Do Lower Minimum Wages for Young Workers Raise their Employment? Evidence from a Danish Discontinuity*

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Abstract

This paper estimates the long-run impact of youth minimum wages on youth employment by exploiting a large discontinuity in Danish minimum wage rules at age 18 and using monthly payroll records for the Danish population. We show theoretically how the discontinuity in the minimum wage may be exploited to estimate the casual effect of a change in the minimum wage of youth on their employment. On average, the hourly wage rate jumps up by 40 percent when individuals turn eighteen years old. Employment (extensive margin) falls by 33 percent and total labor input (extensive and intensive margin) decreases by around 45 percent, leaving the aggregate wage payment nearly unchanged. Data on flows into and out of employment show that the drop in employment is driven almost entirely by job loss when individuals turn 18 years old. We estimate that the relevant elasticity for evaluating the effect on youth employment of changes in their minimum wage is about -0.8.

Keywords: Minimum wage policy, employment, regression discontinuity
JEL: J21, J23, J38

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Minimum wages, set by law or by collective agreement, exist in 3/4 of the OECD countries (OECD 2015). In the United States, minimum wage increases have been high on the policy agenda in recent years, motivated in part by many studies finding small employment effects of minimum wage hikes. Some cities (e.g. LA, Seattle) and the state of California have recently enacted a minimum wage rate of $15, a much higher rate than the current Federal minimum of $7.25 per hour.

As higher minimum wages become common, policy-makers must confront a second question: should a high minimum wage apply to everyone? In particular, should it apply to younger workers? Young workers are low-skilled and enter the labor market without work experience, which make them potentially vulnerable to high minimum wages. The age dimension of minimum wage rules is important in practice. Many European countries with high minimum wages have lower minimum wages for younger workers (OECD 2015). A lower minimum wage for young workers exists in twelve U.S. states and the District of California.[1] Many places that have recently increased their minimum wage have debated, and at times legislated or placed on the ballot, an exception for younger workers, including California, Kansas, Minnesota, South Dakota, and Des Moines, Iowa.[2]

The US Congressional Budget Office reports an elasticity of youth employment with respect to the minimum wage of 0.075, but this estimate is based on US evidence focusing on changes in a global minimum wage—rather than a youth-specific minimum wage—and from a baseline wage level much lower than the levels currently on the policy agenda (Congressional Budget Office 2014).

We provide evidence on the employment effects of age-based minimum wages by exploiting a large discontinuity in Danish minimum wage rules occurring when workers reach age 18. The main policy question we seek to answer is: holding the adult minimum wage fixed at a given level, what would be the effect of a change in the minimum wage applying to young workers on their employment. We use economic theory to show that the answer to this question is plausibly identified by the change in employment occurring at the

[1]Alaska, the District of Columbia, Connecticut, Illinois, Michigan, Minnesota, Ohio, Pennsylvania, Rhode Island, South Dakota, Vermont, and Washington. Some of these minimum wage exceptions are only applicable to a subset of younger workers, such as full-time students or those working in a particular sector. A full list is compiled by the National Federation of Independent Businesses here: http://www.nfib.com/assets/State-MW-Exemptions1.pdf Federal minimum wage rules and some other state minimum wage rules also allow workers under the age of 18 to be paid less than the adult minimum wage for the first 90 days of employment.

[2]The following are some examples of this debate playing out in each of these places:

California: http://www.heritage.org/research/reports/2016/05/californias-unprecedented-minimum-wage-increase-will-hurt-vulnerable-workers

Kansas: https://www.washingtonpost.com/news/wonk/wp/2015/07/17/kansas-raises-its-minimum-wage-but-not-for-teens/

Minnesota: http://www.dli.mn.gov/MinWage2016.asp

Des Moines (Polk County), Iowa: http://www.desmoinesregister.com/story/money/business/2016/08/25/polk-county-minimum-wage-hike-approved-teens-exempted/89345142/

age discontinuity in the minimum wage.

The Danish setting is ideal for this research question for three main reasons. First, as we describe below, Denmark has large changes in minimum wage rates when workers turn 18 (and no change at any other ages). In contrast, extant U.S. evidence only considers global changes in the minimum wage, and for the states that do have minimum wage exceptions for younger workers the wage discontinuities are relatively small. A few studies exist on age-specific minimum wage rules with European data, but as we argue in the next section, these studies are less capable of addressing our policy question.

Second, the adult minimum wage in Denmark is high and comparable to the $15 level currently under consideration in the U.S. Using the current exchange rate of 6.6 DKK/USD and the OECD's comparative price level of 125 to adjust for purchasing power parity between the US and Denmark (OECD 2016*a*), the minimum wage for adult workers over 18 in Denmark is comparable to a US wage rate of about $14.50.

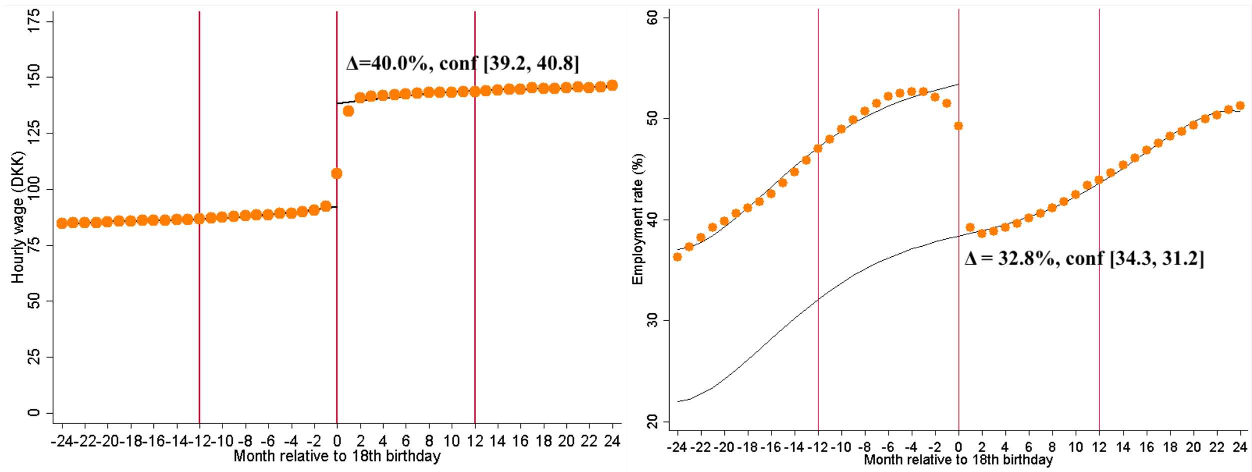
Third, we have access to administrative data with information about wages, employment and hours worked at the monthly frequency for the entire workforce of Denmark, allowing us to study what happens when workers turn 18 with high precision. These administrative data are reported by third parties (employers) to the Danish tax agency (SKAT), and have a direct bearing on the worker's tax liability, ensuring that they are quite accurate (Kleven et al. 2011). Our results complement recent studies exploiting Danish tax return data to identify responses to tax-transfer policies (e.g. Chetty et al. 2011, 2014, Kleven et al. 2014, Kreiner et al. 2014, 2016).

Our main findings are contained in Figure 1, which shows that the age discontinuity in minimum wages has a large impact on employment around age 18. We explain the details behind the construction of the data set and the source of identifying variation below. Figure 1a plots average hourly wages, imputed by dividing for each individual reported monthly wages by reported hours worked, as a function of age (measured in months), for two years before and after their 18th birthday.[3] The average hourly wage rate jumps by DKK 46, or about $7, corresponding to a 40 percent change in the wage level at age 18 computed using the midpoint method. Figure 1b plots the share of individuals who are employed by monthly age. We observe a 15 percentage-point decrease in employment at age 18, which corresponds to a 33 percent decrease in the number of employed individuals (the extensive margin). For comparison, note that the wage and employment

[3] We discuss the measurement of hourly wages and how they relate to mandated minimum wages below, ultimately concluding that there is little measurement error in this variable and that minimum wages are binding for a large majority of workers, so that the percent increase in average imputed hourly wages is very similar to the percent increase in mandatory minimum wages.

Figure 1: Wages and Employment around Workers' 18th Birthdays

(a) Average Imputed Hourly Wage **(b)** Employment Rate



Note: This figure depicts estimates of average hourly wage rates and employment rates by age, in months, for two years before and after workers' 18th birthdays. We observe a sharp, 40 percent increase in average hourly wages when workers turn 18, which is driven by the increase in the minimum wage, and a coincident 33 percent drop in employment. The percent change in the dependent variables and the fitted black line are taken from the estimation of a regression described in Section 4. See also Table 2.

rates develop smoothly when individuals turn 17 and 19 years old, and that it takes two years before the employment rate is back at the level it attains just before the jump downwards at age 18.

A simple estimate of the employment elasticity with respect to the wage change is obtained by dividing the estimates of the percentage changes in employment and hourly wage, which gives an elasticity around -0.8. This effect on the unemployment risk of young individuals is nearly independent on their underlying ability levels, proxied by school GPA in 9th grade, and the income of parents, and the effect is almost exclusively driven by job loss when workers turn 18. There is also a small anticipatory slow-down in hiring as workers approach age 18.

When looking at total hours worked (the intensive and extensive margin), we find an elasticity of about 1.1, indicating that most of the response occurs along the extensive margin. Recall that a unit elasticity would imply that the average wage payment of all individuals, including both employed and non-employed workers, should stay unchanged when the wage rate is raised because its effect on the average wage payment is fully offset by a decrease in employment. Consistent with this reasoning, we find nearly no effect on average earnings. This provides alternative evidence of an elasticity around 1, not depending on the measurement of hourly wages.

Analyses of the distribution of hourly wage rates and of the variation in actual wages and statutory minimum wage rates across sectors strongly indicate that the minimum wage is binding for a large majority of workers, and, consequently, that we obtain a similar elasticity whether we calculate the change in the hourly wage rate using statutory minimum wages or average realized wages. Overall, the data therefore suggest that the reduced-form elasticity of employment with respect to wages is approximately -0.8, and this estimate turns out to be very robust.

We use economic theory to motivate our empirical specification and to show that under reasonable assumptions the estimated elasticity may be used to calculate the effect on youth employment of a change in the minimum wage *specifically for younger workers*. First, we provide a simple, standard model that suggests that the elasticity we estimate using the discontinuity is exactly the same as the elasticity needed for the desired counterfactual policy analysis. In the model, workers have exogenous, heterogeneous productivities and are hired if their productivity exceeds the minimum wage (corresponding to a horizontal demand for labor measured in effective units). In this simple setting, cross-worker effects are zero, a condition which often underlies inference based on difference in differences analyses. A model with downward sloping labor demand for low-skilled work would instead suggest cross-worker effects implying that a higher youth minimum wage increases adult employment. However, we show using such a model that our estimate of the effect on youth employment of a change in the youth minimum wage is a good approximation if the youth share of total low-skilled employment is small, and more generally we derive a a lower bound of the employment effect. We also embed our simple model in an equilibrium search framework incorporating dynamics for aging. The model predicts that many workers discretely lose their jobs at age 18, which matches our finding that the employment effect is driven mainly by job losses. The model also predicts spillover effects of an increase in the youth minimum wage on adult employment, but in this case the sign of the spillover effect is ambiguous. In any case, our elasticity estimate is again a good approximation of the effect on youth employment if the fraction of low-skilled workers that are young is small. Finally, we briefly discuss labor supply effects and how theories of market imperfections, which were introduced in the literature to explain zero or positive effects of global minimum wages hikes, cannot be driving our large negative employment effect.

According to the basic model, we may compute the consequences of increasing the minimum wage for young workers (those under 18) up to the higher level applying to adults by extrapolating as illustrated in Figure 1b. This gives a 15 percentage point drop in youth employment, corresponding to 33 percent of initial employment. To account for potential cross workers effects, we compute the wage share of low-skilled workers under age 18, which depending on the definition gives a range of 1 to 9 percent. Using a conservative share of 10 percent suggests that the relevant employment effect is at least 30 percent of initial employment. One could use identical reasoning to estimate the effect of starting from a minimum wage equal to the adult minimum wage for all workers, and then lowering it only for younger workers. Thus, our results suggest that, in labor markets with high minimum wages as in Denmark, a lower minimum wage for younger workers will substantially increase their employment.

Our estimates of the youth employment elasticity are considerably larger than previous estimates, in particular for the US. We see three likely reasons for this. First, most existing estimates are based on difference in differences studies of minimum wage changes, which may be downward biased by short-run frictions (Chetty et al. 2011, Sorkin 2015, Aaronson et al. forthcoming). Our RD estimates are plausibly long-run effects. Second, nearly all previous studies analyze changes in a global minimum wage, rather than a minimum wage for the young, which theoretically gives a smaller elasticity because relative wages are unchanged. Third, our empirical study is based on a high minimum wage level compared to previous studies and more in line with the recent levels decided or discussed in many places in the US. Minimum wages may not be binding at low levels and if binding they may increase employment due to labor market imperfections (Manning 2003). We review the earlier findings in the next section.

The rest of the paper proceeds as follows: Section 1 reviews the relevant literature; Section 2 provides theoretical foundation for our identification and the policy implications of our results; Section 3 describes the institutional background and dataset; Section 4 presents the results; and Section 5 concludes.

1 Literature review

This section provides a short review of the literature. More comprehensive reviews are found in Card & Krueger (2015), Neumark & Wascher (2008), and Brown (1999).

A recent collection of empirical studies document small or zero effects of minimum wage hikes, in contrast to the predictions of the perfectly competitive model of the labor market. Beginning with Card & Krueger (1994), these studies typically use difference-in-differences (DD) designs comparing the evolution over time of employment in a region or regions experiencing a minimum wage increase to that in other "control" regions not experiencing a minimum wage increase. Control regions are typically neighboring states, or neighboring counties in different states (Dube et al. 2010).[4] The majority of these studies find small or zero effects of minimum wage hikes on employment. Using these studies, the CBO estimated that a 10 percent increase in the minimum wage would reduce employment among teenage workers by 0.75% (CBO, 2014). This effect is calculated using an elasticity of teen employment with respect to a change in the minimum wage of 0.075, from a reading of the empirical literature. As mentioned in the introduction, however, this analysis ignores the distinction between whether the minimum wage is raised for youth or for all workers, and it may severely underestimate the effect on youth employment of changes in minimum wages for young people.

