribution to the right, closer to the median, and compressingthe wage distribution as a whole. This bite is in many ways the primary motivation for a minimum wage (Freeman, 1996), and it is regarded as the main mechanism though whichthe minimum wage can affect wage dispersion.

Then there are the less evident spillover effects. Gramlich (1976) first suggested that pay raises could be spilling over to workers earning above the new minimum (Brown, 1999), butspillovers have been widely recognised in the literature since then (Grossman, 1983; Katz and Krueger, 1992; Lee, 1999; Cengiz et al., 2019; Fortin et al., 2021). The idea that a minimum wage can raise wages above that minimum came first from the notion of substitution effects,as the higher relative price of low-skilled workers would lead employers to substitute towards higher-skilled labour (Gramlich, 1976), although it shifted with time

[2] For instance, Freeman (1996) suggests that increasing the lower wages in a firm increases production costs, likely reducing either firms' shareholder income or higher-wage workers' wages. Firms may also have to increase prices, making those workers' wages, if not nominally, at least in real terms decreasing with the minimum wage.

to more of a relative wage concern, as firms mitigate the deterioration in workers' wages relative to the lower-skilled ones (Grossman, 1983).[3] Spillover effects are also the hardest to detect, but we at least know that their impact varies greatly, and that it is much higher for wages closer to the minimum.

Minimum wage research gained a lot of traction during the credibility revolution in labour economics (Angrist and Pischke, 2010; Belman and Wolfson, 2014), resulting in a wealth of empirical literature estimating the distributional effects of the minimum wage. The most influential papers study the United States over the last two/three decades of the 20th century, exploiting "the longest sustained decline in the real value of the federal minimum wage" inthe US along with a "dramatic rise in earnings and wage inequality" (Lee, 1999). The large majority come to similar conclusions: the falling real minimum wage accounted for much ofthe rise in dispersion in the lower tail of the wage distribution, without a significant effect on the upper tail of the distribution, particularly for women (Katz and Krueger, 1992; Card and Krueger, 1994; DiNardo et al., 1996; Lee, 1999). The higher wages of workers that would earn below the minimum - bite effects - are in all cases the most important driverof this compressing effect on the distribution, although spillovers often have an additional attenuating impact on inequality when they are considered (Lee, 1999; Teulings, 2003), while disemployment effects are rarely accounted for in distributional analyses, as their effect is assumed to be relatively unimportant (DiNardo et al., 1996).

Modern studies, with updated methodologies, keep confirming the inequality-reducing effects of the minimum wage (Card and Krueger, 2015; Autor et al., 2016; Cengiz et al., 2019; Fortin et al., 2021), although some stress that spillovers seem to have lost importanceover time, and studies outside the US have reached analogous conclusions.[4]

2.1. The Portuguese minimum wage

In Portugal, unlike many countries, the minimum wage rate is legislated at the national level. That monthly rate has been set by the government each January 1st almost every yearsince it was first legislated in 1974, and it covers nearly all workers in the country - the few exceptions, like the youth and the agricultural minimum wages, tended to disappear over time.

Sector-specific and firm-specific wage floors, through extended collective bargaining agreements, are very widespread in the Portuguese labour market (Cardoso and Portugal, 2005; Addison et al., 2017; Martins, 2021), although they are oftentimes renegotiated in line with the national minimum wage. In fact, the spillover effects of the minimum wage are regularly formally reflected in these negotiations, as employers are forced to negotiate

[3] Spillovers can also arise in the presence of monopsony power, as unproductive firms close down when the minimum wage rises and their employees move to more productive, better-paying firms (Butcher et al., 2012; Dustmann et al., 2022).

[4] See Machin (1997); Machin et al. (2003) for the UK, Bossler and Schank (2020) for Germany, Aeberhardt et al. (2016) for France, and Koeniger et al. (2007); Joe and Moon (2020) for OECD cross country analyses.

the wages higher up in the distribution in order to preserve job title wage premia.

The real value of the minimum wage grew steadily, but at a slow pace between the 1980s and the mid-2000s – only 10% in 20 years, between 1986 and 2006. After that, it grew ata much faster pace – 30% between 2006 and 2019 – with a slight slump between 2011 and 2014, when its nominal rate was frozen by the government in response to the financial crisis. The minimum wage relative to the average wage saw a severe drop between 1986 and 1994, decreased even more until 2006, although at a much lower pace, but started to increase dramatically since then. The share of workers earning the minimum wage or less decreased consistently but slowly until the mid-2000s but also increased rapidly since then, if we lookat the base wage - strikingly, this sudden rise is not reflected in the aggregate of total wages.To some extent, the importance of the minimum wage in the Portuguese labour market over time can be summarised in the same three periods that characterise wage inequality: it was decreasing until 1994, somewhat stable until 2006, and increased significantly since then.This is illustrated in figure 2 and quantified in table C.6 of the appendix.

So, if we contrast this behaviour with the behaviour of wage inequality over the years, especially in the lower tail, there is a noticeable symmetry that presents clear potential for research of minimum wage's distributional effects. However, the amount of research assessing the role of the minimum wage on wage inequality in Portugal is very limited, mostly concluding that it has had some narrowing effect on the wage distribution (Centeno

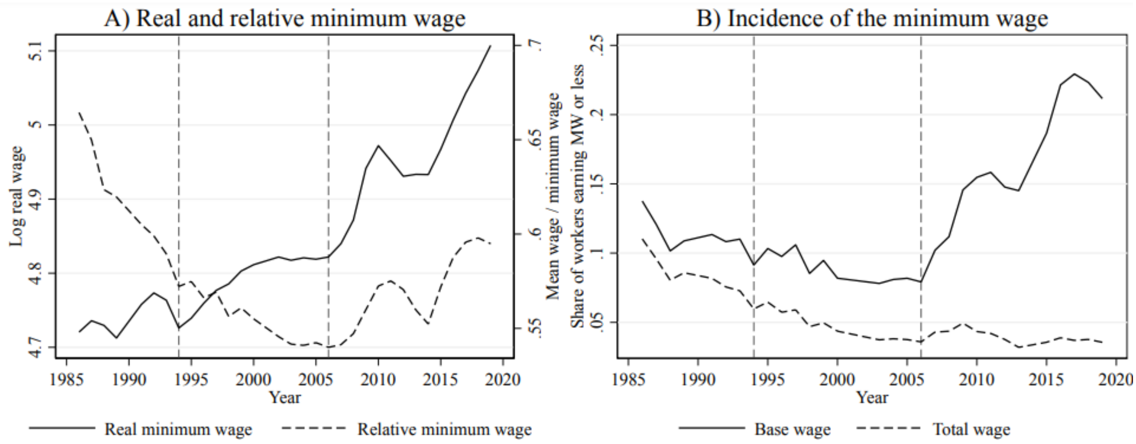

Figure 2: Importance of the minimum wage. Panel A depicts the logarithms of the real value of the minimum wage and the minimum wage relative to the average wage. Panel B depicts the share of workers with wages equal or lower than the minimum, using base and total wages (in 2002 and 2014 wage rounding near the minimum created noisy behaviour in the graph, so those years were omitted). The two dashed vertical lines, in 1994 and 2006, divide the three periods of analysis.

and Novo, 2014; Campos Lima et al., 2021), especially at the lower-tail (Carneiro et al., 2011) - only Pereira and Galego (2019) find no significant contribution of the minimum wage in attenuating wage inequality. Carneiro et al. (2011) acknowledge the presence of spillover effects, which they suggest had a limited impact on the distribution, although they do not get into that. There is also little literature on the disemployment effect in

Portugal, with unsettled, but generally slim impacts on employment and worker flows (Pereira, 2003; Portugal and Cardoso, 2006; Alexandre et al., 2021).

3. Methodology and data

To assess the effects of the minimum wage on wage inequality, the whole wage distribution is modelled by employing a framework that bridges distribution regressions and rank regressions, introduced by Fortin et al. (2021).[5] After modelling the conditional wage distribution, we will be able to construct counterfactual scenarios by changing the distribution of certain covariates and reweighting the sample. This methodology will allow for the detailed assessment of the distributional effects of the minimum wage and its spillovers, assuming no disemployment effects, which is a relatively reasonable assumption in this context, according to recent literature.

3.1. Bridging distribution regressions and rank regressions

The distribution regression framework (Chernozhukov et al., 2013) can be used to estimate the probability of an outcome variable being below or above a given cutoff point in a distribution. For instance, we can estimate the probability of the outcome variable Y being above the cutoff y_k as a flexible function of covariates X using a probit model as $\text{Prob}(Y \geq y_k) = \Phi(X\beta_k)$.

Then we can model the whole distribution by dividing it in $K - 1$ bins, delimited by the cutoff points y_k and y_{k+1} - which may be chosen as percentiles of the unconditional distribution or using a fine grid - and computing the probability of the outcome variable lying inside each bin as:

$$\begin{aligned}\text{Prob}(y_k \leq Y < y_{k+1}) &= \text{Prob}(Y \geq y_k) - \text{Prob}(Y \geq y_{k+1}) \\ &= \Phi(X\beta_k) - \Phi(X\beta_{k+1}) \qquad \text{for } \; k = 1, 2, \cdots, K.\end{aligned} \tag{1}$$

From these regressions, we can construct the conditional distribution from which all kinds of counterfactuals can be estimated, by changing the distributions of covariates or the regression coefficients themselves, allowing for the decomposition of changes in the wage distribution.

The general distribution regression framework as presented in Chernozhukov et al. (2013) is highly flexible, with no restrictions on how β_k coefficients vary across cutoffs, and that flexibility may be counterproductive when constructing the distribution, as we may get negative counterfactual probabilities and face identification problems in allowing for different

[5] Fortin et al. (2021) examine the role of minimum wages spillover effects and unionisation threat effects in changes in the US wage distribution between 1979 and 2017, finding that spillovers magnify the explanatory power of decreasing minimum wages to two-thirds of the increase in inequality at the bottom of the female distribution.

β_k at different points for all covariates, without restrictions.[6] For that reason Fortin et al. (2021) propose a less flexible framework, closer to the rank regressions of Fortin and Lemieux (1998), where the effects of explanatory variables can be fixed or evolve smoothly across the distribution.

In Fortin and Lemieux (1998)'s rank regression framework the coefficients are fixed across the distribution. We can view it as a latent variable model where the latent variable index is given by $Y^* = X\beta + \varepsilon$, with $\varepsilon \sim N(0, 1)$, and the observed variable is the monotonic transformation $Y = g(X\beta + \varepsilon)$, with each observation's latent and observed variable rank being the same. Then we can divide the observed variable range by the cutoffs y_k and compute the probability of it being above a given cutoff as Prob $(Y \geq y_k) = \Phi(X\beta - c_k)$, where $c_k = g^{-1}(y_k)$ are the corresponding cutoffs in the latent distribution. This way, we can model the distribution through an ordered probit where each category is a bin delimited by y_k and y_{k+1} with probability:

$$\text{Prob}(y_k \leq Y < y_{k+1}) = \Phi(X\beta - c_k) - \Phi(X\beta - c_{k+1}) \qquad \text{for } k = 1, 2, \cdots, K. \tag{2}$$

Here β coefficients are fixed across the distribution, as opposed to the β_k coefficients in equation 1. But the flexibility can also be advantageous. That is why we will employ a framework that bridges both methods, by introducing heteroscedasticity. Incorporating the interaction between X and y_k in the model allows for the effect of explanatory variables to evolve linearly across the wage distribution, such that Prob$(Y \geq y_k) = \Phi(X\beta + y_k X\gamma - c_k)$, and therefore:

$$\text{Prob}(y_k \leq Y < y_{k+1}) = \Phi(X\beta + y_k X\gamma - c_k) - \Phi(X\beta + y_{k+1} X\gamma - c_{k+1}) \tag{3}$$

As Fortin et al. (2021) demonstrate, assuming the same effect of covariates across the distribution would be too strong of an assumption to make when modelling the distribution of wages. More so given the existing literature on how the effects of education, in particular, have been rather disparate throughout the distribution in the Portuguese labour market (Machado and Mata, 2005).