Studies estimating small or zero effects via DD challenged the conventional view at the time, and they sparked an intense and ongoing debate. Several theoretical arguments have been advanced to rationalize small, zero, or even positive effects of minimum wages on employment, including models of efficiency wages (Rebitzer & Taylor 1995) and search frictions (Flinn 2006, Ahn et al. 2011). Alternatively, some research suggests that DD designs on global wage hikes may underestimate the true long-run effect due to short-run frictions (Baker et al. 1999, Sorkin 2015). Another difficulty is that minimum wages are not binding for a large number of workers in the United States, which would mechanically reduce the employment effects of a given wage hike (Autor et al. 2016). On its own this possibility would not imply that existing empirical evidence is wrong, but only that it has limited implications for larger minimum wage hikes of the form currently being contemplated in the United States. Relatedly, recent evidence in Clemens & Wither (2016) suggests that the 2007 to 2009 increases in the US minimum wage may have harmed employment more than indicated by previous studies, as the magnitude of the increases and the underlying macroeconomic trends made the 2007 to 2009 increases in the minimum wage more likely to be binding.

We are not interested in the effect of global minimum wage hikes, but rather in the effects of age-specific minimum wages. A smaller strand of the literature does examine these effects. Neumark & Wascher (2004) show that countries that have high minimum wages also tend to have high youth unemployment, but, consistent with our results, this correlation is weakened when countries have a lower minimum wage for young workers. A few more recent studies employ DD designs around age-specific changes in the minimum wage within various countries (recent examples include Pereira 2003, Hyslop & Stillman 2007, Böckerman & Uusitalo 2009, Yannelis 2014). The results of these studies are somewhat mixed. Some find near zero

[4] Card & Krueger (1994) also use a between-establishment design in the same region, for comparable establishments where the minimum wage was and was not binding. This analysis is a different form of DD, for which some of the potential pitfalls of DD, such as an inability to account for certain general equilibrium effects, are not material.

or positive employment effects, especially in the short run (Hyslop & Stillman 2007, Böckerman & Uusitalo 2009).[5] Most consistent with our results are work by Yannelis (2014) and Pereira (2003), both of whom use administrative data (from Greece and Portugal, respectively), and estimate elasticities in the -0.2 to -0.4 range for younger workers. These estimates are larger than those in the global minimum wage literature summarized above, although not as large as ours. A likely reason why we find a large elasticity even relative to existing age-based DD studies is that short-run frictions can attenuate minimum wage employment effects in DD research designs (Sorkin 2015).

One new study, Kabátek (2015), used an age discontinuity, in this case several small age discontinuities in Dutch minimum wages.[6] The changes in wages and employment are therefore much smaller than in our context, though they are well-identified. The actual effect sizes documented in this study are slightly smaller than ours (even accounting for the smaller discontinuities), but they are broadly consistent with what we find in the Danish data. Interestingly, however, the effects in Kabátek (2015) are more diffuse around workers' birthdays, while ours are quite concentrated in the month after the worker turns 18. Combining one large discontinuity with thorough theoretical reasoning and rich data allows us to interpret our effects more precisely and completely.

Two other studies have examined age-related differences in UK minimum wages with discontinuity designs (Dickens et al. 2014, Fidrmuc & Tena 2013). However, these studies are based on survey data, which substantially decreases their precision. Relative to these studies, our main advantages are a high-quality panel data set, an institutional context that is ideal for studying age-specific minimum wage rules, and new theoretical reasoning to make sense of the policy implications of our estimates. Using the Danish monthly payroll data gives us a high degree of precision, as we know workers monthly employment status, earnings, and age, and we have reasonably accurate data on hours worked. Combined with a large discontinuity in minimum wages at a single age, which has been in place for some time, this context allows us to illustrate the effects of the discontinuity cleanly and in great detail.

Additionally, we establish a clear theoretical foundation with which we can make sense of the policy implications of our findings, and perhaps the findings of prior studies as well. For example, we discuss using theory the fact that the age-specific minimum wage reforms may, through a substitution channel, affected

[5]Of these, the Hyslop & Stillman (2007) uses survey data and the Böckerman & Uusitalo (2009) studies a minimum wage reform that was only in effect for two years before being reverted. We believe these are the main reasons that we find much larger estimates than these studies.

[6]We began our project before the release of this study as a working paper, and have worked independently from its author.

the employment of the older "control groups" used in many of these DD studies, and we will carefully consider the implication of such possibilities for our own estimates. Even accounting for this possibility in an extremely conservative fashion, our results suggest that decreasing the minimum wage for younger workers would substantially increase their employment, which suggests this is an important policy tool to consider in the presence of high overall minimum wages.

2 Theory and Empirical Identification

This section develops theory that informs our empirical methodology and justifies interpreting our results in terms of counterfactual policies. We begin by presenting a simple model of the labor market where we show how the age-discontinuity in minimum wages may be exploited empirically to identify how changes in the minimum wage of youth affect their employment. We then relax several of the more restrictive assumptions in the basic model and show that this does not greatly change the policy implications of our results.

2.1 Basic Model and Empirical Approach

A theory needs to explain why some individuals are still employed when passing the high-wage age discontinuity while others lose their job, even under the realistic assumption that individuals slightly younger and slightly older than the age threshold are perfect substitutes. This employment pattern is difficult to reconcile without introducing some kind of worker or job heterogeneity.

To start from the simplest possible model, we suppose all heterogeneity in productivity arises across workers. We broaden the scope of the heterogeneity in productivity in Section 2.3, allowing for match-specific heterogeneity for a worker-firm pair and embedding the simple model in an equilibrium search framework. Productivity of individual i at age a is given by

$$x_{i,a} = \omega_i + \alpha(a), \tag{1}$$

where ω_i is an individual fixed effect, and $\alpha(a)$ is a function capturing changes in productivity over the life cycle. The individual productivity components ω_i are distributed according to a cumulative density function $F(\omega)$ on the domain $[0, \infty)$. We assume all workers have the same disutility of work and, for simplicity, we normalize their reservation wage to zero.

The minimum wage as a function of age is denoted by $\bar{w}_a$ and implies that only individuals with $x_{i,a} \geq \bar{w}_a$

are employed (denoted $e_{i,a} = 1$). Apart from this employment condition, we make no assumptions about the determinants of the actual wage rate workers' receive; employers could compete for workers so that workers would be paid their productivity, or firms could pay all workers the minimum wage and extract all the surplus above this level.[7]

The employment rate e_a and the probability of employment of a randomly selected individual of age a equals

$$e_a = \Pr(e_{i,a} = 1) = 1 - F(\bar{\omega}_a),\ \bar{\omega}_a = \bar{w}_a - \alpha(a). \tag{2}$$

The employment rate is almost completely linear across age in Figure 1b. This suggests that we may simplify the model by assuming that $F(\cdot)$ is approximately linear in the relevant range of the minimum wage, so that the employment propensity $\Pr(e_{i,a} = 1)$ may be approximated by a linear probability model. In this case, we may estimate

$$\Pr(e_{i,a} = 1) = \eta\bar{w}_a + \tilde{\alpha}(a), \tag{3}$$

where $\tilde{\alpha}(a)$ is a simple transformation of $\alpha(a)$ in eq. (2), and $\eta = F'(\cdot)$ is the parameter of interest for measuring the effect on youth employment of changing their minimum wage. If the minimum wage is raised by $\Delta\bar{w}$ for youth (individuals with a below some threshold $\hat{a}$), then their employment rates change by $\Delta e_a = \eta \cdot \Delta\bar{w}$. The η parameter is identified empirically by the discrete jump in the minimum wage where an individual becomes an adult at age $\hat{a}$, under the assumption that productivity develops smoothly around $\hat{a}$, i.e. that the life cycle relationship $\tilde{\alpha}(a)$ is continuous at $\hat{a}$. We can convert this estimate into an elasticity of employment with respect to the minimum wage by using the midpoint method (to account for the large discrete changes in wages and employment).

We may also estimate the effects on average input of hours and average income by using these variables on the left-hand side of the above regression equation in place of employment. Since minimum wage rules vary somewhat in practice depending on a number of characteristics (regular work versus overtime work, type of work etc.), as we will describe more carefully in Section 3, we pursue two different strategies to measure the employment effect. One strategy is simply to estimate specification (3) and use information about statutory minimum wages for regular work in the collective agreements. Another strategy is to estimate the

[7]The notion that firms could extract some surplus is perhaps more intuitive when we consider the case where heterogeneity is match- or employer-specific. In subsection 2.3, we embed the basic model into a standard equilibrium search framework with match specific heterogeneity and where firms have all the bargaining power. In this case, firms only pay a worker the minimum wage because the surplus is match-specific rather than related to particular workers. For further discussion of the role of bargaining power in the effects of minimum wages, see Clemens & Wither (2016).

employment equation

$$\Pr(e_{i,a} = 1) = \psi_e 1\{a \geq \hat{a}\} + \tilde{\alpha}(a), \tag{4}$$

where $1\{\cdot\}$ is an indicator function, so that ψ_e measures the discrete change in employment at the time when individuals become adults. By estimating a similar equation for the imputed hourly wage rates of those working and combining the estimates for these discrete changes in employment ψ_e and wages ψ_w at $\hat{a}$, we may compute the wage-employment relationship as $\eta = \psi_e/\psi_w$, and a corresponding employment elasticity ε.

Note that the employment effect in the first case case is measured relative to a change in *statutory* minimum wages, while the second strategy estimates the change in employment relative to a change in *actual* wages. The two methods should give the same result if the minimum wage is binding for all workers. If this is not the case then we should find that using actual hourly wages yields a larger elasticity. Note also that in principle, one could estimate this model using data from a single cohort or a single time period. With panel data, one can use data from several cohorts and multiple time periods, and also ensure that time-specific shocks or cohort-specific confounds do not bias the estimate of the elasticity in question. Allowing for such time and cohort fixed effects is a trivial extension to the model above.

The remaining parts of this section will relax and extend the ideas of this relatively simple model to ensure that our interpretation of the empirical results is appropriately nuanced.

2.2 Decreasing Labor Demand and Cross-Worker Effects

In the above analysis, the productivity of each worker is independent of other workers—as often assumed in theoretical and empirical studies of tax-transfer policy and its impact on the labor market (e.g. Mirrlees 1971, Feldstein 1999, Saez 2010)— because of a horizontal demand for labor inputs (in effective units) and perfect substitutability of labor.

The second, perfect substitutability assumption is reasonable when looking at age groups close to the threshold $\hat{a}$. On the other hand, a 16 year old individual may not perfectly substitute for an 18 year old. In that case, a policy that, say, raises the minimum wage for all young individuals under the age of 18, and thereby lower their employment rate, will also reduce the productivity of 18 year olds, and thereby decrease their employment too. As a consequence, the true effect on youth employment of changing their minimum wage would be larger than suggested by our estimates because the empirical method measures youth employment relative to that of eighteen years old. As our main finding is that the effect is sizably larger than one would naively conclude from studies of global minimum wage changes, we are not overly concerned with issues that would cause the effect of a lower youth minimum wage to be even larger than our estimates suggest.

Next, we consider the case of a downward sloping labor demand curve for low-skilled workers (including all young workers), but where workers are still perfect substitutes. For simplicity, we disregard life-cycle effects on productivity, and assume that the value of output generated by low-skilled labor is given by

$$y = f(x),\ x \equiv \int_{0}^{1} \int_{i(a)}^{1} \omega(i) di da, \tag{5}$$

where x is total labor input measured in efficiency units, a is the age of an individual, $\omega(i)$ is the productivity/ability level of individual i where individuals are indexed according to productivity, $i(a)$ denotes the marginal individual who is employed for age a, and $f(\cdot)$ is an increasing, concave function. In this setting, firms will hire person i of age a if $\bar{w}(a) \leq f'(x)\omega(i)$, where $\bar{w}(a)$ is the age-specific minimum wage and $f'(x)\omega(i)$ is the marginal productivity of the individual. In line with the empirical analysis, we focus on the case of a given minimum wage rate for the young, $\bar{w}(a) = \bar{w}_1$ for $a \leq \hat{a}$, and a given minimum wage for adults, $\bar{w}(a) = \bar{w}_2$ for $a > \hat{a}$. This implies that the lowest productivity level of an employed person within age group a, depending on whether $a \leq \hat{a}$ or $a > \hat{a}$, is characterized by

$$w_1 = f'(x^*)\omega_1,\ \text{for } a \leq \hat{a}, \tag{6}$$

$$w_2 = f'(x^*)\omega_2,\ \text{for } a > \hat{a} \tag{7}$$

where x^* is the value of x in equilibrium and $\omega_j \equiv \omega(i_j)$ when i_j is the marginally hired person. The number of employed young individuals and adult individuals then become $(1 - i_1)\hat{a}$ and $(1 - i_2)(1 - \hat{a})$, respectively, and their corresponding employment rates are $e_1 = 1 - i_1$ and $e_2 = 1 - i_2$. If $f'(\cdot)$ is constant then this model is equivalent to the basic model above and there are no cross-worker effects. However, if $f(\cdot)$ is strictly concave then it implies that marginal productivity is decreasing. In this case, an increase in the youth minimum wage w_1 reduces their employment (e_1), but increases the employment of adults (e_2), including individuals who are 18 years old. As a consequence, our regression discontinuity approach may overestimate the effect on youth employment of a change in the minimum wage. However, in Appendix A.1

we show that the true labor elasticity $\tilde{\varepsilon}$ for the effect of an increase in w_1 on e_1 is related to the estimated elasticity ε from RD according to

$$\tilde{\varepsilon} \equiv \frac{de_1/e_1}{dw_1/w_1} = \frac{1+\epsilon\frac{(1-\hat{a})\omega_2}{x^*}}{1+\epsilon\frac{(1-\hat{a})\omega_2+\hat{\alpha}\omega_1}{x^*}}\varepsilon, \tag{8}$$

where $\epsilon = -\frac{f''(x^*)x^*}{f'(x^*)}$ denotes the percentage reduction in the marginal product of each individual if aggregate employment in effective units increases by one percent. If $\epsilon = 0$, labor demand is horizontal and $\tilde{\varepsilon} = \varepsilon$ without any bias, as in the previous section. The potential bias is largest when overall labor demand is vertical, so $\epsilon \to \infty$, in which case we have

$$\tilde{\varepsilon} = (1-\delta)\varepsilon, \tag{9}$$

where $\delta \equiv \hat{a}w_1/[\hat{a}w_1 + (1-\hat{a})w_2]$ is the wage share of young workers out of the aggregate wage bill of low-skilled workers. This expression implies that the maximum bias corresponds to δ percent of the elasticity estimate, and if the wage share is small then the bias will be small. When describing the empirical results in Section 4, we use this insight to obtain a lower bound of the elasticity when accounting for cross-worker effects.

2.3 Embedding the Basic Model in an Equilibrium Search Framework

The above theory is silent about labor market dynamics, for example about the effect of the minimum wage on job separation and job finding rates, and also about the dynamics of workers aging. In Appendix A.2, we embed the basic model into a standard equilibrium search framework with firm-worker heterogeneity along the lines of (Pissarides 2000, Ch. 6). In this setting, workers/firms are ex ante homogenous, but the productivity of a job-worker pair is drawn from a known distribution after the worker and firm meet.

We assume that firms have all the bargaining power so that minimum wages are binding, which is realistic for our setting. We compress the life-cycle dynamics into two states (young, adult) where the share of young individuals in the population is determined by a parameter δ.[8] Firms open vacancies for young and adult workers, respectively, and in the competitive equilibrium the expected benefits of a vacancy equals the expected costs. Open vacancies and workers without a job meet according to a constant returns to scale matching function, but the worker is only hired if the match-specific productivity is above the minimum wage. In addition, a firm may decide to fire a worker that becomes an adult, and thereby becomes eligible

[8] Note that this parameter is similar but not identical to the wage bill share in Section 2.2, which was also denoted δ. Here, δ, is the fraction of workers in the given labor market that are young.

for a higher minimum wage.

In this setting, we obtain the following results. First, if the adult minimum wage is higher than the youth minimum wage then firms will fire a share of the young employed workers at the time when they become adults. Thus, empirically we should see a spike in the job separation rate for individuals moving into adulthood.

Second, a higher adult minimum wage reduces the employment rate of adults and—perhaps counterintuitively—reduces also the employment rate of the young. The reason is that it becomes less attractive for firms to open up vacancies for the young because of an increase in the expected wage costs over the duration of a job-worker match.

Third, a higher youth minimum wage reduces youth employment. The effect on adult employment is ambiguous. Intuitively, a higher youth minimum wage reduces youth employment thereby reducing the flow into adult employment. On the other hand, an employed young worker will on average have a higher productivity and therefore a higher chance of staying employed when becoming adult. This ambiguous cross-worker effect of the youth minimum wage on adult employment implies that our empirical measurement of the effect on youth employment may be positively or negatively biased. However, similar to the case of a decreasing labor demand, we find that the bias is small if the share of young workers, δ, is small.

2.4 Labor Supply Effects and Imperfect Competition

We have, so far, considered a fixed labor supply. Here, we extend the simple model in subsection 2.1 by allowing for the possibility that a higher minimum wage could induce workers to enter the labor force, which may also change with the age of the individuals. In a classic perfectly competitive labor market, changes in labor supply have no effect with a binding minimum wage. We consider a more general setting where minimum wage increases may increase employment through labor supply effects.

Suppose that workers participate in the labor force with probability $\Pr(l_{i,a} = 1) = l(\bar{w}_a, a)$ where $\bar{w}_a$ is the minimum wage applying to workers of age a as before.. One should think of $l(\bar{w}, a)$ as the reduced form of a labor force participation decision that may involve the dis-utility of work, the opportunity cost of time, and so on. As such, it is natural to suppose that $l_{\bar{w}} = \partial l/\partial \bar{w} \geq 0$, so that a higher minimum wage may attract workers into the labor force, and $l_a \geq 0$, so that labor force participation is increasing with age. Among other potential mechanisms, this setup provides a simple way to capture the intuition of Flinn (2006) that a higher minimum wage should increase search intensity, which leads to the possibility, in Flinn's model and here, that a higher minimum wage could increase employment.

Given a perfectly competitive market with constant returns to scale on the production side, workers in the labor force will be employed if their productivity is above the minimum wage, exactly as in eq. (2) but conditioning on $l_i = 1$. Supposing for simplicity that all determinants of labor supply, through $l(\cdot)$, such as reservation wages, are independent of the individual-specific component of productivity ω_i, we have that eq. (2) becomes:

$$\Pr(e_{i,a} = 1) = l(\bar{w}_a, a)[1 - F(\bar{\omega}_a)],\ \bar{\omega}_a = \bar{w}_a - \alpha(a). \tag{10}$$

Note that holding fixed the minimum wage, an increase in employment over time, as we observe away from the discontinuity in Figure 1b, could occur due to either an increase in productivity with age (as before), or an increase in labor force participation with age.

To examine the effect of an age-specific change in the minimum wage applying to workers below age $\hat{a}$, we take a first-order Taylor approximation of eq. (10) around the threshold age $\hat{a}$ and the minimum wage applying to adults $\bar{w}_2$ to obtain a regression equation:[9]

$$\begin{aligned} \Pr(e_{i,a} = 1) &= l(\bar{w}_2, \hat{a})[1 - F(\bar{\omega}_2)] \\ &+ \underbrace{\{l_{\bar{w}}[1 - F(\bar{\omega}_2)] - l(\bar{w}_2, \hat{a})F'\}}_{\eta}(\bar{w}_a - \bar{w}_2) \\ &+ \{l_a[1 - F(\bar{\omega}_2)] - l(\bar{w}_2, \hat{a})F'\alpha'\}\,(a - \hat{a}) \end{aligned} \tag{11}$$

where F' is the derivative of $F(\omega)$ and α' is the derivative of $\alpha(a)$; all derivatives are evaluated at $(\hat{a}, \bar{w}_2)$. As in Section 2.1, the employment effect of a change in the minimum wage, η, is identified by the discrete jump in the minimum wage at age $\hat{a}$.

The employment effect consists now of labor supply and demand effects. In the labor supply effect, a higher minimum wage attracts workers into the labor force, represented by the first component of η in eq. (11). In the labor demand effect, as before, young workers with productivity above the old minimum wage and below the new one are no longer employed, represented by the second component of η in eq. (11).

[9] As is often the case when employing first-order approximations, using our discontinuity to estimate the effect of the counterfactual policy experiment requires that the assumption of linearity about $\bar{w}$ and a is a reasonable approximation. Fortunately, however, we can see from Figure 1 that at least two of the three relevant second-order effects are not large. Most importantly, the cross-partial, $dad\bar{w}$, term must be small because the slope of the fitted line is virtually constant across the age 18 threshold, i.e. the effect of age on the probability of employment is not affected by the minimum wage. Similarly, the da^2 term must be small because the fitted curve is approximately linear in age.

Notably, these two effects are opposite in sign, so that the overall employment effect of this policy change is ambiguous. It is ex ante possible that a higher minimum wage would attract so many workers into the work force that the labor supply effect would dominate in η and employment would increase as workers turn 18. Observing instead that employment falls suggests that the labor demand effect is dominant.[10]

Finally, we consider the possibility of imperfect competition. As is well-known, this may lead to a positive relationship between minimum wage levels and employment (Manning 2003). Firms may exploit monopsony power in the labor market to keep wages below the market clearing wage, implying that the introduction of a minimum wage between the monopsony wage level and the market clearing level raises employment. To see how the mechanisms in this type of theory would work with an age-dependency in the minimum wage, consider the case where labor demand is horizontal, all individuals have the same productivity level, but their reservation wages differ thereby giving rise to the same increasing labor supply curve within each age group. Monopsony power implies that employment is below the market clearing level, and is identical for all age groups. In this case, the introduction of binding minimum wages (below the market clearing level) with a higher level for adults implies that employment should increase when individuals move into adulthood. Like the possibility of a labor supply effect that increases employment considered above, this effect is in contrast to our empirical evidence. Hence, although such mechanisms may be at play they will have to be dominated by the other effects pulling towards a negative relationship between the minimum wage level and the employment rate.

3 Institutional Background and Data

3.1 Danish Minimum Wages

In Denmark, and other countries such as Austria, Finland, Iceland, Italy, Norway and Sweden, minimum wages are set by collective wage agreements between trade unions and employers' organizations (OECD, 2015). This is organized by industry sectors nationally. A wage agreement specifies minimum pay rates at the industry level, and the pay rates may vary with age, experience, qualifications, time of work etc. The

[10]Similar to cross-age substitution effects on the labor demand side, there could be intertemporal substitution effects on the labor supply side. When youth minimum wages are increased, some young workers lose their jobs, while those keeping their jobs receive higher wage rates. Intertemporal substitution effects could then imply that the first group would substitute toward working more as an adult, while the second group would like to shift toward working more as a young person. These two possibilities affect adult employment in offsetting directions, and, as with cross-age substitution effects on the demand side, there is no reason to believe that such effects would have a large impact on the employment in the month workers turn 18 years old, and therefore no reason to expect a large bias in our estimate from such effects.

collective bargaining agreements effectively cover 80-90 percent of all Danish workers.[11] Most importantly for our purpose, the minimum wage level in all collective agreements increases sharply when individuals become adults at age 18. An exception is for apprentices (similar to technical education in the United States) where wages change according to education length. Some other countries (for example Australia, Chile, Ireland, Greece, the Netherlands and the UK) and twelve US states also have a lower minimum wage requirement for young workers.[12] The youth (age 15-24) unemployment rate in Denmark is 10.8 percent of youth labor force, which is close to the US level of 11.6 percent, and also near the median youth unemployment rate among OECD countries (OECD 2016*b*).

Table 1, panel A describes the minimum wage levels specified in the wage agreement relevant for persons working in supermarkets and grocery stores (called "*Butiksoverenskomsten*") where around 42 percent of the employed 16- and 17-year olds work according to our data. For young workers the basic salary is DKK 63, while it is DKK 111 for adults. This corresponds to a difference of 55 percent. The minimum wage level is higher in evenings, in the weekend and for overtime work, but the difference between young and adults is approximately 55 percent for all categories. Appendix Table A.1 reports minimum wage levels for young and adults in other wage agreements. It reveals some variation across the wage agreements, but the variation is rather small, compared to the difference in wage levels between young and adults. The degree of dispersion in wage floors is not exceptional in Denmark and is, for example, not very different from the United States (Cahuc et al. 2014).

Denmark has age discrimination laws making it illegal to layoff an employee because of age. However, there is an explicit exception to this rule for when a young person reaches age 18 and becomes eligible for the higher adult minimum wage.[13] In general, it is easy for firms to layoff workers in Denmark and there are no changes in firing costs around age 18.[14] It is legal for a firm to search explicitly for a young worker or for an adult worker.

Certain restrictions apply to the type of work by younger workers. Young workers are not allowed to lift more than 25 kilos, work with certain hazardous material or work certain large machines, and they are not allowed to handle money in certain ways.[15] Also, only adults are allowed to drive a car, and this requires

[11] More information about the Danish system may be found at www.wageindicator.org.

[12] See footnote 1 for more on US state minimum wage rules.

[13] See www.agediscrimination.info/international/Pages/Denmark.aspx.

[14] Adults may receive severance pay, but this depends on seniority and requires typically at least three years of employment in a firm.

[15] This is described in detail in the law document "*Ungebekendtgørelsen*" available at www.retsinformation.dk/Forms/R0710.aspx?id=29935.

Table 1: Example: Wage Rates in Supermarkets and Grocery Stores

Panel A. Collective agreement			
	Young	Adult	Difference
Basic salary:	63	111	55%
Evening:	75	135	57%
Overtime:	94	166	55%
Saturday:	85	155	58%
Sunday:	126	221	55%
Panel B. Computed from data (monthly earnings/hours)			
	17 yrs	18 yrs	Difference
Data, mean	88	152	56%
Data, median	84	151	56%

Note: This table reports the hourly wages (DKK) for workers above and below age 18 in the supermarkets and grocery stores according to their collective bargaining agreement (labelled *Butiksoverenskomsten*) in 2015 and according to our imputed wages using 2015 data (ES codes 4711, 4719). We observe that the percent changes in minimum wages in the collective bargaining agreement are very similar to the percent changes in the mean and median wage rates in our data. Percent differences are calculated using the midpoint method.

obtaining a driver's license. Our empirical analysis of the employment effects of the hike in the minimum wage when individuals become adults presumes that productivity is a continuous function of age. To the extent that productivity jumps up at age 18 because of these rules, our estimates are lower bounds of the total effect of interest.

3.2 Data

Our main data source is an administrative register from the Danish tax agency (SKAT) containing information about wage payments (including pension contributions) and number of hours worked at the monthly frequency for each employee in Denmark. This information is third-party reported by employers to the tax agency, which uses the information to compute annual earnings for employees' preprinted tax returns. The earnings item on the tax return is “locked,” meaning that the employee can only change this item by getting the employers to change their reporting to the tax agency.[16]

The Danish tax agency is allowed to keep information in a five-year window, and we have obtained data for the period January 2012 to December 2015. The data also contains information on the age of the employee and the industry sector of the employer, as well as individual identifiers (the “CPR” numbers assigned to all Danes) and firm identifiers (CVR numbers), enabling links to other registers. The monthly payroll data has been transferred to a centralized governmental statistical agency, Statistics Denmark, for storage and

[16]More information about the third-party information reporting in Denmark may be found in Kleven et al. (2011), which also provides evidence from a randomized field experiment showing that evasion rates on earnings are very small in Denmark.

analysis, and merged with other population register data. For some of the analyses, we use information from Statistics Denmark about the job, the school performance of the individual, and parental background. We describe these variables further when we introduce them in the results section.