3.2. Minimum wage effects

From this kind of framework, minimum wage effects can be estimated straightforwardly, by simply adding a set of dummy variables that indicate the distance to the minimum. We know that the effect of a minimum wage on the cumulative wage distribution would be the generation of a spike over that point. For instance, if in the latent wage distribution without the minimum wage we had Prob$(Y \geq y_k) = \Phi(X\beta - c_k)$ (using the

[6] For instance, the final model will include a set of year dummies to capture macroeconomic conditions, which could absorb the whole effect of the minimum wage if we allowed for full flexibility of the βk coefficients.

rank regression model for simplification), if y_k is the cutoff point just above the minimum wage ($y_{k-1} \geq MW < y_k$), the probability of Y being above that cutoff point in the observed distribution can be characterised as Prob($Y \geq y_k$) = $\Phi(X\beta - c_k + \delta_0)$, where δ_0 is a parameter that captures the effect of the minimum wage. In fact, Prob($Y \geq y_k$) = $\Phi(X\beta - c_k + \delta_0)$ for all y_k above the minimum wage.

Furthermore, in the presence of spillover effects, they can also be accounted for with a similar strategy. For example, if the effect of the minimum wage spills over to only one wage bin above the minimum wage, we have Prob($Y \geq y_k$) = $\Phi(X\beta - c_k + \delta_0 + \delta_1)$ for all $y_{k-1} > MV$.

With this in mind, we can estimate the effect of the minimum wage, above and below, by adding a set of dummy variables $D^m_{kt} = 1[yk-m \leq MW_t]$ indicating the distance to that year's minimum wage, such that Prob($Y \geq yk$) = $\Phi(X\beta + \Sigma_m D^m_{kt}\,\delta_m - c_k)$, or in our framework:

$$\text{Prob}(Y \geq y_k) = \Phi\left(X\beta + y_k X\gamma + \sum_m D^m_{kt}\,\delta_m - c_k\right) \tag{4}$$

3.3. Empirical model and estimation

To model the entire wage distribution, the log wage range is divided into 60 wage bins between 4.5 and 7.5 (a range that comprises more than 99% of all observations), where eachbin has a length of 5 log points, plus the first and the last bin, for a total of 62 bins (seethe corresponding histograms in figure 3). Then we estimate one stacked probit model, by stacking 62 copies of the original dataset, and adding the outcome variable, equal to 1 if$y_{it} > y_k$ and zero otherwise, for $k = 1, \cdots, 61$ (this stacking is illustrated in table C.7 of the appendix). This way we can allow the coefficients to evolve linearly throughout the distribution. The full model is:

$$\text{Prob}(Y_{it} \geq y_k) = \Phi\left(X_{it}\beta + y_k X_{it}\gamma + \sum_{m=b}^{a} D^m_{kt}\,\delta_m - c_k\right) \qquad \text{for } k = 1, 2, \cdots, 61. \tag{5}$$

The covariates X_{it} include the set of individual characteristics - gender, age and squared age,tenure and squared tenure and years of education - as well as 18 age-education interactiondummies in order to capture supply and demand dynamics (Bound and Johnson, 1992), year and region fixed effects. Some specifications also include a "heaping variable".[7] Then we have the interaction term $y_k X_{it}$, although not all covariates are interacted with the cutoff points for computational convenience - only age-education

[7] Autor et al. (2016), in their critique of some minimum wage empirical research methods, suggest that the heaping of hourly wages at integer values in the US could be creating spurious spillovers when the minimum wage is slightly below an integer. Fortin et al. (2021) correct for that by including this type of variable which aims to capture the effect of heaping. Here an analogous strategy is used to capture heaping at multiples of 50€.

interactions and year dummiesare included here, capturing both supply and demand and education changes at different points of the distribution - which are the two main explanatory factors of changes in wage inequality according to the literature - as well as macroeconomic conditions. Minimum wage effects are captured in the δ_m coefficients, through the dummies $D^m{}_{kt}$, where $m \in \{b, a\}$ and $(b < 0 < a)$. δ_0 measures the jump in probability at the minimum, $\delta_{m>0}$ measure the spillovers and $\delta_{m<0}$ measure any decrease in probability below the minimum. The numberof bins above and below the minimum wage at which the effect is measured is different for different specifications, as these effects are not always the same. We will go further into thisin section 4, but these dummies were allowed for up to 3 bins below and 8 bins above the minimum wage bin. Finally, c_k are wage bin dummies.

3.4. Details on data

The analysis in this paper makes use of the incredibly rich longitudinal matched employer-employee dataset of *Quadros de Pessoal* (QP), an annual mandatory survey of all establishments in Portugal with at least one wage earner, collected by the Portuguese Ministry of Labour and Social Solidarity. Among a remarkably extensive list of variables on firms, establishments, and workers, the QP dataset provides demographic information such as age, gender and education, and employment information like base and total monthly wages, hours worked, tenure at the firm and occupation, for all employees in Portugal since 1982 (except for 1990 and 2001, when it was not available). Few matched employer-employee datasets are as detailed and precise as QP, since employers are not only required to provide their full roster of employees to the Ministry, but they must also ensure that workers are provided with that information, in order to monitor compliance with labour law provisions.

All estimation exploits a random sample of 10% of all full-time workers between the agesof 18 and 64, from 1986 to 2019 - between 111*,* 987 observations in 1986 and 226*,* 191 in 2019. The random 10% sample is drawn for computational convenience, in order to handle a stacked dataset of 62 x N observations, since there is no reason to believe that any problem would arise from the use of a random sample given the large size of the original dataset andthe nature of the estimations. The variable of interest in most cases is the total monthly wage (deflated to 1986 CPI), which is most relevant in measuring wage inequality, and othervariables utilised include age, gender, tenure, region and level of education (transformed into years of education). Still, base wages will also be utilised, since they presented a ratherdifferent behaviour compared to total wages, but this phenomenon will be further discussedin section 4.4 - see figure 3.

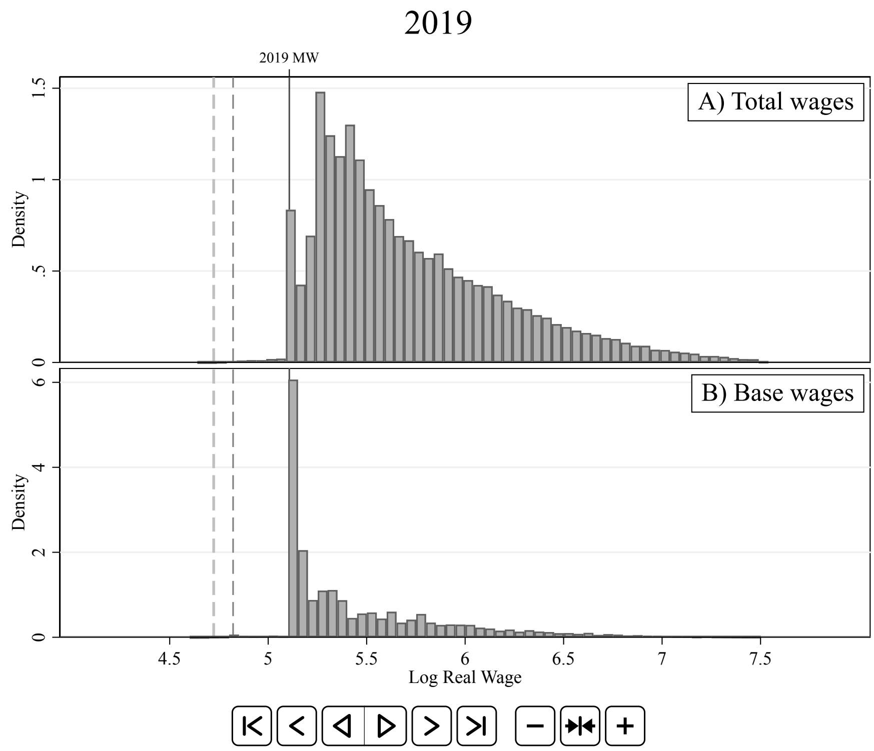

Figure 3: Distribution of wages from 1986 to 2019. This figure depicts the distribution of the logarithm of real wages across the years using total wages and base wages. Histograms have the same wage bins that areused in the estimation of the model (0.05 log bins, between 4.5 and 7.5). The black vertical line indicateseach year's minimum wage, while the dashed lines indicate the reference years' minimum wages as they appear. This is an interactive figure - click play or use the controls to see the distribution moving over the years (Acrobat Reader recommended).

4. Results

As discussed in section 2.1, the joint behaviour of wage inequality and the minimum wage between 1986 and 2019 can be organised into three distinct periods: 1986-1994, whereinequality grew and the importance of the minimum wage was stagnant, 1994-2006, whereinequality stabilised and the minimum wage rose modestly, and 2006-2019, where inequality significantly decreased and the importance of the minimum wage increased unprecedentedly.

For a most complete analysis, the model laid out in section 3.3 was separately estimated for the three time-periods. The coefficients of interest resulting from that estimation - the coefficients measuring minimum wage effects, δ_m - are reported in table 1, specifications (1-3). After looking at the results for the three periods, we will focus the analysis on the lastone, 2006-2019, which was the most interesting, in order to dissect even further the impactof the minimum wage on the wage structure. Discussion in section 3.4 suggested that base wages could be reacting to changes in the minimum wage in a different way than total wages, so a model was also estimated for the period 2006-2019 using base wages instead of total wages, reported in table 1, specification (4).

δ_m coefficients	Total wages			Base wages
	1) 1986-1994	2) 1994-2006	3) 2006-2019	4) 2006-2019
10%-15% below MW (δ_{-3})	0.096 (0.008)	0.459 (0.010)		
5%-10% below MW (δ_{-2})	0.127 (0.007)	0.370 (0.007)		
0%-5% below MW (δ_{-1})	0.045 (0.006)	0.336 (0.006)		
At the minimum wage (δ_0)	0.302 (0.005)	1.092 (0.005)	1.097 (0.005)	1.649 (0.003)
0%-5% above MW (δ_1)		0.068 (0.002)	0.117 (0.001)	0.166 (0.001)
5%-10% above MW (δ_2)		0.052 (0.002)	0.145 (0.001)	0.067 (0.001)
10%-15% above MW (δ_3)		0.067 (0.002)	0.172 (0.001)	
15%-20% above MW (δ_4)		0.057 (0.002)	0.121 (0.001)	
20%-25% above MW (δ_5)		0.042 (0.002)	0.086 (0.001)	
25%-30% above MW (δ_6)			0.055 (0.001)	
30%-35% above MW (δ_7)			0.033 (0.001)	
35%-40% above MW (δ_8)			0.021 (0.001)	
Number of observations	34724200	71344988	99422358	70180488

Table 1: Estimated coefficients of minimum wage effects. This table reports the probit regression estimates for the δ_m coefficients in equation 5. All specifications include the explanatory variables mentioned in section 3.3, although the heaping variable is only present in specifications (3) and (4), where the heaping of wages was more obvious. Standard errors, in parentheses, are clustered by individual

The range of *m*, the maximum distance to the minimum at which minimum wage effects are allowed, above and below, was differently determined for each specification by excluding insignificant coefficients, in order to best fit the model to each case. For instance, while minimum wage effects are identified up to 40% above the minimum in the period 2006-2019, no spillovers are found in 1986-1994. As such, the adopted ranges of *m* were {−3, 0}, {−3, 5}, {0, 10} and {0, 2} for specifications (1), (2), (3) and (4), respectively.

These are probit regression coefficients so their direct interpretation can be problematic, but we already see that they are all positive, which is expected since they refer to the cumulative distribution. We can also identify the spike created by the minimum wage in the δ0 coefficients, which are much higher than other δ_m, and see that spillover effects tend to decrease as they draw away from the minimum, as coefficients are decreasing for *m* > 0.

Still, the beauty of this kind of methodology does not come from the coefficients themselves, but from its ability to let us play with all kinds of counterfactual scenarios in order to extract, from specific statistics, or from the entire distribution, the effect associated to certain explanatory factors. In this paper, a series of counterfactuals scenarios are constructed in order to assess the effects of the minimum wage at different points of the distribution - which is straightforward after the estimation of the conditional wage distribution.

We will first look at a series of actual and counterfactual density estimates of the wage distribution, which are obtained using an adaptive kernel density estimator (Abramson, 1982). The construction of counterfactual densities is done through the reweighting approach of DiNardo et al. (1996) whereby samples are appropriately weighted in a similar way to common propensity score methods (Fortin et al., 2011). Then, we will quantify the effect of the minimum wage in several statistics of interest, decomposing changes in those statistics into the underlying change, minimum wage bite effects and minimum wage spillover effects.