Our data consists of observations for each month of Jan 2012 – Dec 2015 for all individuals in Denmark who are 16-19 years old in this month. There are 577,795 individuals and around 14 million observations. Figure A.1 in the appendix displays the development of key statistics over time in our sample period of 48 months. Figure A.1a depicts employment—defined as having positive earnings in a month—and Figure A.1b depicts average earnings conditional on employment. Roughly one in two Danish persons age 16-19 is employed in a typical months. The figures reveal some seasonal variation, with elevated employment in the summer months and in the Christmas month. Predictably, average earnings among employed individuals are also higher in the summer, especially in August. Figures A.1c and A.1d show the evolution among employed individuals of deciles of hours worked and hourly wage rates. The hourly wage rate of an employee in a given month is not reported, but is imputed by dividing earnings by hours worked. The median of hours worked is about 30 hours per month, with significant skew above the median, so that the average of monthly hours is about 60 hours in a typical month. The top decile equals the statutory level of full time work in many months, meaning that in most months, just over 10 percent of the sample works full time. With some exceptions, therefore, most of these individuals work part time, often to supplement their income while pursuing an education. We also observe seasonality in hours worked that is qualitatively similar to what we observe for employment and monthly earnings. Hourly wages are also positively skewed, with a median of about DKK 90 per month and only a little seasonal variation.

As mentioned above, wage agreements of apprentices do not have a jump in the hourly wage at age 18. In our main analyses, we therefore only include observations of individuals who are not registered as apprentices in a given month unless otherwise noted. We use the apprentices sample (6 percent of the observations) for a placebo analysis and show also that the main elasticity estimate is almost unchanged when using the full sample including apprentices (reflecting that it reduces the changes in both average employment and hourly wage at age 18).

In panel B of Table 1, we show the mean and median hourly wage rate for 17 and 18 year old employees, respectively, in the supermarkets and grocery stores computed from our data. For each age group, the mean and median are almost identical and lying in the range of the collective agreement for the age group. More importantly for our analysis, the percentage difference between wage rates of 17 and 18 year olds is 56 percent, and thus basically the same as in the collective agreement displayed in panel A.

Appendix Table A.2 shows imputed average hourly wages for 17- and 18-year olds in various sectors. Variation in average wage rates between sectors could be driven by differences in minimum wages in collective bargaining agreements, by differences in the composition of hours between conventional, weekend, and overtime hours, or by differences in the frequency with which the minimum wage is binding. In any case, we observe that the variation in wages between age 17 and age 18, which is due to the change in minimum wage rules, is typically much larger than the between-sector variation in wages at a given age. We see the same pattern, when we examine the variation in statutory minimum wages imposed by specific collective bargaining agreements in Appendix Table A.1. The variation across ages dominates variation across sectors. There is not a one-to-one mapping from the wage agreements to the sectors as defined in our data, but note that the simple average of the wage changes at age 18 across the agreements (48% in Table A.1) is very close to the simple average across sectors (47% in Table A.2).

4 Empirical Results

This section presents the results of the paper. We show that the minimum wage hike at age 18 has a strong effect on hourly wages and employment, and that, calculated in a variety of ways, the relevant reduced-form elasticity of employment with respect to the minimum wage hike is near -0.8. We use these estimates to inform the effect of employment of adopting a counterfactual policy that eliminates the lower wage for younger workers. We also show that, consistent with the predictions of the search model described above, the employment effect operates primarily through job losses, and we provide suggestive evidence of a significant impact of job loss beyond just one month after the 18th birthday. We study how these employment effects vary by worker characteristics. Finally, we demonstrate that the potential threats to our research design do not bias our results.

Wages and Employment

The main results of the paper are presented in Figure 1 in the Introduction, which examines workers' hourly wage and employment at each age, in months, for two years before and after the month of their 18th birthday. We observe a large jump in wages and a large drop in employment right as workers turn 18, and no discrete changes when they turn 17 or 19.[17] We also observe a small anticipatory drop in employment in the two months before the worker turns 18, and perhaps a small amount of inertia in the month just after the worker turns 18.

To obtain a point estimate and standard error for the size of these effects, we first estimate regressions of the following form:

$$E[y_{it}] = \psi \cdot 1\{a_{it} \geq 18\} + \sum_{d=0}^{D} \alpha_d a_{it}^d + \rho \cdot 1\{a_{it} = 18\}, \tag{12}$$

where y_{it} is the outcome variable. The main effect of interest is ψ, which captures the change in $E[y_{it}]$ when the worker turns 18 (as in eq. (4) in the theory section). The second term on the right-hand side of this specification is a polynomial in age of degree D. We use $D = 5$ throughout the paper. The fitted polynomial and discontinuity ψ are depicted in solid lines on all figures. One can observe directly from the figures that the fit of the 5th-degree polynomial is very good and even nearly linear. The third term is a dummy variable removing the exact month the individual turns 18 from the estimation of ψ, as in this month, a worker is only over age 18 for a portion of the month. To obtain estimates of the percentage change from the estimated large discrete changes ψ, we use the midpoint method. Within our regression framework, this percent change is:

$$\Delta = \frac{\psi}{\sum_{d=0}^{D} \alpha_d a_{18}^d + \frac{\psi}{2}}, \tag{13}$$

where the denominator is evaluated where age a equals exactly 18 years (216 months). Later on, we shall add several components to the regression specification in eq. (12), but we shall still compute the percent change in the outcome of interest (Δ) in the same fashion.

Table 2 presents these results for a variety of alternative specifications, for the hourly wage (estimated only for employed individuals), number of employed persons (extensive margin), total input of hours worked (extensive margin plus intensive margin), and earnings (including zero for non-employed individuals). Column 1 of the table contains our preferred estimates, using exactly the specification in eqs. (12) and (13).

We first consider the size of the increase in average wages. For reasons discussed in the previous section, we do not observe precise (minimum) hourly wage rates, so we must instead estimate this percent change. Figure 1A and Panel A of Table 2 analyze the average of the imputed hourly wage rate around workers

[17] Note that for the point in the figure corresponding to exactly the month of the 18th birthday, only about half of workers will have turned 18 by the time their employment status is recorded for this month. That explains why this point appears roughly in the mid-point of the drop in employment around the 18th birthday.

Table 2: Estimates of the Effect of the Minimum Wage Hike at age 18

	(1)	(2)	(3)	(4)
Specification:	Baseline	Month FE	Month & Cohort FE	Month & Cohort FE & dummies for event time -2 to 2
	Panel A: Hourly wage			
Coefficient (DKK)	46.1	46.1	46.1	49.6
[95% Conf. Interval]	[45.2,47.0]	[45.4, 46.8]	[45.5, 46.8]	[49.0, 50.2]
Percent Change (%)	40.0	39.2	39.1	42.0
	[39.2, 40.8]	[38.6, 39.8]	[38.6, 39.7]	[41.4, 42.6]
	Panel B: Employment			
Coefficient (% points)	-15.0	-15.1	-15.0	-17.8
	[-15.7, -14.3]	[-15.6, -14.6]	[-15.5, -14.6]	[-18.4, -17.2]
Percent Change (%)	-32.8	-31.9	-32.2	-38.0
	[-34.3, -31.2]	[-33.0, -30.9]	[-33.2, -31.2]	[-39.3, -36.6]
Implied Elasticity	-0.82	-0.81	-0.82	-0.90
	Panel C: Hours worked			
Coefficient (hrs.)	-7.2	-7.3	-7.2	-8.6
	[-7.9, -6.4]	[-7.8, -6.7]	[-7.8, -6.7]	[-9.5, -7.8]
Percent Change (%)	-45.0	-45.1	-44.4	-53.2
	[-49.6, -40.4]	[-48.7, -41.7]	[-48.3, -40.5]	[-59.0, -47.7]
Implied Elasticity	-1.13	-1.15	-1.13	-1.27
	Panel D: Wage Earnings			
Coefficient (DKK)	-40.3	-53.0	-46.2	-125.2
	[-125.1, 44.5]	[-118.1, 12.2]	[-115.5, 23.1]	[-237.4, -12.9]
Percent Change (%)	-0.02	-0.03	-0.03	-0.07
	[-0.07, 0.03]	[-0.06, 0.01]	[-0.06, 0.01]	[-0.13, -0.01]
Observations	13,130,982	13,130,982	13,130,982	13,130,982

Note: This table reports estimates of the effect of the discrete change in minimum wages occurring at age 18 on average hourly wages, employment, hours worked, and earnings. For each outcome variable, we report the coefficient of interest measuring the effect at the discontinuity, (e.g. ψ in Eq. 12), and the percent change in the outcome, calculated using the midpoint method (e.g. Δ in Eq. (13)). We report 95 percent confidence intervals, calculated from standard errors clustered by (monthly) birth cohort, in square brackets below these point estimates. In Panels B and C, we report the elasticity implied by the percent change in the labor input and the percent change in hourly wages from Panel A. Column (1) is our baseline specification (Eq. 12), and subsequent columns add elements to this specification. Whenever we include month fixed effects, we use December 2009 as the baseline to calculate the percent change; for cohort fixed effects we use the December 1993 birth cohort. Neither of these choices has a meaningful impact on the estimates.

18th birthday. We observe that wages are relatively constant around 90 DKK beforehand, and then increase to about 135 DKK after the wage change. Using eq. (13) to convert this into a percent change with our preferred specification, we estimate that this 46 DKK increase constitutes a 40 percent increase in hourly wages.

Figure 1B and Panel B of Table 2 analyze the change in employment when workers turn 18. In our preferred specification in the first column of Table 2, we estimate a 15 percentage point drop in employment, equivalent to a 33 percent decrease in the number of employed workers. In other words, the presence of the wage hike causes roughly one in three workers employed before 18 to lose their jobs when they turn 18.

Combining the percentage change in hourly wages and in employment, we obtain the implied elasticity of -0.82 shown in the table.

The increase in average hourly wages depicted in Figure 1a is driven by increases in wages throughout the distribution of hourly wages. Appendix Figure A.2 depicts deciles of the hourly wage distribution by age. The distribution is quite compressed with over 70 percent of workers having an hourly wage between 60 and 100 DKK before 18, which is similar to the range of wages dictated by collective bargaining agreements accounting for the mix of conventional, weekend, and overtime work (see Table 1 and Appendix Table A.1). We observe a sharp parallel increase in imputed hourly wages throughout the distributions. This suggests that the increase in the minimum wage that occurs at age 18 affects the vast majority of workers.[18]

Our measurement of average hourly wages around the age-18 discontinuity does not seem substantially affected by selection bias, which might arise because those fired at age 18 systematically earn an hourly wage rate below or above the average. Appendix Figure A.3 plots average imputed hourly wages for individuals employed continuously from two months before to two months after age 18. The figure is virtually identical to Figure 1a, and the discontinuity at age 18 constitutes a 40 percent increase in average hourly wages in either case.

The effect of the minimum wage hike at age 18 on total hours worked happens mostly along the extensive margin. Figure 2a and Panel C of Table 2 analyze average monthly hours worked, including both employed workers and non-employed workers with zero hours worked, around the 18th birthday. This gives an elasticity of -1.1, implying that 3/4 of the total hours elasticity is explained by responses along the extensive margin.

[18]It is possible that some of the increase in hourly wages that occurs happens not just because the minimum wage is binding for all workers, but also because workers making above the minimum wage receive a raise when the minimum wage increases, as in Autor et al. (2016). Our data are not well-suited to look for this interesting pattern in wage determination, and in any case it matters little for the overall interpretation of our results.

With a total hours elasticity close to -1, it is natural to expect that the average wage earnings of all individuals, including both employed and non-employed workers, should stay unchanged when the wage rate is raised, because its effect on the earnings of employed individuals is fully offset by a decrease in employment. Consistent with this reasoning, Panel D of Table 2 reports that the percent change in earnings is close to zero. Notice that this evidence of a total hours elasticity close to 1 is derived directly from the earnings data, and therefore does not depend on the measurement of hourly wages.

The remaining other columns of Table 2 replicate the main results for a variety of alternative specifications. Column (2) of the table adds month fixed effects to the regression, and Column (3) adds month and (monthly) birth cohort fixed effects. Neither of these additions have a meaningful impact on the estimates, suggesting that neither business cycle shocks nor cohort-specific shocks affect the estimates. Relatedly, in Appendix Figure A.4, we show that the evolution of employment around workers' 18th birthday is virtually identical for all the birth cohorts in our data.

In order to more aggressively account for the anticipatory drop in employment before age 18 and slight inertia in employment just after 18, we add in Column (4) dummy variables from two months before to two months after the workers' 18th birthday to remove these months from the estimation of the age polynomial and discontinuity. One can think of the resulting estimate as one that more deliberately includes workers who lost their jobs in the months just before or after turning 18, rather than in the exact month they turned 18.[19] With this specification, the elasticities are only slightly larger.[20]

The results above are all conducted using the estimation sample excluding apprenticeships, but our result is strongly evident in full population data as well. Appendix Figure A.5 shows that imputed hourly wage rates for apprentices do not change when individuals turn 18. Mechanically, therefore, including apprentices in the dataset should not greatly affect our imputed employment elasticity, as one can think of apprentices as representing a constant fraction of the numerator and the denominator with zero (percent) changes in employment and hourly wages at age 18.[21] However, both the percent change in employment and the percent change in hourly wages should be smaller when we include apprentices. We confirm that all this is the case

[19]The smoothing required by the age polynomial clearly picks of some of this effect already. This specification also ensures that anticipation and inertia are not exercising undue influence over the shape of the polynomial.

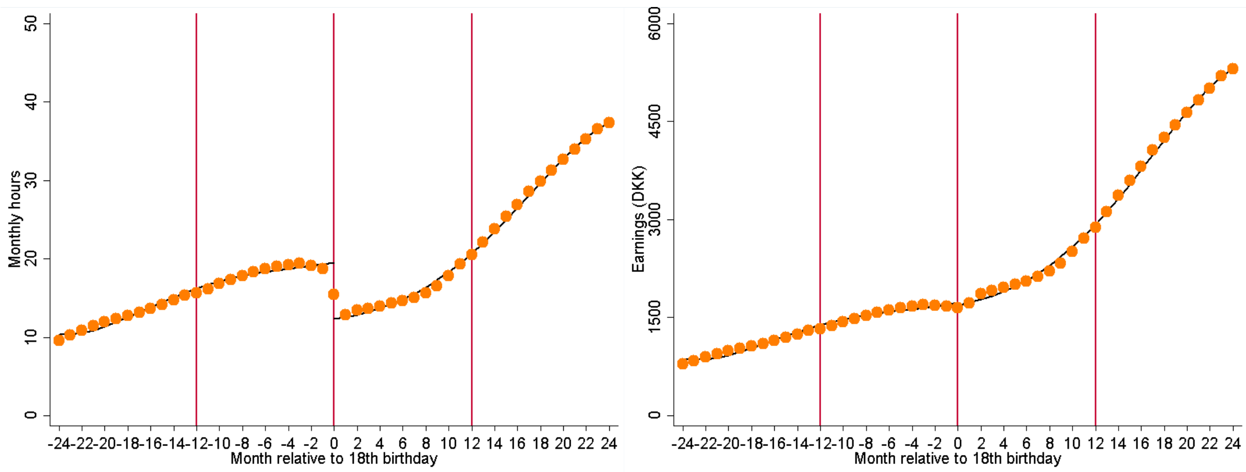
[20]Conversely, we could completely abandon any attempt to account for anticipation and inertia and simply compare wages and employment one month before and one month after workers turns 18. Doing so, we would estimate an elasticity of extensive margin employment with respect to the minimum wage of -0.7. However, we can see from Figure 1 that this specification plainly misses much of the anticipation effect that decreases employment just before workers turn 18, and thus it underestimates the total employment effect of interest.