In short, counterfactual densities and statistics are obtained by changing the distribution of certain covariates - in this case, what changes is the distribution of the D^m_{kt} minimum wage effect dummy variables - and then reweighting the sample in accordance to the new distributions of the covariates. For instance, to compute the wage the distribution that would have prevailed in 2019, had the minimum wage stayed at its 2006 level, we simply compute the above-mentioned probabilities, using the parameters that we estimated, but switching the distribution of the minimum wage effect dummies with their 2006 level, $D^m_{kt=2006}$. If the objective is to estimate the 2019 counterfactual wage distribution in the absence of spillovers, then we simply set the minimum wage effect dummies above the minimum - the spillovers - to zero: $D^m_{kt}=2019 = 0$ for $m > 0$. After that, we can estimate counterfactual wage densities and distributional statistics by reweighting the sample through the use of the reweighting factor $\psi(X_k)$ (DiNardo et al., 1996), estimated as

$$\hat{\psi}(X_k) = \frac{\bar{Y}_k^C(X)}{\bar{Y}_k(X)}, \quad k = 1, \cdots, K \tag{6}$$

where $\bar{Y}k$ are the averages of the outcome variable, per wage bin, in the actual scenario, and $\bar{Y}_K^C$ are the averages of the outcome variable in the counterfactual.[8]

4.1. Counterfactual wage densities

All in all, the wage distributions that would have prevailed in 1994, 2006 and 2019, hadthe minimum wage remained at its 1986, 1994 and 2006 level, respectively, are presentedin figure 4, while the corresponding changes in density between the actual and the counterfactual can be seen in figure 5. Figure D.17 of the appendix portrays the counterfactual densities of the last year, if the minimum wage had risen but no spillovers occurred sincethe first year, to aid disentangling the role of spillover effects.

As we can see in figure 4, while the wage distribution visibly widened to the right between 1986 and 1994, the real value of the minimum wage in 1986 was nearly the same eight yearslater. Unsurprisingly, the mere 1% real increase in the minimum wage over this

[8] The reweighted adaptive kernel density estimator, used in the estimation of the wage densities, is very briefly laid out in Appendix A.

period had nearly zero impact on the 1994 wage density, which is almost identical to the actual wage density, except for a slight smoothing around the minimum which can be attributed to a lack of common support[9] The absence of spillovers, reflected in specification (1), makes thecounterfactual in figure D.17 indistinguishable from the actual 1994 density, so we concludethat the unchanged minimum wage had no discernible effect on the wage density between1986 and 1994.

In the second period of analysis we start to notice some minimum wage effects. Over twelve years, the minimum wage increased 9%, which is not much, but certainly enough to reshape the wage distribution to some extent. In figure 4 we can see that the mass of workers earning wages below the 2006 minimum would be much more representative hadthe minimum wage not risen by those 9%, and that a visible portion of the workers thatearned wages up to 25% above the 2006 minimum would be earning lower-wages, many of them earning less than that new minimum. Figures 5 and D.17 confirm that the rise in the minimum wage was not only responsible for a rise in wages for those who are now earning the new minimum, but it also spilled over to workers that would not be affected by a higher minimum at first sight.

However, it is between 2006 and 2019 that we can observe the true potential of a minimum wage. Looking at the actual wage densities of 2006 and 2019 in figure 4 we can see that the distribution shifted to the right over 13 years, but that mainly happens through a significant compression of the distribution at the bottom. And watching the wage histograms move throughout the years in the interactive figure 3 does hint that it is the minimum wage that is pushing that left-tail more and more to the right. But it is by looking at the 2019 counterfactual density with the 2006 minimum wage, in figure 4, that we can truly graspthe effect of the minimum wage on the shape of the distribution.

Had the real minimum wage not risen by the impressive 29% that it did, the shape of the distribution would be incredibly different in 2019, with the very high mass of workers earning wages close to the minimum, that we see in the actual distribution, significantly diluting, with a very large portion of workers shifting back in the pay-scale to wages much lower than the 2019 minimum, and many remaining at the 2006 minimum. And if the effect

[9] This type of weighting method can always be subject to problems of common support (Frōlich, 2004; Fortin et al., 2011), especially taking into account the binding nature of the minimum wage in the Portuguese context.

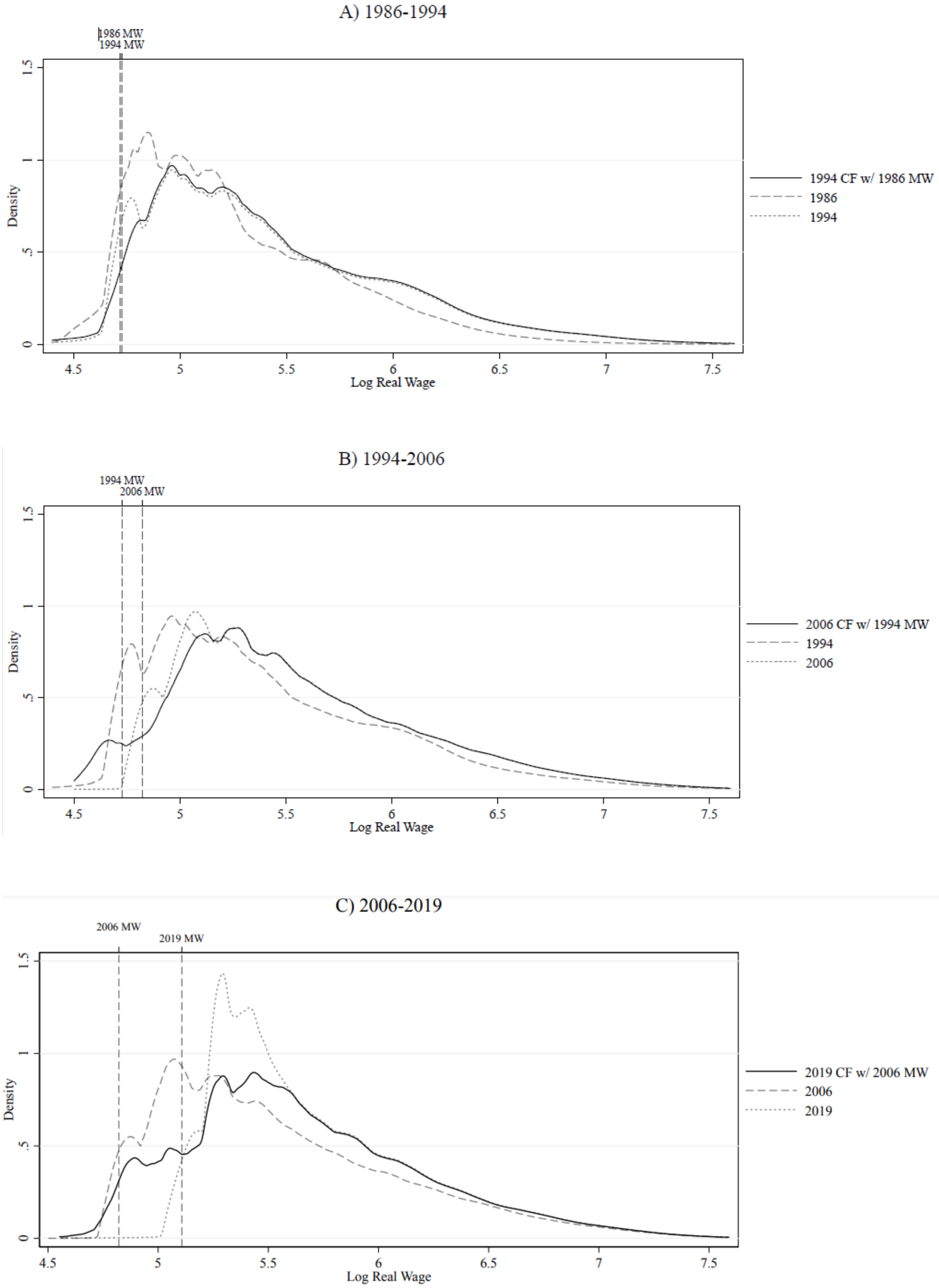

Figure 4: Counterfactual densities for the periods 1986-1994, 1994-2006, and 2006-2019. Each panel of this figure depicts the counterfactual density estimate for the last year, had the minimum wage stayed at its first year level, in blue, as well as the actual estimates for the first and the last year of each period of analysis,in red and green, respectively. The dashed vertical lines indicate the first and last years’ minimum wages.

Figure 5: Changes in density attributed to the change in the minimum wage. This figure depicts the difference in densities between the actual last year distribution and the counterfactual distribution with first year's minimum wage for the three time periods. Dashed vertical lines indicate the minimum wages.

of spillovers is not clear enough, figures 5 and D.17 make it even more evident that a verylarge share of lower-wage workers saw their wages increase significantly, and that portiondid not "accumulate" at the new minimum wage, but it actually spilled-over quite abovethat, to wages up to 40% above the 2019 minimum.

4.2. Quantifying minimum wage effects

After recognising the clear visual impact that the minimum wage has had on the wage distribution, it is important to quantify that impact. The distributional effects of the changes in the minimum wage were quantified into several statistics of interest, laid out in table 2. The table is divided into three panels, for the three time-periods, where the columns present those statistics, measuring inequality across the distribution (standard deviation and 90-10 percentile differential), upper-tail and lower-tail inequality (90-50 and 50-10 differentials), the share of workers on the first and last years' minimum wages (incidence of the minimumwage), and the average wage. The first four rows of each panel present these statistics for the different scenarios that were estimated - first year, last year, counterfactual last year with first year's minimum wage, and counterfactual last year without spillovers. The three rows after that present the actual change in those statistics between the first and the last year, the *total change*, as well as the decomposition of that change into the *underlying change* - the change that would have occurred between those years if the real value of the minimumwage had stayed at its first year level - and the *change due to the minimum wage* - the change driven by the shift in the minimum wage.

The two final rows of each panel present the further decomposition of the *change due to the minimum wage* into the *change due tothe minimum wage bite*, the change driven by the workers whose wages would be below the new minimum but the minimum wage managed to push up to that minimum, and the *change due to spillovers effects*, driven by the workers who would got their pay pushed evenhigher than the new minimum.[10]

	Sd	90-10	90-50	50-10	Incidence 1st year	Incidence last year	Mean wage
A) 1986-1994							
1986	0.5	1.21	0.79	0.42	0.11	0.11	5.24
1994	0.57	1.41	0.92	0.49	0.02	0.06	5.42
1994 w/ 1986 MW	0.58	1.4	0.92	0.48	0.03	0.05	5.43
1994 w/o spillovers	0.57	1.41	0.92	0.49	0.02	0.06	5.42
Total change	0.07	0.2	0.13	0.07	-0.09	-0.05	0.18
Underlying change	0.08	0.19	0.13	0.06	-0.08	-0.06	0.19
Change due to MW	-0.01	0.01	0	0.01	-0.01	0.01	-0.01
Change due to bite	-0.01	0.01	0	0.01	-0.01	0.01	-0.01
Change due to spillovers	0	0	0	0	0	0	0
B) 1994-2006							
1994	0.57	1.41	0.92	0.49	0.06	0.11	5.42
2006	0.58	1.43	0.95	0.48	0	0.04	5.57
2006 w/ 1994 MW	0.6	1.47	0.95	0.52	0.05	0.07	5.56
2006 w/o spillovers	0.58	1.47	0.94	0.52	0	0.06	5.57
Total change	0.01	0.02	0.03	-0.01	-0.06	-0.07	0.15
Underlying change	0.03	0.06	0.03	0.03	-0.01	-0.04	0.14
Change due to MW	-0.02	-0.04	0	-0.04	-0.05	-0.03	0.01
Change due to bite	-0.02	0	-0.01	0	-0.05	-0.01	0.01
Change due to spillovers	0	-0.04	0.01	-0.04	0	-0.02	0
C) 2006-2019							
2006	0.58	1.43	0.95	0.48	0.04	0.23	5.57
2019	0.51	1.21	0.86	0.35	0	0.04	5.73
2019 w/ 2006 MW	0.57	1.43	0.86	0.57	0.03	0.16	5.67
2019 w/o spillovers	0.53	1.34	0.85	0.49	0	0.1	5.71
Total change	-0.07	-0.22	-0.09	-0.13	-0.04	-0.19	0.16
Underlying change	-0.01	0	-0.09	0.09	-0.01	-0.07	0.1
Change due to MW	-0.06	-0.22	0	-0.22	-0.03	-0.12	0.06
Change due to bite	-0.04	-0.09	-0.01	-0.08	-0.03	-0.06	0.04
Change due to spillovers	-0.02	-0.13	0.01	-0.14	0	-0.06	0.02

Table 2: Decomposition of changes in statistics of interest for the three periods. Each panel depicts statistics of interest for the first year, the last year, and the counterfactuals of the last year with the first year minimumwage and with no spillovers. They also contain the change in these statistics between the first and the last year, decomposed into the underlying change and the change attributed to the shift in the minimum wage, which is then itself decomposed into minimum wage bite effects and spillover effects.

The minimum wage practically stagnated during the first 8 years of the sample, sothe deviation across the different 1994 scenarios for all statistics is negligible. Inequality increased rapidly, especially at the upper tail, the average wage increased too, but virtuallyall of it is explained by the underlying changes in the economy and not by any minimum wage changes.

Between 1994 and 2006 there was a 9% increase in the minimum wage and the

[10] The decomposition of results is explained with more detail in Appendix B.

growthin inequality slowed. The underlying increase in the standard deviation of log wages wasonly 3 log points over 12 years, much lower than the 8 points in the previous 8 years, sothere clearly were other more important factors mitigating wage inequality. Nonetheless,the minimum wage was still able to cut the increase in the standard deviation and the 90-10 percentile differential by two thirds, and was actually responsible for the 1 point decrease inthe 50-10, which increased by 3 points in the counterfactual. Notably, if the minimum wage had not gone up, 5 of the 6% of workers that were on the minimum wage in 1994 would still be earning that value in 2006.

Having said that, it is again in the third period that we see the full impact of the minimum wage. As discussed before, wage inequality decreased greatly between 2006 and 2019 - the standard deviation of log wages decreased by 7 points, the 90-50 differential decreased by 9 points and the 50-10 by 13, for a total decline of 22 points in the 90-10 differential. Whenwe decompose those changes we find that, as the wage density estimates suggested, the minimum wage had a crucial role in those developments.

Had the minimum wage not increased, the standard deviation would have decreased by only one log point - the minimum wage bite was able to reduce the standard deviation by4 extra log points and its spillovers managed to reduce it another 2 points. More striking,the 90-10 differential would not have changed at all - while upper-tail inequality decreasedby 9 log points due to other factors, lower-tail inequality would have increased by 9 points, offsetting any changes in the 90-10 differential. Instead, it decreased by 22 points, 13 of those in the 50-10, and most of that was due to spillovers, which alone reduced the differential by14 points.

Figure 6 perfectly illustrates this impact on wage inequality: while the actual 2006-2019 wage growth incidence curve was straightly decreasing - meaning that wage growth between those years was almost inversely proportional to a worker's position in the wage distribution, with wages at the very bottom of the distribution growing by 30%, while wages at the verytop almost stagnated - if the minimum wage had not gone up we would be seeing an reverse-U-shaped curve - whereby the wages of workers in the lowest percentiles of the distribution, the ones who saw their wages increase the most in reality, would have actually been theones with the smallest growth. In figure D.18 of the appendix, we can see these curves forthe first two periods, where the difference between the actual and counterfactual curves is almost trivial compared to the third period.

In 2019, no worker was earning a wage equal or lower than the real value of the 2006 minimum wage. However, had the minimum wage not risen, the share of workers earning the 2006 minimum wage in 2019 would still be 3%. But what is more striking is the share of workers earning the the real value of the 2019 minimum in both years. In 2019 the minimum wage was €600, and its incidence was only 4%, but the share of workers earning that

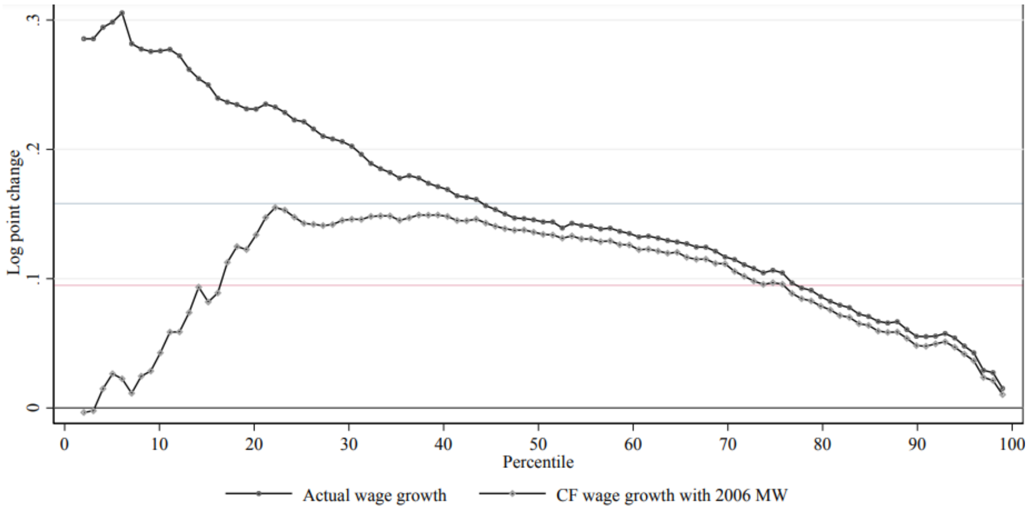

Figure 6: Wage growth incidence curves, 2006-2019. This graph depicts the actual and counterfactual growth rate of wages by wage percentile from 2006 to 2019. The shaded horizontal lines indicate the mean wage growth. The first percentile was omitted. The slight difference between the actual and counterfactual curves at the higher percentiles of the distribution is due to the reweighing, not representing actual lower wage growth.

value in 2006, in real terms, was a staggering 23%. This 19 point decrease over 13 years is due in part to other changes in the economy, but mostly due to the increase in the minimum wage - the minimum wage bite put 6% of the workforce above that threshold and the spillovers put another 6%.

In the end, such a powerful impact of the minimum wage across the distribution could only translate itself in the average wage. And it did. The average wage increased by 16 points over 13 years. That is not much, but it would have been only 10 points if the minimum had not risen by those 29%. The rise in the minimum wage was responsible for almost 40% of the growth in the average wage between 2006 and 2019.

4.3. Breaking down minimum wage effects

The two previous subsections clearly documented the unequivocal impact of the minimum wage on the wage distribution. In general, but even more so in the third period - which is the most interesting, since it was where the minimum wage grew the most and its impact was greater - the rise in the minimum wage completely reshaped the wage distribution, triggered a sharp decline in wage inequality, and lifted the average wage up. This subsection will focus on that third period in order to dissect even further the impact of the minimum wage, by looking at differences within and between different segments of the workforce. We will look at differences between and within genders, education levels, between workers of different ages, and workers' firm characteristics.

4.3.1. Gender

The minimum wage is generally recognised as having a greater impact on women than men, since women tend to be over-represented among low-wage workers (Card et al., 2016) - in Portugal, 2019, women represented only 46% of the workforce, but 58% of minimum wage earners. To understand that different impact of the minimum wage within and between genders, the actual and counterfactual female and male wage densities were estimated. They are portrayed in figure 7.

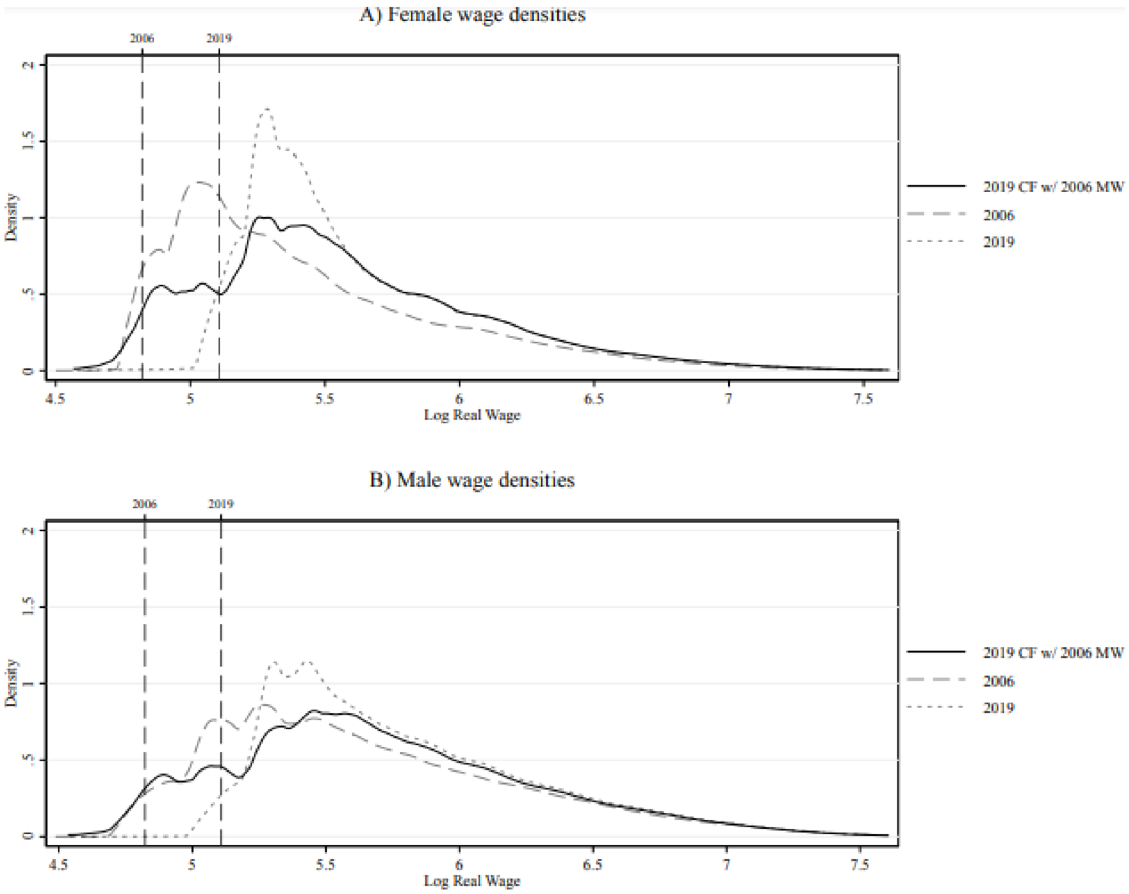

Figure 7: Counterfactual densities by gender. This figure depicts the counterfactual density estimate for the last year, had the minimum wage stayed at its first year level, in blue, as well as the actual density estimates for the first and the last year of each period of analysis, in red and green, respectively, for female and male workers, analogously to figure 4.

We already saw that the 29% rise in minimum wage significantly compressed the wage distribution at the bottom, pushing a large mass of workers higher up in the pay-scale. When we estimate the female and male distributions separately, the impact of the rise in the minimum turns out to be similar in shape for both: a significant compression at the bottom, with a large share of workers receiving higher wages. However, the female wage distribution was already much more compressed at the minimum in 2006 - while the male distribution was wider and further to the right - so the impact was much more significant for women.

Table 3 reports analogous results to table 2, but divided by gender (for 2006-2019).

The quantitative results display even more clearly how the minimum wage was much more influential for women than for men. While male wage inequality would have declined over this period anyway - since the underlying change was negative for all inequality indicators

- female wage inequality would have actually increased, had the minimum wage not risen

- there would have been an increase of the standard deviation (2 points) and the 90-10 differential (7 points), pushed by the sharp increase in lower-half wage inequality (increase of 14 points in the 50-10 differential), even with the decrease in upper-half inequality (7 points). The actual change in within-gender inequality indicators was comparable for both genders, but the share of that change that can be attributed to the shift in minimum wage was much greater for women.

	Sd	90-10	90-50	50-10	Incidence 1st year	Incidence last year	Mean wage
A) Females ($\Delta MW = 0.29$)							
2006	0.52	1.26	0.88	0.38	0.05	0.32	5.44
2019	0.46	1.08	0.79	0.29	0	0.04	5.64
2019 w/ 2006 MW	0.54	1.33	0.81	0.52	0.05	0.24	5.52
2019 w/o spillovers	0.48	1.17	0.8	0.37	0	0.13	5.61
Total change	-0.06	-0.18	-0.09	-0.09	-0.05	-0.28	0.2
Underlying change	0.02	0.07	-0.07	0.14	0	-0.08	0.08
Change due to MW	-0.08	-0.25	-0.02	-0.23	-0.05	-0.2	0.12
B) Males ($\Delta MW = 0.29$)							
2006	0.6	1.48	0.95	0.53	0.03	0.16	5.68
2019	0.54	1.29	0.88	0.41	0	0.03	5.82
2019 w/ 2006 MW	0.57	1.39	0.87	0.52	0.02	0.08	5.81
2019 w/o spillovers	0.56	1.44	0.87	0.56	0	0.09	5.8
Total change	-0.06	-0.19	-0.07	-0.12	-0.03	-0.13	0.14
Underlying change	-0.03	-0.09	-0.08	-0.01	-0.01	-0.08	0.13
Change due to MW	-0.03	-0.1	0.01	-0.09	-0.02	-0.05	0.01

Table 3: Decomposition of changes in statistics of interest by gender, 2006-2019. This table depicts the statistics of interest, analogously to table 2, separately for females and males.