[21]This logic breaks down if individuals enter into apprenticeships just after they turn 18, perhaps due to job loss at age 18. Appendix Figure A.6 shows that this is not the case.

Figure 2: Hours Worked and Earnings around Workers' 18th Birthdays

(a) Average Monthly Hours

(b) Earnings



Note: This figure depicts estimates of average hours worked and earnings (including zeros) by age, in months, for two years before and after workers' 18th birthdays. We observe a sharp drop in hours worked, and very little change in earnings (see also Table 2 Panel C and D). The fitted black lines depict the estimated polynomial and discontinuity at age 18 from regressions described by eq. 12.

in Appendix Table A.3, which shows that the estimates of the employment elasticity are almost identical whether or not we include apprentices.

Counterfactual policy simulations

The main counterfactual policy we are interested in is one in which there were no lower minimum wages for younger workers. One can imagine either starting from a regime where the minimum wages were equal across ages and lowering the minimum wage for younger workers, or starting from the present regime in Denmark and eliminating the lower minimum wage for younger workers. The black lines in Figure 1b depicts our estimate for employment of younger workers in the current regime, and in the regime where employers would be required to pay them the minimum wage currently applying to older workers. Overall our results suggest employment would be 33 percent lower, or 16 percentage points lower, under this alternative policy.

As discussed above, the theory underlying this counterfactual policy experiment is that employment above age 18 would not change as a result of changing the minimum wage for younger workers. However, a model with decreasing demand for low-skilled labor does predict that employment above age 18 would increase if the minimum wage for younger workers is increased. Our estimate of the employment effect at age 18 should nevertheless be a good approximation of the actual effect because the share of workers under age 18 in the low-skilled labor market is plausibly small. More precisely, the true elasticity for the policy

Table 3: The Share of Younger Workers in the Low-Skilled Labor Market

Population	Age 16-17 Workers' Share (%)
Full population	4.0
Employment (persons)	2.8
Employment (hours)	0.8
Wage income	0.3
Low-skilled occupations*	2.1
Supermarkets	6.5
Supermarkets, low-skilled occupations**	9.0
Hourly wage $<$ 95th percentile for 18 yr olds***	1.0
Highest Education 9th grade or lower	2.2

Note: This table reports the wage share of workers aged 16 and 17 in selected populations, to provide suggestive evidence on the share of younger workers in the low-skilled labor market. In calculating the shares we use data for all Danish employees age 16-65, i.e. including apprentices and workers over 19 years of age. *We identify low-skilled occupations using four-digit ISCO classification. We select the 10 most important occupations/job types for youth, which correspond to ≈83% of youth employment. **We define low-skilled work for supermarkets as all the job types/ISCO classifications in Supermarkets where youth work. *** We define low-skilled, adult workers as having a wage below the 95th percentile for 18 year olds. The last row counts as low-skilled all workers over 18 with an education level of 9th grade or lower, together with all 16- and 17-year-old workers.

change is bounded below by $(1-\delta)\varepsilon$, corresponding to the case of a fixed demand for low-skilled work, where ε is our reduced form elasticity from the discontinuity and δ is the wage share of under-18 workers in the low-skilled labor market (See Section 2.2).

Table 3 contains information on this share using full population data (including apprentices and workers over age 19), for various definitions of low-skilled work. Only about 2.8 percent of employed individuals are young, and, due to the fact that younger workers work fewer hours on average than older workers, the share of employment in hours is even smaller, at 0.8 percent. Focusing on wage shares to match our theory, we find that the overall wage share is only 0.3 for young workers. This number ranges from 1 to 9 percent, however, when we focus on populations that, based on their occupation, hourly wage, or education, are part of the low-skilled labor market and more directly comparable to younger workers. Even using a conservative wage share of $\delta = 0.1$, our results suggest that the implied elasticity of youth employment (on the extensive margin) with respect to the youth minimum wage would be at least -0.7. The drop in employment from increasing the minimum wage for young persons up to the level of adults would be 30 percent instead of 33 percent, and thus does not change dramatically.

Employment Flows

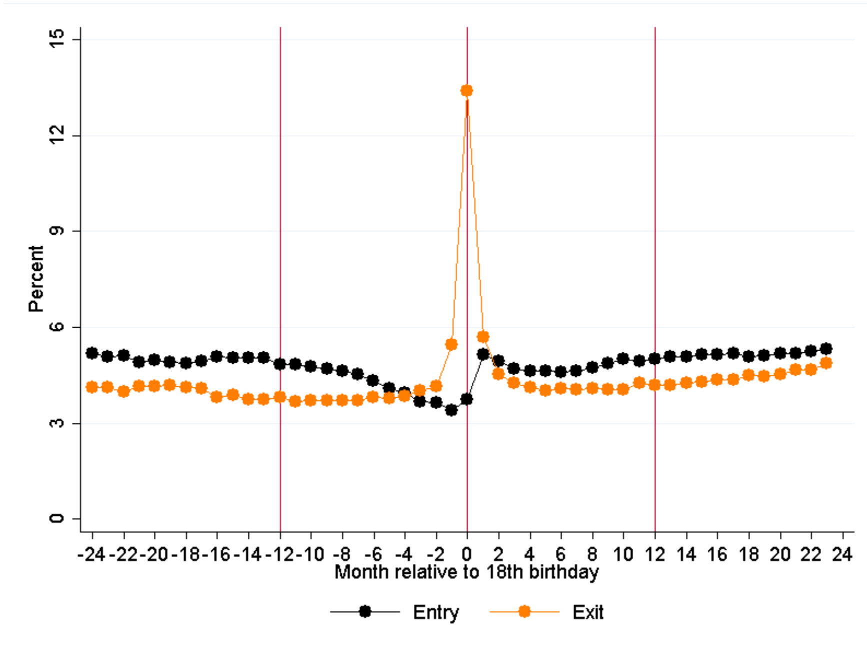
The employment effect we observe in Figure 1b is driven largely by a jump in the job separation rate, as predicted by our search model in Section 2. Figure 3 decomposes the overall changes in employment into the flows in and out of employment around workers 18th birthday. For the flow in, we tabulate the fraction of workers not employed in the current month who become employed in the subsequent month. The flow out tabulates the fraction of workers employed in the current month who are no longer employed in the subsequent month. A striking spike in flows out of employment occurs just after workers turn 18. This spike drives the drop in employment observed in Figure 1b. Perhaps surprisingly, the effect is almost entirely concentrated in a three-month period, from the month of the worker's 18th birthday to two months later. We also observe a slight decrease in the flow into employment just before the 18th birthday, suggesting that employers are somewhat reluctant to hire workers who will turn 18 very soon. This explains the slight decrease in the rate of increase in employment depicted just before the 18th birthday in Figure 1b, suggesting that the anticipation effect is primarily driven by a drop in hiring. Apart from the months right after the 18th birthday, the flow into employment is slightly greater than the flow out, which reflects that as they age, workers are more likely to seek a job and/or to find a job conditional on seeking one.[22]

Differences across Groups of Workers

Figure 4a reports estimates of the employment elasticity (based on imputed hourly wages) by deciles of workers' Grade Point Average (GPA) in 9th grade of school (the last year of compulsory schooling where students are 15-16 years old). We observe that the employment elasticity is slightly decreasing in GPA, falling from roughly -0.9 to -0.7 from the bottom to the top decile of GPA. This difference of about 0.2 in the elasticity is small relative to the overall elasticity, and the elasticity remains large even for students with high GPAs. In Figure 4b, we report equivalent elasticities by deciles of workers' parental income using the average income of individual's parents from age 11 to 13. Here, we find elasticities that are even more uniform across the distribution of parental income. The similar elasticities show that a wage increase has the same effect on the unemployment risk of young individuals independent on their cognitive performance and earnings capabilities of parents. That our estimated elasticities are unrelated to these broad measures of underlying ability levels is consistent with the search model in Section 2.3 where workers (and firms) are

[22]In an unreported analysis of job-to-job flows, we found a small increase, around 1 percentage point, in the flow from one job to another at exactly age 18. This suggests that a small number of workers change jobs in response to the minimum wage hike, either losing their job and finding another before the end of the month or voluntarily changing jobs.

Figure 3: Employment Entry and Exit Rates around Workers' 18th Birthdays



Note: This figure shows that our results are driven primarily by a spike in workers exiting employment when they turn 18, and also a slight decrease in entry into employment before workers turn 18. We calculate the rate of entry into employment as the fraction of workers not employed in a given month who become employed in the subsequent month. The rate of exit is defined similarly.

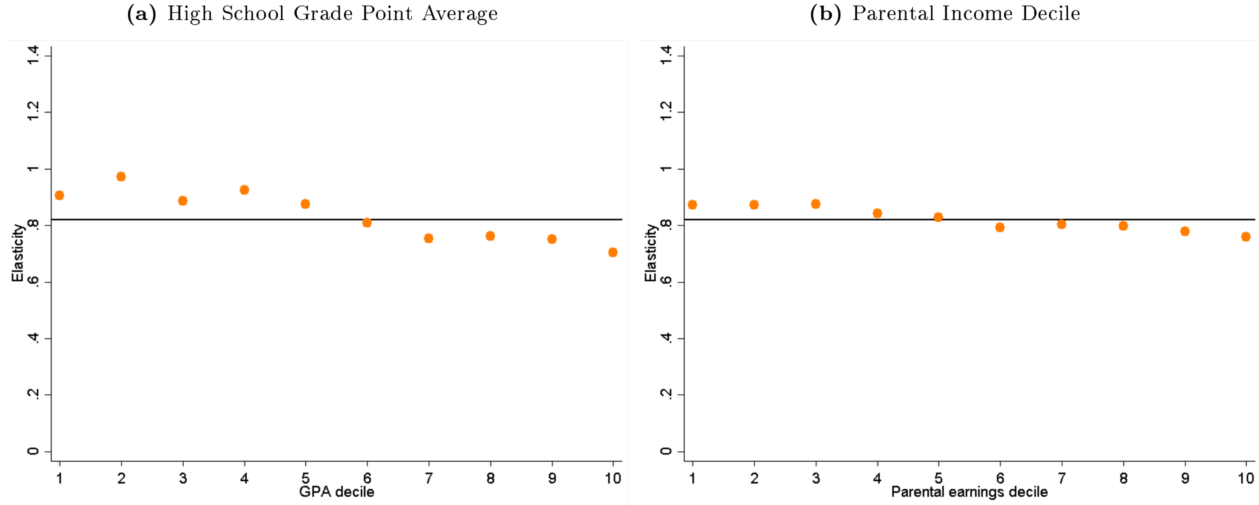
ex ante identical.

Consequences of Job Separations

Finally, we present some evidence that the consequences of job loss when workers turn 18 are non-trivial. One might think from the results thus far that workers simply re-time their endogenous job switches to coincide with the break in minimum wages at age 18. That is, workers looking to change jobs might wait to do so until they turn 18, or do so earlier than they otherwise would because they turned 18. The data on job flows in Figure 3 already suggests this is unlikely: the flow into employment does not increase significantly after workers turn 18, as one would suggest if workers losing their job at age 18 already had a backup plan. Evidence that job loss at 18 has effects further out beyond the month workers turn 18 further suggests that the explanation for our findings really is one of involuntary job loss due to demand-side factors in the labor market.

In Figure 5, we look at the rate of employment after turning 18, for workers employed at age 17 years 11 months that did and did not lose their jobs when they turned 18. These rates of employment are at 0 and

Figure 4: Employment Elasticity by Worker Characteristics

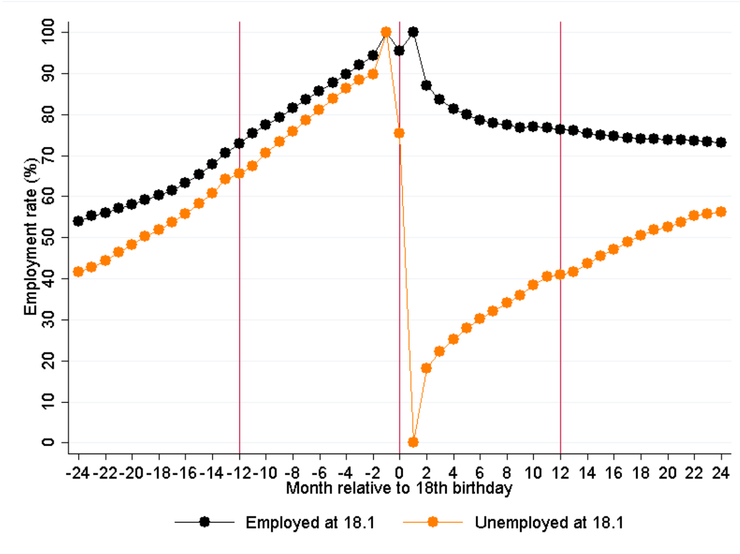


Note: This figure depicts estimated elasticities of employment with respect to hourly wages, as in Table 3, column (1), panel B, by deciles of workers GPA and parental income. We use GPA in 9th grade, which is the last year of compulsory schooling, when workers are 15 to 16 years old. For parental income, we use the the average parental income from ages 11 to 13, and construct deciles separately for each birth cohort. The elasticity in the overall population is depicted as a horizontal black line in both figures. We observe very little heterogeneity in the employment elasticity by these two worker characteristics.