More, the impact of the rise of the minimum wage on the average wage was completely disparate for men and women: men's average wage grew by 14 log points between 2006 and 2019, and only 1 of those 14 points (7%) was due to the rise in the minimum wage, while women's average wage grew by 20 points and 12 of the 20 points (60%) can be attributed to that shift.

Such a large difference in the impact of the minimum wage between genders may seem surprising at first, but is almost expected if we are aware of the large differences between the female and male distributions. Figure 7 showed how the female distribution was much more compressed at the minimum beforehand, and if we look, for instance, at the share of workers earning the real value of the 2019 minimum wage or less in 2006, we can see that it was 32% of women and only 16% of men. This large difference is also consistent with the international economic literature, as mentioned in section 2, since women tend to be over-represented in the low-wage worker population of most countries.

Finally, it would be important to understand if the minimum wage had an impact on the gender wage gap. Economic literature has suggested that the minimum wage can trigger a compression of the adjusted differential between male and female wages.[11] As Rubery and Grimshaw (2011) put it: "a minimum wage can act as a strategic instrument in countering distortionary effects and smoothing out the imbalances that result from the interactions between sex segmentation of labour supply and sex segregation in employment with processes of wage-setting".

To address that, a simple wage equation was estimated for 2006, for 2019 and for the two 2019 counterfactual scenarios, with the reweighted samples. The coefficients of the main explanatory variables are reported in table 4, while the covariates not included in the table were: age and squared age, tenure and squared tenure, region, industry, and professional category.

	1) 2006	2) 2019	3) 2019 w/ 2006 MW	4) 2019 w/o spillovers
male	0.199 (0.002)	0.167 (0.002)	0.216 (0.007)	0.173 (0.002)
education				
2nd cycle	0.088 (0.003)	0.058 (0.003)	0.070 (0.009)	0.056 (0.004)
3rd cycle	0.178 (0.003)	0.126 (0.003)	0.133 (0.013)	0.125 (0.004)
secondary	0.307 (0.003)	0.232 (0.003)	0.249 (0.010)	0.244 (0.004)
higher	0.636 (0.006)	0.488 (0.004)	0.532 (0.013)	0.518 (0.005)
Number of observations	207539	226187	226187	226187

Table 4: Estimated coefficients of interest from the log wage equation. The explanatory variables not included in the table were: age and squared age, tenure and squared tenure, region, industry, and professional category. Robust standard errors are reported in parentheses.

In 2006, a man would receive a 19.9% higher wage than a woman with the same observable characteristics. 13 years later, in 2019, that gap had decreased by 3.2 points, to 16.7%. However, had the minimum wage not risen, the gender wage gap would have actually increased to 21.6% in 2019. That means that the rising minimum wage was responsible for a decrease in the gender wage gap of 4.9 percentage points, almost a quarter of the total gap, which would have actually increased, had the minimum wage not risen. And almost all of that effect was due to the minimum wage bite (4.3 of the 4.9 points). This suggests that, when employers were forced to increase their employees' wages due to the rise in the minimum, they avoided paying the discrimination component

[11] See evidence from the UK (Robinson, 2002; Bargain et al., 2019), Germany (Caliendo and Wittbrodt, 2021), Poland (Majchrowska and Strawiński, 2018), China (Li and Ma, 2015), Korea (Cho and Yang, 2021), or Canada (Shannon, 1996). Interestingly, one offbeat paper on Portuguese young workers finds a positive effect of the minimum wage on the gender gap (Cerejeira et al., 2012).

of the gender wage gap on top of the unavoidable pay raise by substituting the discrimination premium for the minimum-wage-pay-hike, shrinking that discrimination component.

4.3.2. Education

Another important aspect to be studied is the impact of the minimum wage for workers with different levels of education. As we discussed in the introduction, education was probably the most important driver of wage inequality dynamics over the last decades in Portugal. Increasing demand for skilled-workers in the 1980s and 1990s sharply inflated the returns to education, especially for higher-wage workers. When people began to get more educated, some workers started to detach from the generally uneducated majority of the workforce, increasing wage inequality at the top (Machado and Mata, 2005). But as more and more people obtained better education, that growth in wage inequality was mitigated (Centeno and Novo, 2014; Pereira, 2020).

However, since the mid-2000s, real wage growth was almost inversely proportional to education level: as we can see in figure 8, the average real wage growth of workers with the 1st and 2nd Cycles of education was 13% and 17%, respectively, while workers with secondary and higher education saw an average decrease in real wages of 3% and 14%.

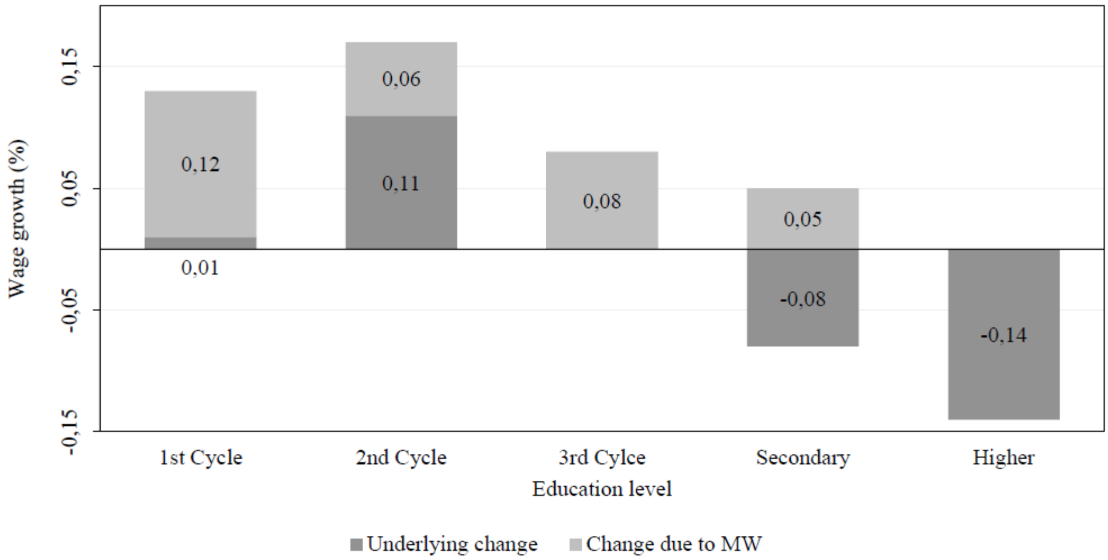

Figure 8: Average wage growth by education level, 2006-2019. This figure depicts the average real wage growth by level of education, and the part of that growth that can be attributed to the rise in the minimum wage. In the Portuguese education system the 1st and 2nd Cycles correspond to basic education, the 3rd Cycle to lower-secondary education, Secondary to upper-secondary education, and Higher to higher education, according to the ISCED classification.

The rise in the minimum wage was, in part, responsible for that inequality decreasing phenomenon, since it managed to increase more the wages of lower-educated workers relative to higher-educated ones. For instance, almost all of the 13% wage growth for workers with the 1st Cycle was due to the rise in the minimum wage, while workers with higher education saw no direct effect in their paycheck from the rise in the minimum, on average.

Understanding the effect of the minimum wage on the returns to education would also be of interest - unlike for the gender wage gap, the literature on the effect of the minimum wage on the returns to education is very limited (Funkhouser, 1998 Bárány, 2016). While the wage equation coefficient estimates presented in table 4 are subject to a degree of endogeneity that does not allow us to infer causality, it may at least point us in some direction. In general, we can see that the wage premia coefficients from getting higher levels of education than the 1st cycle - the base level - all decreased between 2006 and 2019, and in all cases the decrease would have been lower, had the minimum wage not risen.

In sum, while education served to increase wage inequality in the past, between 2006 and 2019 lower-educated workers saw higher real wage gains than higher educated ones, and the minimum wage played a very important role in that phenomenon. The rise in the minimum wage actually seems to have lowered the returns to education, even if it was not the most important factor in their decrease.

But more than just decreasing inequality between workers with different levels of education, the minimum wage was also able to reduce wage inequality within education levels. As we can see in figure 9, wage inequality within education levels was much higher in the 2019 counterfactual scenario where the minimum wage stayed at its 2006 level than the "real" 2019, especially for the lower education levels - the rise in the minimum wage reduced the standard deviation of log wages among workers with the 1st cycle of education by 7 points, but only reduced it by 2 points among higher educated workers.

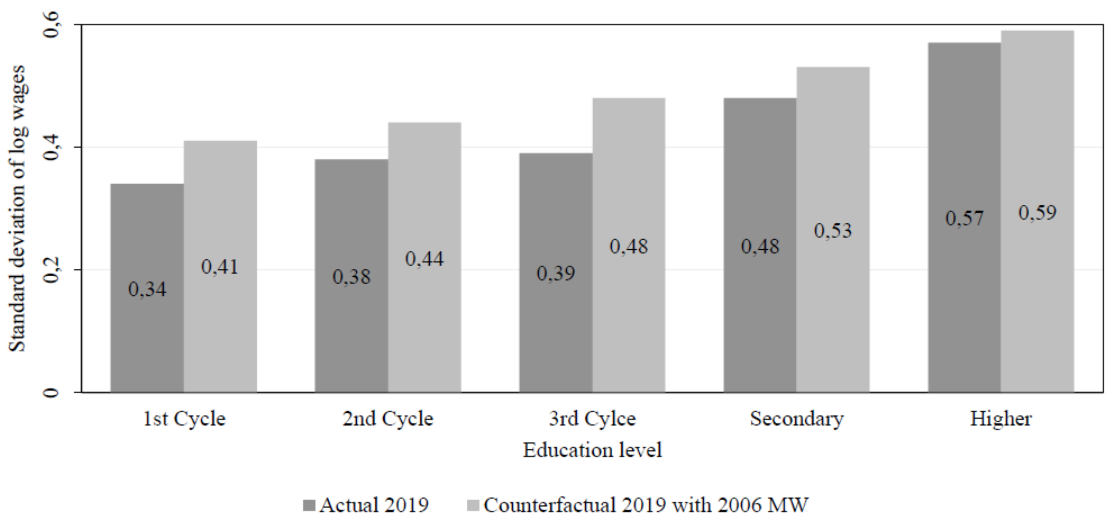

Figure 9: Wage inequality by education level, 2019. This figure depicts the standard deviation of log wagesby level of education, as well as the counterfactual where the minimum wage stayed at its 2006 level.

4.3.3. Age

Regarding individual characteristics, it would also be useful to investigate how the minimum wage affected workers of different ages, the most renowned proxy for labour marketexperience. Figure 10 plots the average wage growth between 2006 and 2019 by years of age, as well as the part of that growth that can be attributed to the rise in the minimum wage.

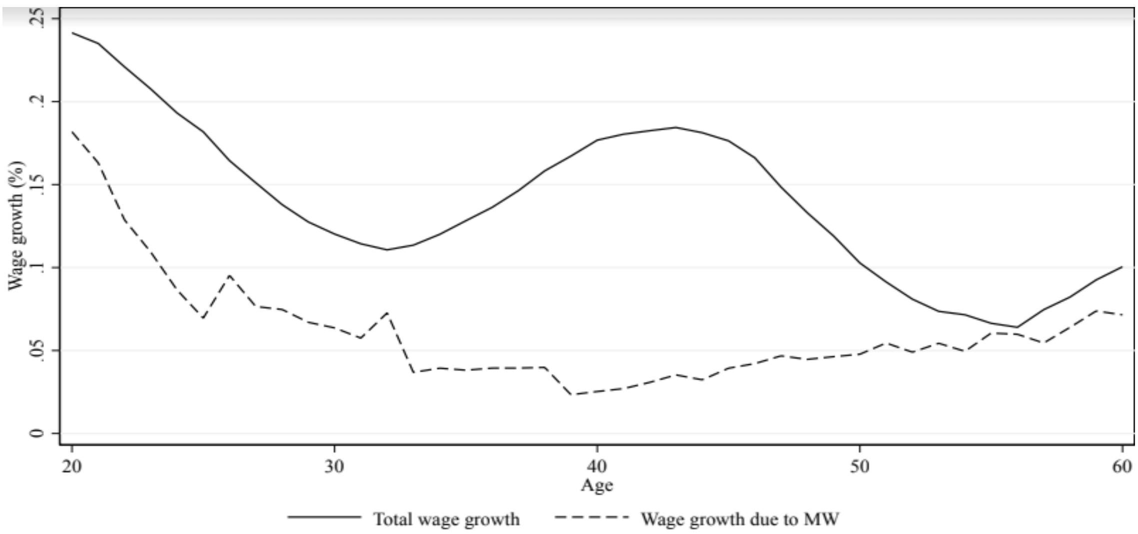

Figure 10: Average wage growth by age, 2006-2019. This figure depicts the moving average of real wage growth by years of age, and the part of that growth that can be attributed to the rise in the minimum wage.

From 2006 to 2019, the wages that grew the most across the age spectrum were the wages of young workers in their 20s, and the wages of adults in their late-30s and 40s. However, the share of that growth that can be attributed to the rising minimum wage was very disparate - for a 20 year old worker, 18 of the 24 log point wage growth was due to the minimum wage (75%), while for a 40 year old worker, that was only 3 of the 18 points (17%).

It is expected that younger workers would be the ones benefiting the most from minimum wage hikes, since they are traditionally over-represented in the low-wage population due to their lack of work experience - and that is exactly what happened. Still, the impact of the minimum wage was not straightly decreasing across the age spectrum - it is decreasing at first, but starts to increase for older workers - for 55-year-olds and older, almost all wage growth was due to the rise in the minimum wage. That happens because, in Portugal, older workers tend to have lower wages than middle-aged workers, on average, due to the very strong dynamics in levels of education over time. These composition effects result in a U-shaped minimum wage effect curve across the age range.

4.3.4. Firms

Lastly, we may also look at the effects of the minimum wage on workers in different typesof firms. Figure 11 portrays the average wage growth, and the part of that growth the can be attributed to the rise in the minimum wage, by firm size.

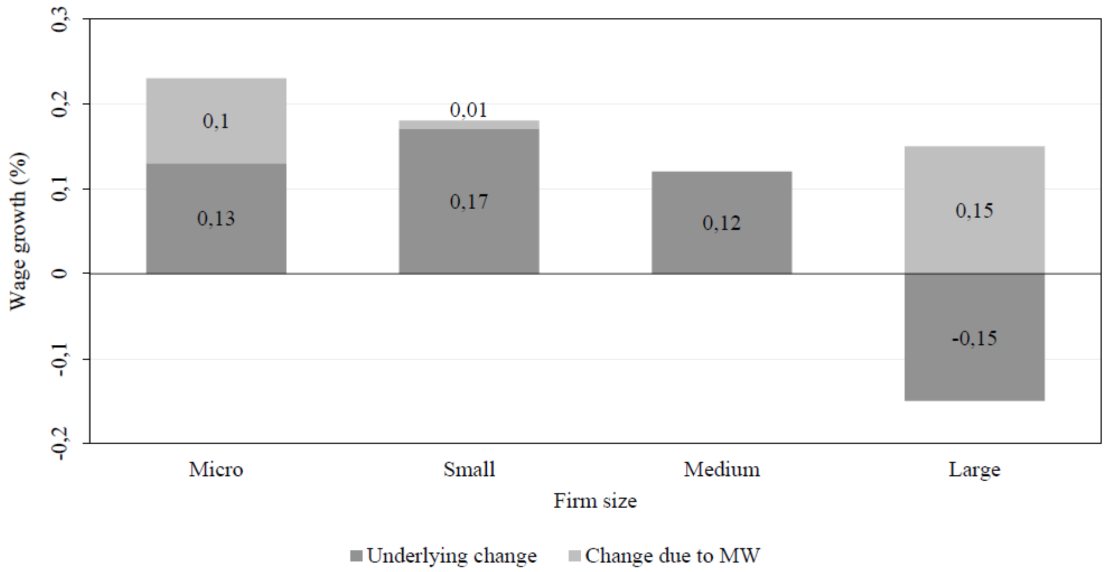

Figure 11: Average wage growth by firm size, 2006-2019. This figure depicts the average real wage growth by firm size, in number of employees, and the part of that growth that can be attributed to the rise in the minimum wage. The firm sizes in number of employees are: micro (1-9), small (10-49), medium (50-249)and large firms (+250).

In general, wages tend to grow with firm size, and the incidence of the minimum wage tends to decrease. That would lead us to believe that the impact of the minimum wage on average wages would be negatively correlated with firm size. However, it was significantly greater for workers in micro firms and large firms, while the average impact on workers insmall and medium firms was negligible - the rise in the minimum wage was responsible for43% of the 23 point rise in the average wage of workers in micro firms and was able to fully mitigate the 15 point decline in the average wage of workers in large firms.

This is because wage inequality is also greater within workers that work in larger firms, as figure 12 reports. The wage of workers in micro firms is low, on average, and concentrated at the bottom, while the average wage of workers in large firms is higher, but it is so because of a larger number of high-earning workers, since large firms also concentrate a very significant share of low-wage workers. That is why the rise in the minimum wage was responsible for a large increase in average wages of workers in these firms, as well as a larger reduction in inequality between these workers. On the contrary, small and medium firms have maintained relatively higher wages for the majority of their workers, not being as sensitive to changes in the minimum wage. Another reason for this phenomenon could be the larger collective agreement coverage and union power among large-firm-employees (Addison et al., 2022), which tend to be renegotiation at a broad scale whenever there is a minimum wage hike.

Another way to divide firms is by their productivity. In figure 13 we proxy the labour productivity of a firm as its sales divided by the number of employees. As we can see, the average growth of wages between 2006 and 2019 was stable across the productivity distribution, around 20%, except for workers at the 20% less productive and 20% more

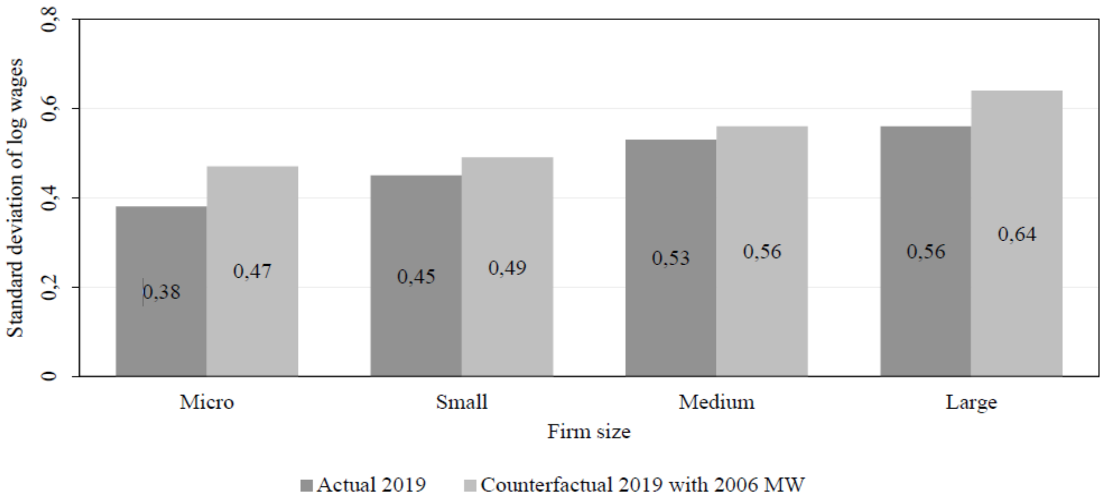

Figure 12: Wage inequality by firm size, 2019. This figure depicts the standard deviation of log wages by firm size, and the counterfactual where the minimum wage stayed at its 2006 level.

productive firms, where it was lower.

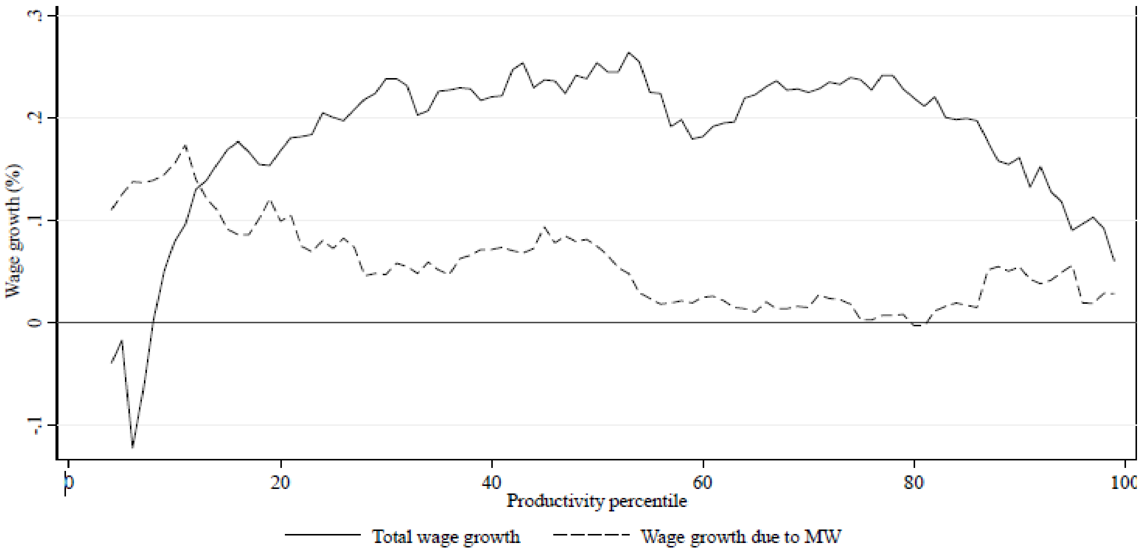

Figure 13: Average wage growth by firm's labour productivity percentile, 2006-2019. This figure depicts the average real wage growth of workers by their firms' percentile in the labour productivity distribution, andthe wage growth that can be attributed to the change in the minimum wage. A firm's labour productivityis measured as sales divided by the number of employees.

At the very least productive firms, wages actually went down. It is, of course, expected that less productive firms have less leverage to raise their workers' wages, but the minimumwage was still able to prevent much larger pay-cuts at these firms. That may have even triggered the phenomenon that we discussed in section 2, confirmed by

Alexandre et al. (2021), whereby a number of unproductive firms are likely going under - as they cannot support the extra labour costs - increasing the average productivity of the economy. For relatively more productive firms, at the second and third quintiles, the minimum wage wasstill able to generate wage gains at a visible rate, but for workers at more productive firms,the rise in minimum wage was not very significant - not being able to prevent the much slower wage growth at the most productive firms.

4.4. Total wages and base wages

All prior analysis was done by looking at the total monthly wage - composed by thebase wage and other regular and irregular benefits[12] - which is the most relevant in the measurement of inequality. But the distributions of base and total wages have presented rather different shapes, as portrayed by the histograms in figure 3. And figure 2 had already hinted that base and total wages were not reacting to changes in the minimum wage in thesame manner since 2006, as the share of workers on the minimum wage has been rapidly increasing if we look at base wages, but if we look at total wages it actually decreased.

Figure 14 depicts the evolution of the average difference between total and base wages - the total-base wage differential - at different points of the distribution. As can see, the total wages of middle- and low-wage workers have been increasing at a pace that is not reflected in their base wages. This phenomenon has increased the total-base wage differential across the distribution over the years, except at the top, where it remained stable.

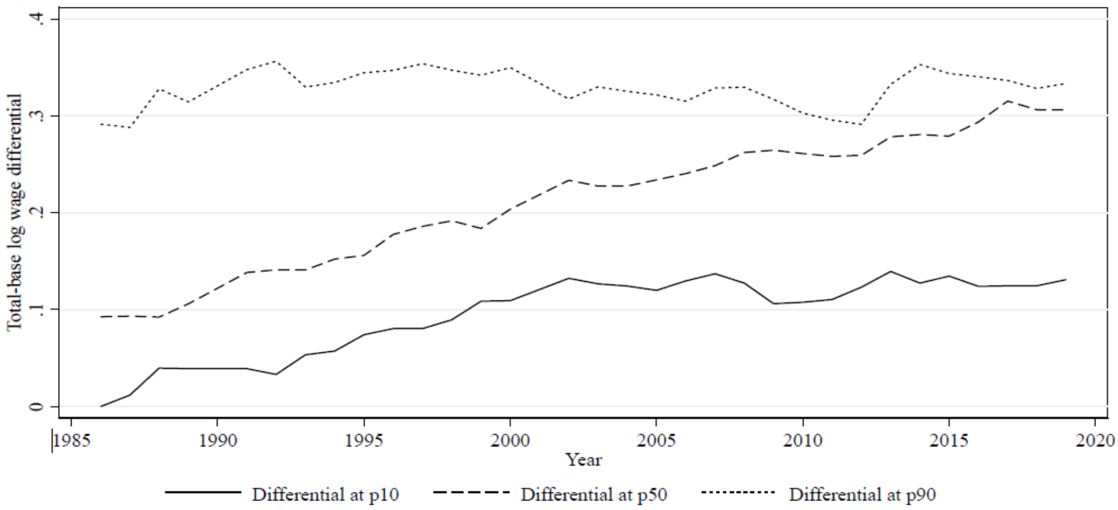

Figure 14: Evolution of the total-base wage differential at different points of the distribution. This figuredepicts the average log differential between total and base wages at the 10th, 50th and 90th percentiles.