100 percent at 18 years plus one month mechanically. If job loss at age 18 were relatively inconsequential, we should expect relatively quick convergence of these employment rates. Instead, we observe that the difference in employment rates between the two groups is substantial even two years after age 18. Almost 20 percent of individuals leaving employment one month after turning 18 find another job in the next month. However, by one year after job separation at age 18, only 40 percent of separated individuals are employed, compared to just over 75 percent of individuals who did not experience a separation. Even two years after turning 18, individuals who kept their job at age 18 are about 20 percent more likely to be employed than individuals who did not, and employment in the job loss group is still increasing significantly over time, suggesting that these workers continue to seek jobs. In the months prior to turning 18, individuals experiencing a separation at age 18 were only a few percentage points less likely to be employed than individuals who were employed after age 18, suggesting that these differences are unlikely to be driven solely by unobservable worker characteristics that correlate with employment.[23]

[23] One potential consequence of losing one's job at age 18 could be entering into an apprenticeship, as these are exempt from the minimum wage hike at age 18. In Appendix Figure A.6, we show that this is not the case; we see no sharp increase in the probability of being employed as apprentice at age 18. Rather, there is is a steady increase from age 16 to age 20.

Figure 5: Effect of Job Separations at Age 18 on Future Employment



Note: The graph depicts employment around the 18th birthday for workers employed in the month before they turn 18. We split the sample into workers who remain employed in the month after they turn 18, and those who are no longer employed in the month after they turn 18. We observe a large gap in employment rates between those who stay employed and those who leave employment even two years after the month workers turn 18.

Potential Threats to Identification

The most important threats to our identification strategy are other (discrete) changes that can happen when individuals turn 18. We are aware of two such changes. First, as described in section 3.1, there are a few limitations on the type of work that young workers may carry out: not lift more than 25 kilos, not work with certain hazardous materials and machines, and not make money transports. These rules tend to raise the productivity, and thus the employment, of 18-year-olds relative to 17-year-olds. The true effect of the wage discontinuity, adjusting for any increase in productivity from additional permitted work activities, would then be larger than what we estimate.

Second, adults are eligible for benefits payments for certain social programs, specifically student benefits for those pursuing post-secondary education and general social assistance payments for those not in education/employment and fulfilling additional requirements. If workers started receiving either of these benefits and, as a result, stopped working, we would overestimate the effect of the minimum wage increase on employment by attributing the full drop in employment at age 18 to the minimum wage increase. Figure 6 replicates our main results in samples constructed in such a way that we can rule out that they are driven by either student benefits or social assistance.

Individuals are eligible for student benefits in the quarter after turning 18 years old, and when receiving student benefits they are allowed to earn DKK 7,500-11,800 per month,[24] depending on the type of education, after which student benefits are phased out with the level of your earnings. Importantly, this is computed at an annual basis. In Figure 6a, we restrict our analysis to October birth cohorts. As student benefits can only be received starting in the quarter after individuals turn 18, individuals born in October can only begin receiving student benefits the January after they turn 18, and income earned in October–December has no bearing on the amount of student benefits, because income in these months does not count towards income in the year the student receives student benefits. The figure reveals a drop in employment exactly at age 18 that is nearly identical to what we see in the main analysis (Figure 1b), although the development is naturally somewhat noisier than the earlier results due to the smaller sample size. As explained, this drop in employment cannot be attributed to a supply effect driven by student benefit eligibility. We also observe changes in employment due to seasonal patterns (see also Figure A.1a), and very little change in employment three months after when the individual becomes eligible for student benefits.

In the data, we observe individuals receiving social assistance. This is the case for around 5 percent of 18 year old individuals. In Figure 6b, we repeat the main employment graph for individuals who never receive social assistance at any point in time in our sample period. The graph is almost identical to Figure 1b and so are the key estimates of the wage change and employment effect; a 36 percent increase in imputed hourly wages and a 32 percent decline in employment at age 18.

Overall, this robustness analysis suggests that substitution between labor market earnings and either student benefits or social assistance cannot explain our main results. These findings, along with the absence of any other significant changes in policy or other incentives to work that occur when individuals turn 18, lead us to conclude that the decline in employment we observe when workers turn 18 is driven by a decline in labor demand because of the increase in minimum wages.[25]

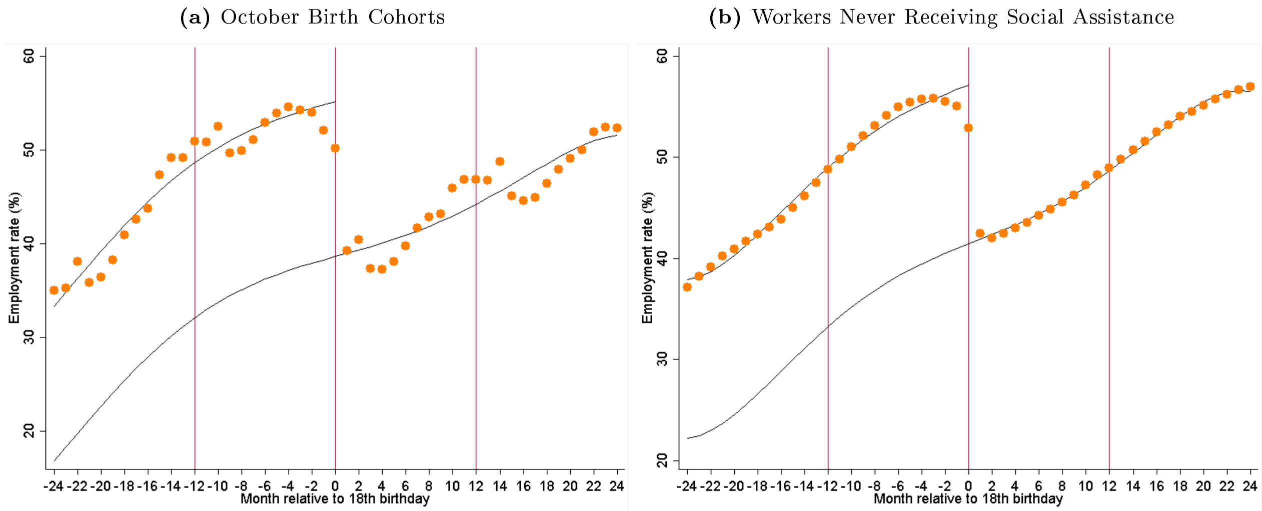
5 Conclusion

Danish minimum wages cause an increase in average wages of 40 percent when workers reach age 18. This increase in wages causes a 33 percent decrease in employment when workers turn 18, almost all of which

[24] Level in 2015 obtained from www.su.dk.

[25] We have also compiled anecdotal evidence that the increase in minimum wages at age 18 leads to job losses. These anecdotes come from several Danish workers, including one coauthor on this paper.

Figure 6: Replications of Main Employment Result for Select Sub-Samples



This figure replicates the main result in Figure 1b for select sub-samples. These replications ensure that the results are not driven by workers leaving employment because they become eligible for student benefits (which could not be received until three months after the 18th birthday for October birth cohorts), or because they start receiving social assistance.

comes from job loss. Theory suggests that we can use this effect to estimate the effect of a change in the youth minimum wage on their employment, holding adult minimum wages fixed. Applying this reasoning, we find that the relevant employment elasticity is likely about 0.8. This elasticity is much larger than the elasticity of youth employment with respect to minimum wages typically estimated via difference in differences with a global minimum wage change, which we argue is not the appropriate elasticity to study the employment effects of *youth-specific* minimum wages on youth employment. Other explanations for the higher elasticity include that the difference-in-diferences estimates may be attenuated by short-run frictions, and that high Danish minimum wages are much more likely to be binding than the low minimum wages typically seen in many other countries, e.g. the United States. In any event, our results suggest that adopting a lower minimum wage for younger workers would substantially increase youth employment in U.S. regions that adopt a high minimum wage, and it would also likely increase youth employment in European countries that already have a relatively high minimum wage.

Our results do not imply that studies of global minimum wage increases are necessarily under-estimating the effect on youth employment. Arguably we do identify an upper bound for the employment effects of global minimum wage increases on workers around age 18. An employer facing an increase in the minimum wage when a certain worker turns 18 essentially has all of the margins of substitution available from a global minimum wage hike – substitution for more skilled labor or capital – plus one more: substitution across worker ages. Such reasoning is based on a partial equilibrium model, however. Global minimum wage hikes also have plausibly different general equilibrium effects on employment, prices etc. (MaCurdy 2015). In any case, extreme caution is warranted when considering the implications of our results for global minimum wage hikes. We have focused on the employment effects of youth minimum wages specifically for this reason.

Youth employment is often a focal point in policy discussions about minimum wages, as described in the Introduction. The effect on youth employment is a vital input to evaluate the welfare impact of youth minimum wage changes, but it is decidedly not the only factor. For example, if employers substitute from older to younger workers when the youth minimum wage falls, employment effects on adults are also relevant. This substitution effect is difficult to identify with our data and empirical strategy. Additionally, increasing youth employment will alter the accumulation of experience and thereby some kinds of human capital, which could have important effects on workers' labor market outcomes beyond the contemporaneous effect on employment. Evaluating the impact of youth minimum wages on these factors is a topic for future research.

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Appendix (for Online Publication Only)

A Theory

This appendix contains derivations for the central claims made with the model of decreasing labor demand for low-skilled work in Section 2.2, and the full equilibrium search model outlined in Section 2.3.

A.1 Derivation of Equation (8)

We wish to relate the estimated employment elasticity at the age discontinuity to the relevant elasticity for a policy change in the youth minimum wage. For this purpose, consider a reform that raises the minimum wage of the young, w_1, up to the level of adults, w_2. Empirically, we observe the following differences in wage and employment (defined positive) at the age discontinuity

$$\Delta w_1 = \quad w_2 - w_1 = \quad f'(x^*)(\omega_2 - \omega_1) \tag{14}$$

$$\Delta e_1 = \quad e_1 - e_2 = \quad i_2 - i_1 \tag{15}$$

where we have used eqs (6) and (7). The corresponding employment elasticity equals

$$\varepsilon \equiv \frac{\Delta e_1/e_1}{\Delta w_1/w_1} = \frac{(i_2 - i_1)/i_1}{(\omega_2 - \omega_1)/\omega_1}. \tag{16}$$

Next, we compute the elasticity of youth employment $e_1$with respect to a policy change in their minimum wage w_1. The change in the wage rate is $\Delta w_1 = w_2 - w_1$, and after using a Taylor expansion on the wage equation (6), this may be approximated by

$$\Delta w_1 = f''(x^*)\Delta x^* \omega_1 + f'(x^*)\Delta\omega_1. \tag{17}$$

Measured relative to the original wage in eq. (6), this becomes

$$\frac{\Delta w_1}{w_1} = \frac{f''(x^*)x^*}{f'(x^*)}\frac{\Delta x^*}{x^*} + \frac{\Delta\omega_1}{\omega_1}. \tag{18}$$

A Taylor expansion of eq. (5) gives

$$\frac{\Delta x^*}{x^*} = -\frac{\hat{a}\cdot\omega_1}{x^*}\frac{\Delta\omega_1}{\omega_1} - \frac{(1-\hat{a})\omega_2}{x^*}\frac{\Delta\omega_2}{\omega_2}. \tag{19}$$

A Taylor expansion of eq. (7) gives

$$0 = \frac{f''(x^*)x^*}{f'(x^*)}\frac{\Delta x^*}{x^*} + \frac{\Delta\omega_2}{\omega_2},$$

where we have used that the minimum wage for adults w_2 is unchanged. By isolating $\Delta\omega_2/\omega_2$ in this expression and inserting the result into eq. (19), we obtain

$$\frac{\Delta x^*}{x} = -\frac{\hat{a}\cdot\omega_1}{x^*}\frac{\Delta\omega_1}{\omega_1} + \frac{(1-\hat{a})\omega_2}{x^*}\frac{f''(x^*)x^*}{f'(x^*)}\frac{\Delta x^*}{x^*},$$

which simplifies to

$$\frac{\Delta x^*}{x} = \frac{-\frac{\hat{a}\cdot\omega_1}{x^*}\frac{\Delta\omega_1}{\omega_1}}{1 - \frac{(1-\hat{a})\omega_2}{x^*}\frac{f''(x^*)x^*}{f'(x^*)}}.$$

Insertion of this expression in eq. (18) gives

$$\frac{\Delta w_1}{w_1} = \left[1 + \frac{\frac{\hat{a}\cdot\omega_1}{x^*}\epsilon}{1 + \frac{(1-\hat{a})\omega_2}{x^*}\epsilon}\right]\frac{\Delta\omega_1}{\omega_1}$$

where $\epsilon \equiv -\frac{f''(x^*)x^*}{f'(x^*)}$. The relevant policy elasticity then becomes

$$\tilde{\varepsilon} = \frac{\Delta e_1/e_1}{\Delta w_1/w_1} = \left[1 + \frac{\frac{\hat{a}\cdot\omega_1}{x^*}\epsilon}{1 + \frac{(1-\hat{a})\omega_2}{x^*}\epsilon}\right]^{-1}\frac{(i_2 - i_1)/i_1}{\Delta\omega_1/\omega_1}.$$

where we have used eq. (15). After using the expression for the empirically observed elasticity in (16), we obtain the result in eq. (8). To obtain (9), we take the limit of eq. (8), use eqs (6) and (7) to eliminate ω_1 and ω_2, and simplify.

A.2 An Equilibrium Search Model

A.2.1 Basics

We consider an equilibrium search model with heterogeneity along the lines of (Pissarides 2000, Ch. 6). Time is continuous, we disregard discounting, and the population is normalized to one. Compared to the standard model, we assume that firms have all the bargaining power, implying that minimum wages become binding, and we extend the model with a simple life-cycle dynamics by considering separately young individuals (type 1) and adult individuals (type 2), indexed by j. Let L_j denote the number of type j individuals, and let E_j and U_j denote the number of employed and unemployed individuals of type j. The minimum wage levels of the two groups are $\bar{w}_2 \geq \bar{w}_1$.