[12] Regular benefits include food/ rent/ transport allowances, seniority/ tenure/ productivity/ assiduity bonus and allowances for heavy, dangerous or nightly work. Irregular benefits include payment of profits, securities, indemnities, retroactive, assiduity and productivity bonus, and Christmas and Holidays bonus.

However, since the 2000s, that differential ceased to increase at the very bottom of the distribution. One driver of that phenomenon could be the swiftly rising minimum wage, which started catching up and pushing up the slower-growing base wages of more and more workers at the bottom of the distribution, where the minimum wage bound, as figure 15 illustrates. Since total wages kept their pace of growth, the differential stopped growing.

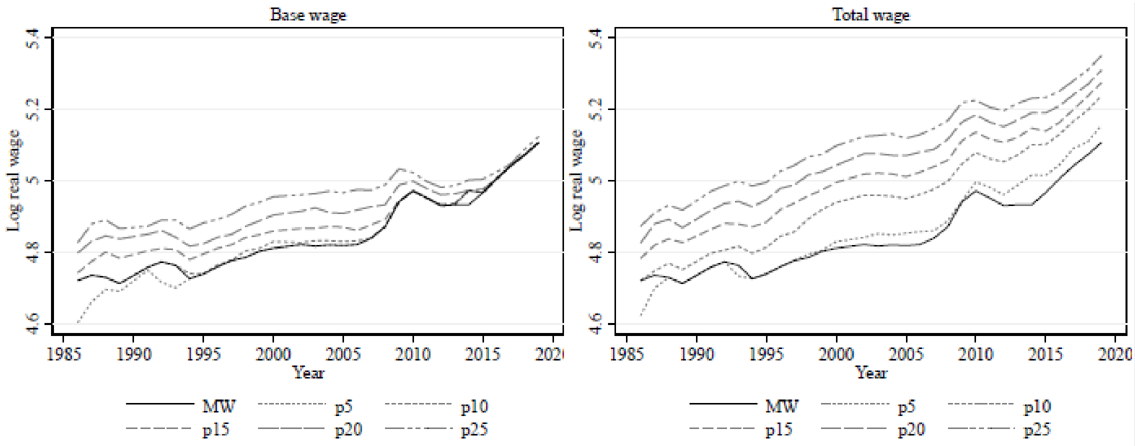

Figure 15: Evolution of base and total wages for different percentiles at the bottom of the distribution. This figure depicts the average wage at different percentiles at the lower-end of the distribution for base and total wages, as well as the minimum wage line.

In order to understand how the minimum wage participated in this development, the actual and counterfactual wage densities were estimated, but using base wages instead of total wages - figure 16. The counterfactual wage density in panel A is not of straightforward interpretation, but if we compare the change in density that can be attributed to rise in the minimum wage for total and base wages, in panel B, we can see that the effect of the minimum wage on the distribution of base wages was much more concentrated at the new minimum, while total wages experienced considerably larger spillover effects.

This suggests that, while minimum wage bite effects are widely reflected in the base wage, spillover effects predominantly manifest themselves in the other benefits that make up the total wage. Since 2006, a very significant share of workers at the bottom of the distribution saw their wages increase due to the rise in the minimum wage. By looking at base wages it would appear that the minimum was only pushing up the wages of the workers for whom the minimum bound, but when we look at the effect on total wages, we can understand that spillovers greatly magnified the effect of the minimum wage, pushing an extremely significant mass of wages higher up in the pay-scale. While spillover effects were minimal in base wages, they were much greater when we look at the entirety wages.

This was quantified in table 5. Just like for total wages, we see a great impact of the minimum wage in reducing base wage inequality, although in this case it is almost all due to the minimum wage bite - spillovers are minor, and only reach up to 10% above the minimum. For instance, the bite single handedly cut the 90-10 percentile differential by 21 points, while spillovers cut it by only 1 point. The bite also raised the wages of the 8% of workers forwhom the minimum wage bound in 2006, and was responsible for one-third of the 12 point increase in the mean wage.

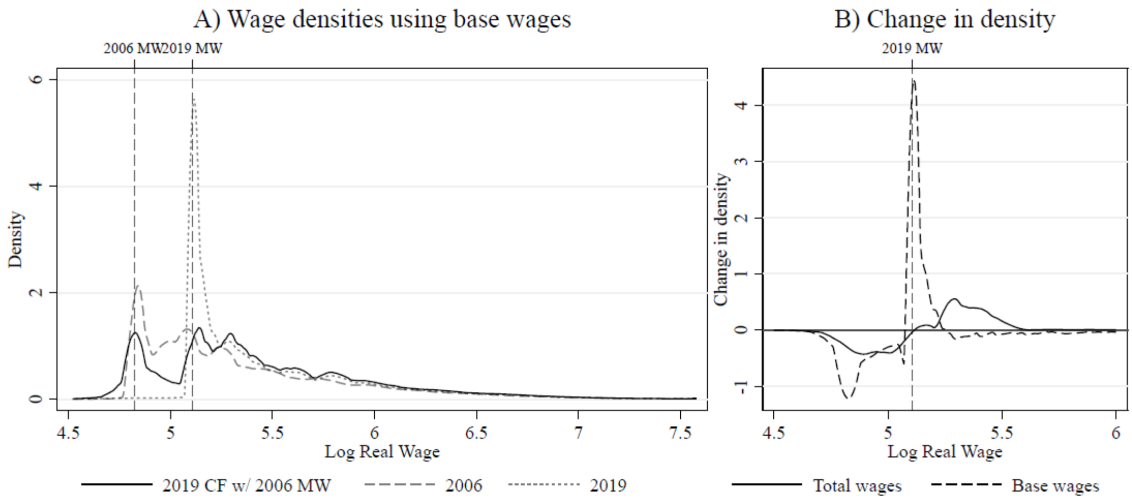

Figure 16: Density estimates using base wages. This figure depicts the density estimate graph previously presented, but using base wages instead of total wages. Panel A depicts the densities analogously to figure4, and Panel B depicts the change in density reported in Panel C of figure 5 and the analogous change in density using base wages.

Still, the influence of the minimum on the distribution is visibly smaller for base wages, especially due to the lack of spillovers: while the share of workers earning more than the real value of the 2019 minimum wage grew between 2006 and 2019, for both base (58% to 79%) and total wages (77% to 96%), the share of that increase thatcan be attributed to the minimum is only one-third in the case of base wages, much lessthan the two-thirds we found for total wages.

This difference may look like an accounting detail but it is rather important since both public debate and academic research often focus solely on base wages when addressing the impacts of the minimum wage - for instance, the incidence of the minimum wage has been rapidly approaching one fourth of the the workforce, looking at base wages, a figure which frequently makes newspaper covers. However, that figure hides a more intricate reality whereby a significant share of minimum wage effects are materialising in total wages and not on base wages.

Still, the reasons for why employers have been compensating their employees with other benefits is not clear. Although it is reasonable that, when the minimum wage increases and employers feel the need to compensate relatively more productive or more senior employees, they do it through benefits like productivity or seniority bonuses, other plausible reasons come to mind. It could be happening as employers shield themselves from extreme nominal wage rigidity in the base wage (Carneiro et al., 2014; Guimarães et al., 2017) that may not reflect in the other components of wages, because of the decline in unionisation, since unions tended to focus collective agreements negotiations on base wages, which employers partly offset in other benefits

	Sd	90-10	90-50	50-10	Incidence 1st year	Incidence last year	Mean wage
			Base wages				
2006	0.51	1.24	0.87	0.37	0.08	0.42	5.35
2019	0.46	1	0.83	0.17	0	0.21	5.47
2019 w/ 2006 MW	0.5	1.22	0.84	0.38	0.08	0.29	5.42
2019 w/o spillovers	0.46	1.01	0.86	0.15	0	0.25	5.46
Total change	-0.05	-0.24	-0.04	-0.2	-0.08	-0.21	0.12
Underlying change	-0.01	-0.02	-0.03	0.01	0	-0.13	0.07
Change due to MW	-0.04	-0.22	-0.01	-0.21	-0.08	-0.08	0.05
Change due to bite	-0.04	-0.21	0.02	-0.23	-0.08	-0.04	0.04
Change due to spillovers	0	-0.01	-0.03	0.02	0	-0.04	0.01

Table 5: Decomposition of changes in statistics of interest using base wages, 2006-2019. This table depicts the statistics of interest, analogously to table 2, but using base wages instead of total wages.

(Cardoso and Portugal, 2005; Addison et al., 2022), or simply due to tax optimisation by firms, since not all the benefits that compose the differential aresubject to the same tax rules. Unfortunately, the data collected in *Quadros de Pessoal* do not discriminate these components.

5. Conclusion

Over the last three-and-a-half decades, wage inequality in Portugal increased, then it stagnated, and then it fell. And the importance of the minimum wage in the labour market presented a nearly symmetric behaviour. This paper explored this significant negative correlation to try and understand the impact of the minimum wage on the whole shape of the wage distribution.

The results visually and quantitatively show how much the minimum wage can structurally reshape the wage distribution. Between 2006 and 2019, the remarkable rise in the real minimum wage was responsible for virtually all of the decrease in wage inequality in Portugal, especially by deterring an increase in inequality at the lower-tail of the distribution. And most of that impact was often driven by spillover effects, since workers' wages did not simply accumulate at the minimum - they cascaded up to 40% above the minimum wage. More, the minimum wage was not only able to structurally reshape the wage distribution, but it actually shifted it to the right, explaining 40% of the Portuguese average wage growth over that period.

In accordance with the literature, the minimum wage was most important in reducing wage inequality between women, which would have actually increased had the minimumwage not risen, and between genders, being responsible for 60% of the female average wage growth (just 7% for men), and for a reduction of 5 p.p., or a quarter of the gender wage gap.It was also highly important in reducing within and between wage inequality in regards to education, explaining almost all of the wage growth of uneducated workers and none of the wage change for higher educated workers, and showing signs of a potential mitigating effecton the returns to education. The minimum wage also benefited younger workers the most, along with older workers approaching retirement age. By looking at firm characteristics, wesee that the minimum wage was most impactful on workers at micro and large firms, and on workers at less productive firms, displaying a possible productivity inducing effect.

The analysis was mostly done using total wages, but looking at base wages uncovered a rather interesting phenomenon. While minimum wage bite effects were reflected in the base wage, spillover effects predominantly manifested themselves in fringe benefits and other components of the total wage. Since spillovers embody an extremely significant share of theeffects of the minimum wage on the wage distribution, focusing only on the base wages - which frequently happens both in academic research and in the public debate - hides a substantial part of the true impact of the minimum wage.

Such a powerful reshaping of the wage distribution, such high spillovers, or such an impact on the average wage are not common in the literature, but neither is a compression of the distribution and a minimum wage hike like these. Exploring that phenomenon, this article adds several insights to the existing minimum wage research, laying the groundwork for other issues to be addressed in future research. Via an alternative approach, this article notonly addresses the proposed research question with meaningful results - yes, the minimumwage does reshape the wage distribution - but it also discloses various paths through whichminimum wage externalities may arise - like the compression of the gender gap and education premium, the impact on labour costs of unproductive firms, or its magnifying effect on fringe benefits.

Appendix A. The reweighted adaptive kernel density estimator

The reweighted adaptive kernel density estimator applied in the construction of counterfactual wage densities is defined as

$$\hat{f}_h(y) = \frac{1}{hN\lambda_i}\sum_{i=1}^{n}\psi(X_k)\cdot K\left(\frac{y-Y_i}{h\lambda_i}\right) \tag{A.1}$$

where $K(.)$ is an alternative Epanechnikov kernel function, h is the Silverman (1986) bandwidth, and λ_i are the local bandwidth factors (Abramson, 1982; Jann, 2007), based on a preliminary fixed bandwidth density estimate, and estimated as

$$\lambda_i = \sqrt{\frac{G(\hat{f}_h(Y))}{\hat{f}_h(Y)}}, \quad i = 1, \cdots, n. \tag{A.2}$$

where $G(.)$ stands for the geometric mean over all i. Note that $G(\lambda) = 1$, and thus

$G(h\lambda) = h$.