Aging is modeled probabilistically by assuming that a share δ of adults die at each point in time and that this flow out of the labor market is replaced by a corresponding flow into the labor market of new young individuals, who all begin without a job. We assume that a share $1-\delta$ of young workers become adults. This implies that the share of adults dying δ and the share of young individuals becoming adults $(1-\delta)$ sum to one. Doing this as opposed to having separate rates of flow from young to old and old workers being replaced by young workers is just a normalization (corresponding to choosing a specific unit of time). All this implies that the share of young individuals in steady state equals δ. To see why, note that the steady state condition that the flow into L_1 equals the flow out, $\delta L_2 = (1-\delta)L_1$ implies $L_1/(L_1+L_2) = \delta$. We shall also normalize $L_1 + L_2 = 1$.

Firms open up vacancies for each age group of workers, where V_j denotes the number of vacancies and c is a flow search cost for a vacancy.[26] Labor market tightness is defined as the number of vacancies relative to the number of non-employed individuals, $\theta_j \equiv V_j/U_j$. Firms with vacant jobs and individuals without a job meet according to a constant returns to scale matching function. The productivity of the match x is drawn from the cumulative distribution function $F(x)$, and, since it is always possible to open up a new vacancy and vacancy costs are sunk, the firm hires the worker if the productivity of the match is above the minimum wage.

[26] That firms search for young and old workers separately matches anecdotal descriptions of our Danish institutional setting.

The rate at which a vacancy is in contact with a potential employee may be written as a decreasing function of labor market tightness $q_j(\theta_j)$, so that the probability of a match is $q_j(\theta_j)(1 - F(\bar{w}_j))$. For workers, the meeting rate is an increasing function of tightness, $\theta_j q_j(\theta_j)$, while the hiring probability equals $\theta_j q(\theta_j)(1 - F(\bar{w}_j))$.

A firm-worker pair may separate because an adult worker dies or because an employed young worker is fired when becoming an adult. In addition, we assume firm-worker pairs separate exogenously at the rate λ.

A.2.2 Firms

In an optimum, with free entry of firms and no discounting the flow cost per unit of time of a vacant job for young workers equals the expected value of a match:

$$c = q_1(\theta_1) \int_{\bar{w}_1}^{\infty} J_1(x) f(x) dx, \tag{20}$$

where $J_1(x)$ is the expected profit from a firm-worker pair with productivity x, and a firm will only hire the worker if the match-specific productivity level x is above the minimum wage $\bar{w}_1$. The value of a filled job with a young worker of productivity x equals

$$J_1(x) = x - \bar{w}_1 + (1 - \lambda - (1 - \delta))J_1(x) + (1 - \delta) \cdot 1\{x \geq \bar{w}_2\} J_2(x). \tag{21}$$

The first term, $x - \bar{w}_1$, is the flow profit; the second term is the continuation value if the firm-worker match stays unchanged; and the last term reflects the expected continuation value if the worker becomes an adult, where $1\{x \geq \bar{w}_2\}$ indicates that the firm only retains the worker if the productivity of the match is above the adult minimum wage. Otherwise, firm profits would become negative when the worker becomes an adult, so it is better for the firm to fire the worker.

For vacant jobs of adults, we have the following relationship

$$c = q_2(\theta_2) \int_{\bar{w}_2}^{\infty} J_2(x) f(x) dx, \tag{22}$$

which is similar to eq. (20). The value of a filled job with an adult with productivity $x$equals

$$J_2(x) = x - \bar{w}_2 + (1 - \lambda - \delta) J_2(x), \tag{23}$$

which is similar to eq. (21) with the exception that aging in this cases causes the firm to lose the profit from the match, whereas with the young worker the match may continue after aging.

A.2.3 Worker Flows

In a steady state, the flow of workers into youth employment E_1 has to equal the flow out, which gives the relationship

$$\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))U_1 = (1 - \delta + \lambda)E_1. \tag{24}$$

We obtain an equivalent equation for the flow in and out of adult employment E_2:

$$\theta_2 q_2(\theta_2)(1 - F(\bar{w}_2))U_2 + (1 - \delta)\frac{1 - F(\bar{w}_2)}{1 - F(\bar{w}_1)}E_1 = (\delta + \lambda)E_2, \tag{25}$$

where the second term reflects that some of the young employed workers are fired when the become an adult if $\bar{w}_2 > \bar{w}_1$, noting that $\Pr(x \geq \bar{w}_2 | x \geq w_1) = \frac{1-F(\bar{w}_2)}{1-F(\bar{w}_1)}$.[27]

A.2.4 Solving the Model

From eq. (23), we have

$$J_2(x) = \frac{x - \bar{w}_2}{\lambda + \delta}. \tag{26}$$

By inserting this expression into eq. (21) and simplifying, we obtain

$$J_1(x) = \begin{cases} \frac{x-\bar{w}_1}{1-\delta+\lambda} & \text{for } \bar{w}_1 \leq x \leq \bar{w}_2 \\ \frac{x-\bar{w}_1}{1-\delta+\lambda} + \frac{1-\delta}{1-\delta+\lambda}\frac{x-\bar{w}_2}{\delta+\lambda} & \text{for } x > \bar{w}_2 \end{cases}. \tag{27}$$

By substituting eq. (26) into eq. (22), we obtain

$$c = q_2(\theta_2)\int_{\bar{w}_2}^{\infty} \frac{x - \bar{w}_2}{\lambda + \delta} f(x)dx. \tag{28}$$

For a given minimum wage of adults $\bar{w}_2$, this equation determines the labor market tightness for adults θ_2, independently of the youth minimum wage $\bar{w}_1$. We see that an increase increase in $\bar{w}_2$ decreases θ_2.

By inserting eq. (27) into eq. (20), we get

$$c = q_1(\theta_1)\left[\int_{\bar{w}_1}^{\infty} \frac{x - \bar{w}_1}{1 - \delta + \lambda} f(x)dx + \int_{\bar{w}_2}^{\infty} \frac{1 - \delta}{1 - \delta + \lambda}\frac{x - \bar{w}_2}{\lambda + \delta} f(x)dx\right], \tag{29}$$

which determines labor market tightness in the labor market for the young θ_1 for given minimum wages of

[27] One can relatively straightforwardly derive similar steady state conditions using U_1 and U_2 and solve the model using these instead.

youth and adults $\bar{w}_1$ and $\bar{w}_2$. We see from this expression that an increase in $\bar{w}_1$ implies a higher equilibrium meeting probability $q_1(\theta_1)$,implying a lower labor market tightness θ_1, and therefore a lower *worker* meeting probability $\theta_1 q(\theta_1)$. This reduces the hiring probability of the worker, $\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))$, which is also reduced directly by the higher cutoff productivity $\bar{w}_1$ for those workers meeting a firm. A higher adult minimum wage $\bar{w}_2$ implies a lower labor market tightness of the young θ_1 according to eq. (29) and therefore a lower worker match probability $\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))$ of the young.

From eq. (24), the definition of the employment rate $e_1 = E_1/L_1$ and $U_1/L_1 = 1 - e_1$, we obtain

$$e_1 = \frac{\theta_1 q(\theta_1)(1 - F(\bar{w}_1))}{\theta_1 q(\theta_1)(1 - F(\bar{w}_1)) + 1 - \delta + \lambda} = \frac{1}{1 + \frac{1-\delta+\lambda}{\theta_1 q(\theta_1)(1-F(\bar{w}_1))}}. \tag{30}$$

From eq. (25) and the relationships $U_2 = L_2 - E_2 = (1 - e_2)L_2 = (1 - e_2)(1 - \delta)$, $E_2 =_2 L_2 = e_2(1 - \delta)$ and $E_1 = e_1 L_1 = e_1 \delta$, we obtain

$$e_2 = \frac{\theta_2 q(\theta_2)(1 - F(\bar{w}_2)) + \delta e_1 \frac{1-F(\bar{w}_2)}{1-F(\bar{w}_1)}}{\lambda + \delta + \theta_2 q(\theta_2)(1 - F(\bar{w}_2))}. \tag{31}$$

Note that this expression is similar to eq. (30) with the exception of the second term in the numerator, which reflects the flow into adult employment of young employed workers who age.

A.2.5 Results

We obtain four results. First, eqs. (25) and (27) show directly that young employed workers with productivity levels in the range $[\bar{w}_1, \bar{w}_2]$ are fired immediately when they become adults, implying that the share $\frac{F(\bar{w}_2)-F(\bar{w}_1)}{1-F(\bar{w}_1)}$ of the employed young individuals are fired. In other words, the model predicts a spike in the flow out of employment right when workers become adults.

Second, we find that an increase in the minimum wage of the young $\bar{w}_1$ and an increase in the minimum wage of adults $\bar{w}_2$ both decrease the youth employment rate e_1. To see this, recall from eq. (29) that the hiring probability of young workers, $\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))$, is decreasing in both $\bar{w}_1$ and $\bar{w}_2$, which implies from eq. (30) that e_1 is also decreasing in $\bar{w}_1$ and $\bar{w}_2$.

Third, we see from eq. (31) that an increase in the minimum wage for adults $\bar{w}_2$ decreases their employment e_2. We know from eq. (28) that θ_2 decreases and therefore that the term $\theta_2 q(\theta_2)(1 - F(\theta_2))$ decreases, and an increase in $\bar{w}_2$ reduces directly the second term in the numerator of eq. (31).

Fourth, the effect of an increase in the youth minimum wage $\bar{w}_1$ on adult employment e_2 is ambiguous. This effect occurs only through the second term in the numerator of eq. (31), where for a given increase in

$\bar{w}_1$, e_1 decreases and $\frac{1-F(\bar{w}_2)}{1-F(\bar{w}_1)}$ increases. The intuition here is that an increase in the youth minimum wage $\bar{w}_1$ reduces the number of young workers who are employed when they become adults, but it also increases the probability that workers becoming adults will keep their jobs when they age. Note, however, that the effect of $\bar{w}_1$ on adult employment e_2 is small if the share of young individuals in the population is small, because the second term in the numerator is close to zero when δ is close to zero. Intuitively, the flow into adult employment from young, employed workers will have less of an effect on total adult employment when there are few young workers.

B Supplementary Empirical Results

The next several pages contain additional data and empirical results referenced in the body of the paper.

Table A.1: Variation in Basic Wage Rates from Collective Bargaining Agreement

Name of collective agreement	Description	Basic wage (DKK) 17 year	Basic wage (DKK) 18 year	Deviation from mean (%) 17 year	Deviation from mean (%) 18 year	Difference btw. age 17 and 18 (%)
3F - Dansk Håndværk	Craftsmen	83	118	13%	-1%	35%
Arbejdsdreng metal-/auto-/cykelværksted	Mechanics	65	116	-12%	-2%	57%
Bageri: Ekspedition	Bakeries	63	111	-15%	-7%	55%
Bank	Banks	81	135	11%	13%	50%
Biograf	Cinemas	77	138	5%	15%	57%
Butiksoverenskomst	Retail	63	111	-15%	-7%	55%
Byggeri	Construction	83	118	13%	-1%	35%
COOP Danmark	Particular retail cooperative	63	111	-15%	-7%	55%
Diskoteker og spillesteder	Discotheques and arcades	77	135	5%	13%	55%
Fitness	Fitness	59	111	-22%	-7%	61%
HK-Kommunalt	Public administration	72	119	-2%	0%	50%
Hotel og restauration	Hotels and restaurants	71	117	-3%	-2%	49%
Industriens overenskomst	Manufacturing, trade and service industry	63	110	-14%	-8%	54%
Landbrug	Agriculture	92	130	24%	9%	34%
Rengøring og teknisk service	Cleaning	89	121	20%	1%	30%
Servicestationer	Gas stations	63	111	-15%	-7%	55%
Slagter (ekspedition)	Butchers	59	114	-22%	-4%	64%
Transport og lager	Transportation and storage	92	118	23%	-1%	24%
Average		**73**	**119**	**14%**	**6%**	**48%**

Note: This table reports, for various collective bargaining agreements, the minimum basic wage (the wage paid for work during normal working hours, rather than overtime, evenings, and weekends) for 17 and 18 year olds in 2015. For these minimum wages, we also report the percent deviation from the mean wage in the agreements (with the mean absolute percent deviation in the last row), and the percent difference between the 17- and 18-year old wages in a given agreement.

Table A.2: Variation in Average Hourly Wage by Sector

Sector	Empl. share of 17 year olds (%)	Average hourly wage (DKK) 17 year	Average hourly wage (DKK) 18 year	Deviation from wtd. mean (%) 17 year	Deviation from wtd. mean (%) 18 year	Difference btw. age 17 and 18 (%)
Retail - grocery	30.1%	86	151	4%	4%	54%
Non-specialized retail	15.3%	86	155	5%	7%	58%
Restaurants	8.7%	90	135	0%	7%	40%
Bakeries	3.0%	82	140	8%	3%	52%
Retail - clothing	2.4%	81	136	10%	6%	51%
Public service	1.6%	65	126	28%	13%	63%
Postal and courier service	1.4%	106	158	18%	9%	39%
Sports clubs	1.4%	111	141	24%	3%	23%
Hotels	1.1%	96	149	7%	3%	43%
Café, pubs and clubs	1.1%	113	140	25%	3%	22%
Cinemas	1.1%	90	128	1%	12%	35%
Retail - construction	1.1%	86	150	4%	3%	53%
Retail - homeware	1.0%	82	143	9%	1%	54%
Gas stations	0.9%	84	134	7%	7%	46%
Retail - gift items and handicraft	0.9%	74	130	17%	10%	55%
Agriculture	0.8%	74	127	18%	12%	53%
Retail - bread and pastries	0.7%	82	138	9%	5%	51%
Craftsmen	0.7%	92	146	3%	1%	45%
Retail - outdoor equipment	0.7%	88	135	2%	7%	42%
Theme parks	0.6%	82	136	9%	6%	50%
Other	25.4%	99	144	10%	1%	36%
Weighted average	**100**	**90**	**145**	**7%**	**4%**	**47%**

Note: This table reports the average hourly wage for 17- and 18-year-olds by sector in 2015, along with the share of 17-year-olds employed in each sector. We include the 20 most common sectors for 17-year-old's employment and an "other" category for workers in other sectors. For these average hourly wages, we also report the percent deviation from the weighted average within each sector (with the weighted absolute difference in the last row), and the percent difference between the 17- and 18-year old wages in a given sector. The weighted average in the last row is weighted according to the share of 17 year old employment. We observe that wages increase substantially when workers turn 18 in all sectors, and the change in average wages between ages is typically much larger than the differences between sectors for a given age.