Then, $\psi(X_k)$ is the reweighting factor proposed in DiNardo et al. (1996) and generalizedin Fortin et al. (2011), estimated as

$$\hat{\psi}(X_k) = \frac{\bar{Y}_k^C(X)}{\bar{Y}_k(X)}, \quad k = 1, \cdots, K. \tag{A.3}$$

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Appendix B. Interpreting the decomposition tables and results

Tables 2, 3 and 5 present some of the main quantitative results of this paper. The firstfour rows of each panel present statistics of interest for the different scenarios that wereestimated. Using panel A of table 2 as reference: *1986*, the actual statistics of the first year;*1994*, the actual statistics of the last year; *1994 w/ 1986 MW*, the counterfactual statisticsof the last year, had the minimum wage stayed at its first year level; *1994 w/o spillovers*, thecounterfactual statistics of the last year, had there been no minimum wage spillover effects.

The three rows after that present the decomposed change in those statistics. *Total change* is the actual change that occurred between 1986 and 1994, *underlying change* is the change that would have occurred between those years if the real value of the minimum wage had stayed at its 1986 level, and the *change due to the minimum wage* is the change driven by the shift in the minimum wage between those years:

$$\begin{aligned} \textit{Total change} &= \textit{Underlying change} + \textit{Change due to MW} \\ \textit{Underlying change} &= \textit{1994 w/ 1986 MW} - \textit{1986} \\ \textit{Change due to MW} &= \textit{1994} - \textit{1994 w/ 1986 MW} \end{aligned} \tag{B.1}$$

The two final rows of each panel present the *Change due to MW* decomposed into the *change due to the minimum wage bite*, the change driven by the workers whose wages would be below the new minimum but the minimum wage managed to push to that new minimum, and the *change due to the spillovers*, driven by the workers who would be earning the new minimum wage or more but, due to the minimum wage raise, still benefited from a wage boost:

$$\begin{aligned} \textit{Change due to MW} &= \textit{Change due to bite} + \textit{Change due to spillovers} \\ \textit{Change due to bite} &= \textit{1994 w/o spillovers} - \textit{1994 w/ 1986 MW} \\ \textit{Change due to spillovers} &= \textit{1994} - \textit{1994 w/o spillovers} \end{aligned} \tag{B.2}$$

Appendix C. Tables

Year	1986	1994	2006	2019
Mean wage	5.24	5.42	5.57	5.73
Mean wage (base wage)	5.10	5.24	5.35	5.47
Standard deviation	0.50	0.57	0.58	0.51
Standard deviation (base wage)	0.40	0.49	0.51	0.46
90-10 percentile differential	1.21	1.41	1.43	1.21
90-50 percentile differential	0.79	0.92	0.95	0.86
75-25 percentile differential	0.66	0.77	0.76	0.65
50-10 percentile differential	0.42	0.49	0.48	0.35
Minimum wage	4.72	4.73	4.82	5.11
Minimum wage relative to the mean	0.66	0.59	0.54	0.59
Incidence of the minimum wage	0.11	0.06	0.04	0.04
Incidence of the minimum wage (base wage)	0.14	0.09	0.08	0.21

Table C.6: Descriptive distributional statistics. This table provides descriptive measures of log total real monthly wages in Portugal (unless specified) for the four years that divide the three periods of analysis, namely on mean wages wage inequality, and the minimum wage.

Year	Id	Log real wage
...	...	...
2010	3825	7.26
2010	3836	4.73
...	...	...

Year	Id	Log real wage	Wage bin	Outcome
...	...	...	...	...
2010	3825	7.26	55	1
2010	3825	7.26	56	1
2010	3825	7.26	57	0
2010	3825	7.26	58	0
2010	3825	7.26	59	0
2010	3825	7.26	60	0
2010	3825	7.26	61	0
2010	3825	7.26	62	0
2010	3836	4.73	1	1
2010	3836	4.73	2	1
2010	3836	4.73	3	1
2010	3836	4.73	4	1
2010	3836	4.73	5	1
2010	3836	4.73	6	0
2010	3836	4.73	7	0
...	...	...	...	...

Table C.7: Illustration of the stacked dataset. This table illustrates how the original dataset was stacked in order to perform the estimation. Each observation in the original data was multiplied by 62, the number of wage bins, and the outcome variable was determined for each wage bin, so as to “simultaneously estimate62 probit regressions”.

Appendix D. Figures

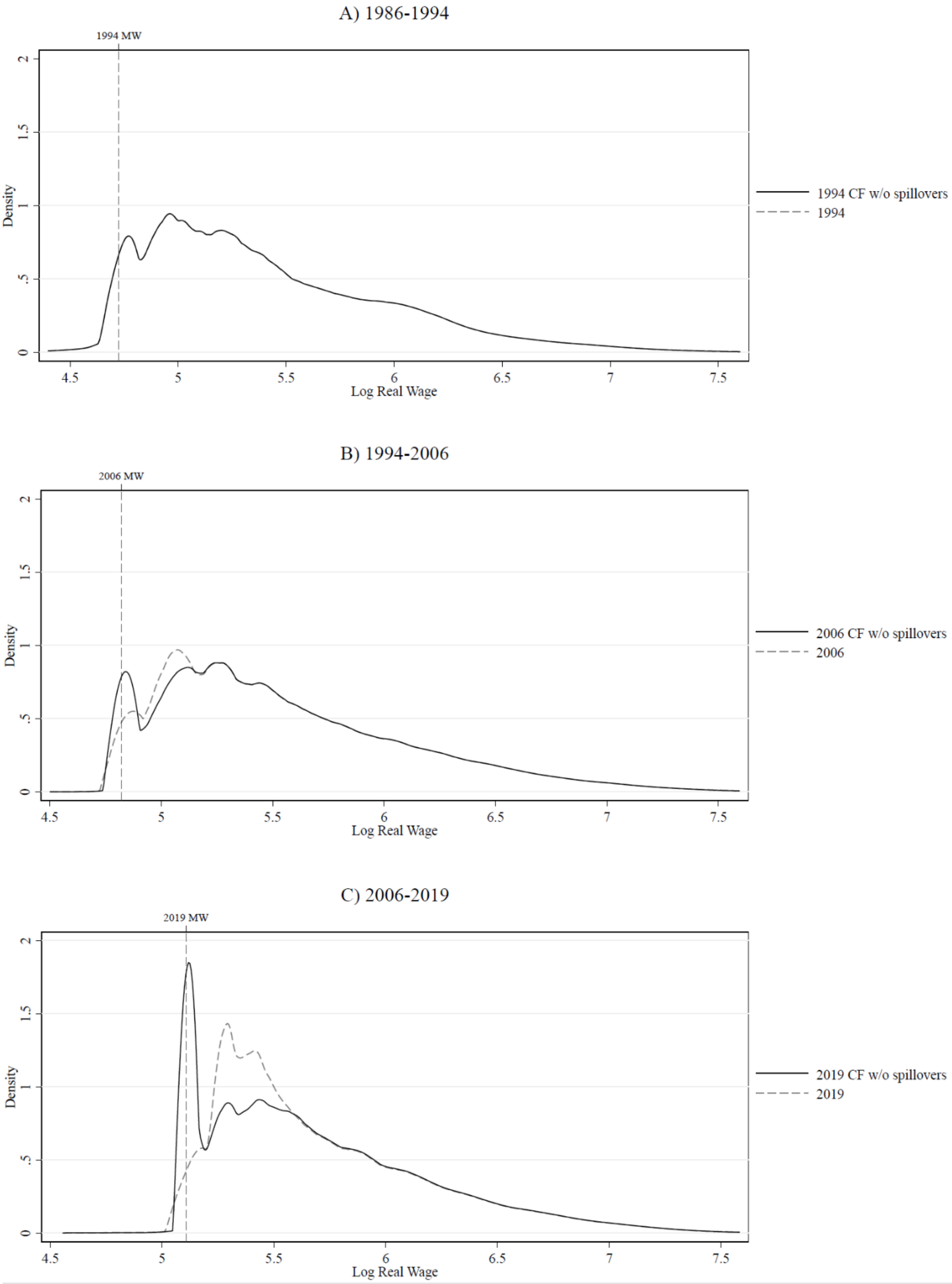

Figure D.17: Counterfactual densities in the absence of spillovers for 1986-1994, 1994-2006, and 2006-2019. Each panel of this figure depicts the counterfactual density estimate for the last year of each period of analysis, had there been no minimum wage spillover effects, as well as the actual density estimate for that year. The dashed vertical line indicates minimum wage.

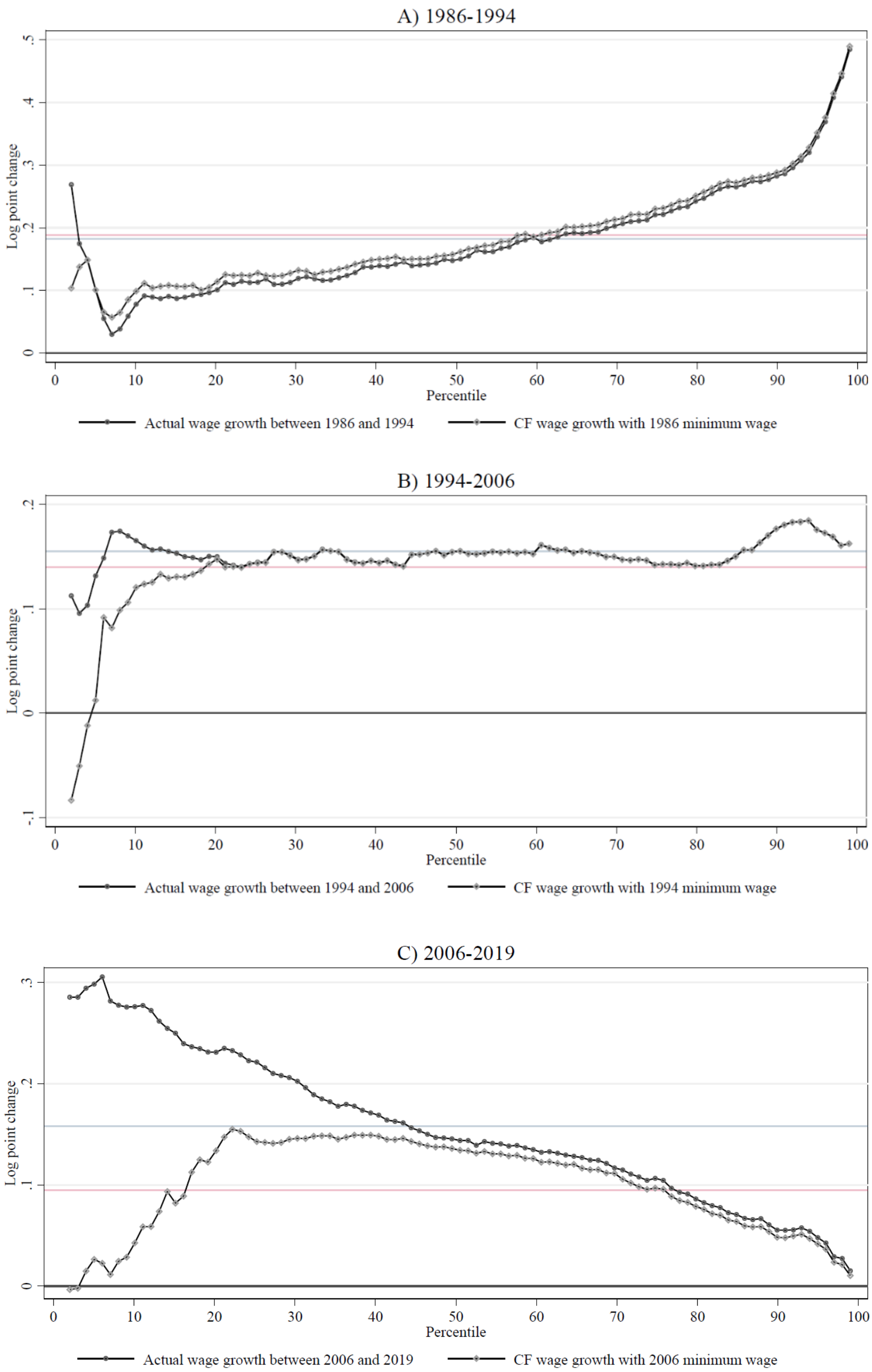

Figure D.18: Wage growth incidence curve over the three periods of analysis. This graph depicts the actual and counterfactual growth rate of wages by percentile of the distribution between 1986-1994, 1994-2006, and2006-2019. The slight difference between the actual and counterfactual curves at higher percentiles of the distribution is due to the reweighing, not representing actual lower wage growth.

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