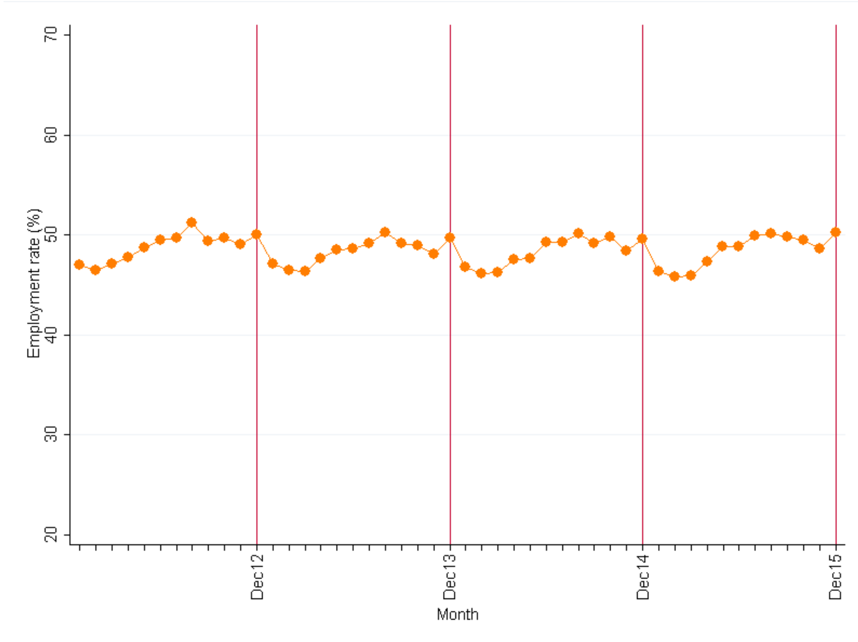
Table A.3: Estimates of the Effect of Minimum Wage on Employment, Not Excluding Apprentices

	(1)	(2)	(3)	(4)
Specification:	Baseline	Month FE	Month & Cohort FE	Month & Cohort FE & dummies for event time -2 to 2
	Panel A: Hourly wage – Excluding Apprentices			
Coefficient (DKK)	46.1	46.1	46.1	49.6
	[45.2,47.0]	[45.4, 46.8]	[45.5, 46.8]	[49.0, 50.2]
Percent Change (%)	40.0	39.2	39.1	42.0
	[39.2, 40.8]	[38.6, 39.8]	[38.6, 39.7]	[41.4, 42.6]
	Panel B: Employment – Excluding Apprentices			
Coefficient (% points)	-15.0	-15.1	-15.0	-17.8
	[-15.7, -14.3]	[-15.6, -14.6]	[-15.5, -14.6]	[-18.4, -17.2]
Percent Change (%)	-32.8	-31.9	-32.2	-38.0
	[-34.3, -31.2]	[-33.0, -30.9]	[-33.2, -31.2]	[-39.3, -36.6]
Implied Elasticity	-0.82	-0.81	-0.82	-0.90
Observations	13,130,982	13,130,982	13,130,982	13,130,982
	Panel C: Hourly Wage–All Individuals			
Coefficient (DKK)	38.5	38.5	38.5	41.1
	[37.6, 39.5]	[37.9, 39.1]	[37.8, 39.1]	[40.5, 41.6]
Percent Change (%)	35.2%	34.4%	34.4%	36.6%
	[34.4, 36.0]	[33.8, 34.9]	[33.9, 34.9]	[36.0, 37.1]
	Panel D: Employment–All Individuals			
Coefficient (% points)	-14.0	-14.1	-14.0	-16.5
	[-14.6, -13.6]	[-14.6, -13.6]	[-14.4, -13.5]	[-17.1, -15.9]
Percent Change (%)	-28.5%	-27.9%	-28.1%	-33.0%
	[-29.9, -27.1]	[-28.9, -26.9]	[-29.1, -27.2]	[-34.3, -31.8]
Implied Elasticity	-0.81	-0.81	-0.82	-0.90
Observations	13,988,918	13,988,918	13,988,918	13,988,918

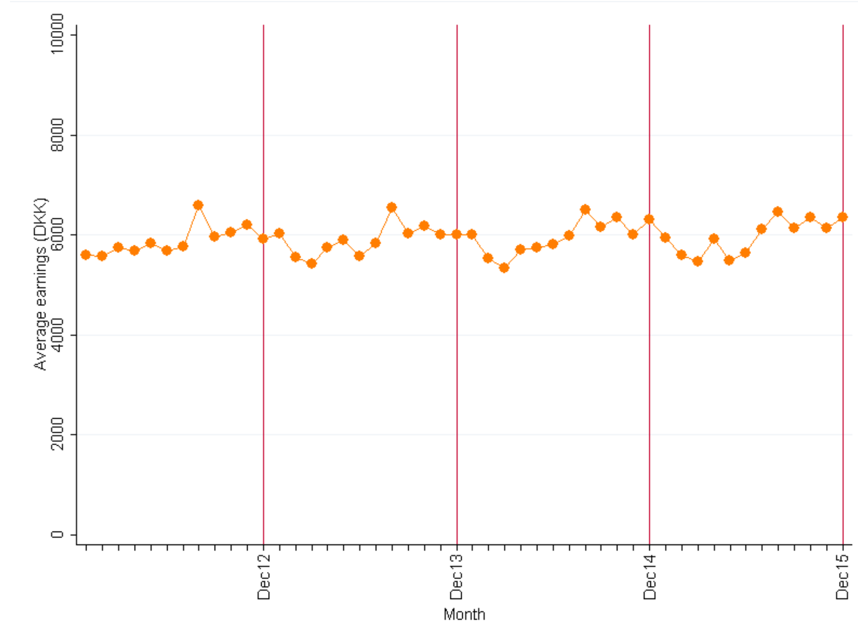
Note: This table reports estimates of the effect of the discrete change in minimum wages occurring at age 18 on average hourly wages and employment. Panels A and B exclude apprentices, exactly as in Table 2. Panels C and D include apprentices. We observe slightly smaller percentage changes when we include apprentices, but the implied elasticity of employment is very similar. Details of the analysis are exactly as before (see the notes to Table 2).

Figure A.1: Raw Time Series' of Average Employment, Income, Hours Worked, and Hourly Wages

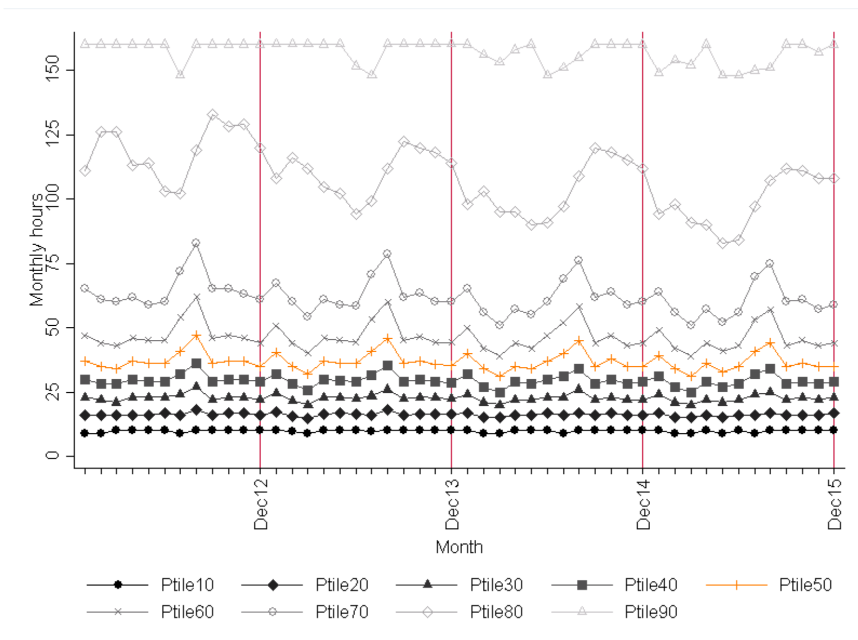
(a) Employment Rate



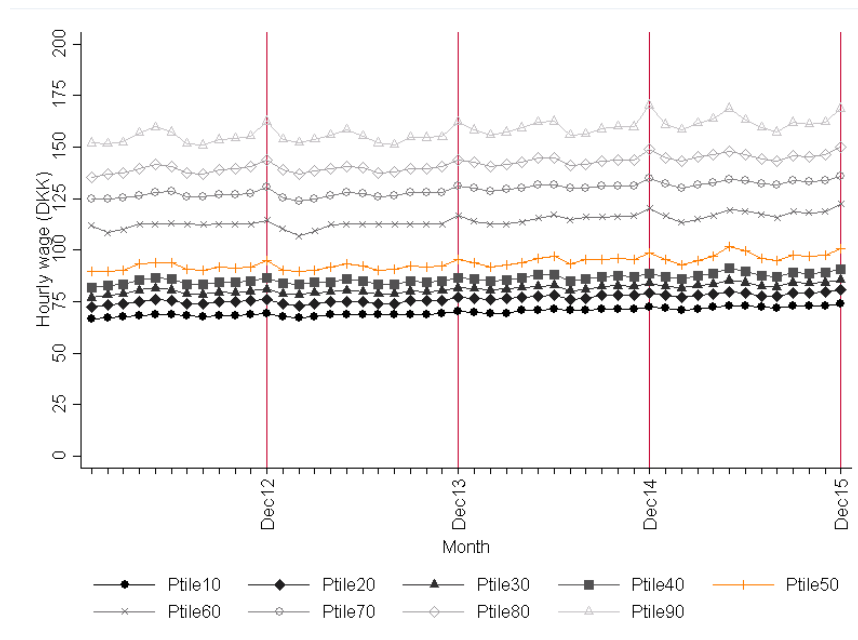
(b) Average Monthly Earnings (Conditional on Employment)



(c) Quantiles of Monthly Hours (Conditional on Employment)

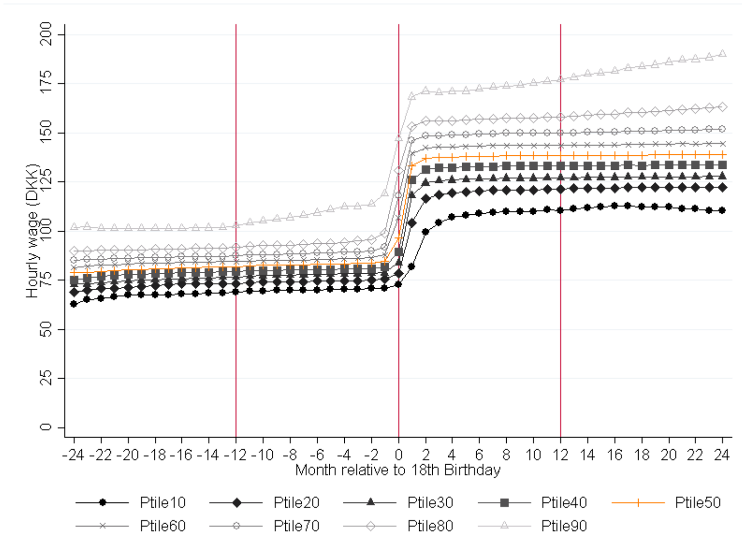


(d) Quantiles of Hourly Wage (Conditional on Employment)



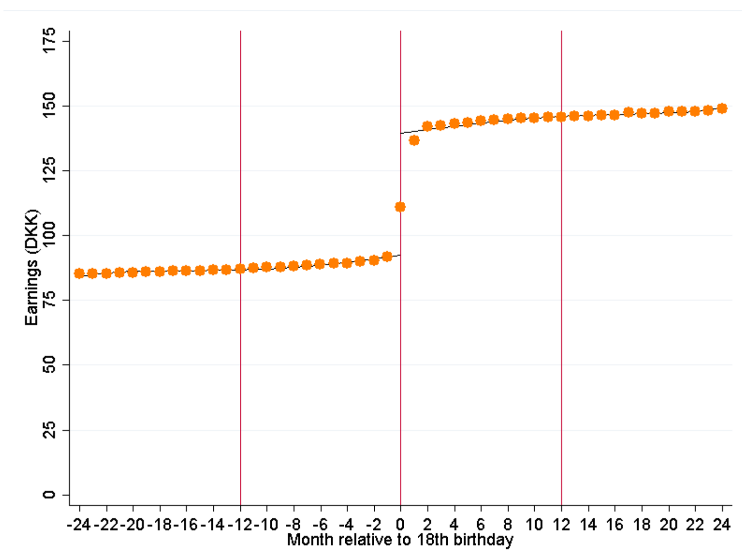
Note: This figure provides simple time series of key variables of interest for our analysis over our sample period.

Figure A.2: Quantiles of Imputed Hourly Wages Around Workers' 18th Birthday



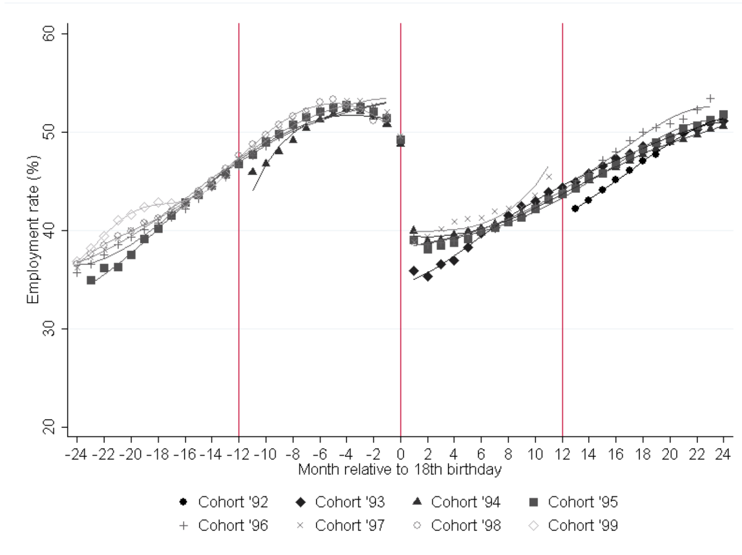
Note: This figure depicts quantiles of imputed hourly wages around workers' 18th birthday. We observe a sharp increase in the distribution of hourly wages at all quantiles.

Figure A.3: Selection into Employment: Employed Continuously from Two Months Before to Two Months After Age 18



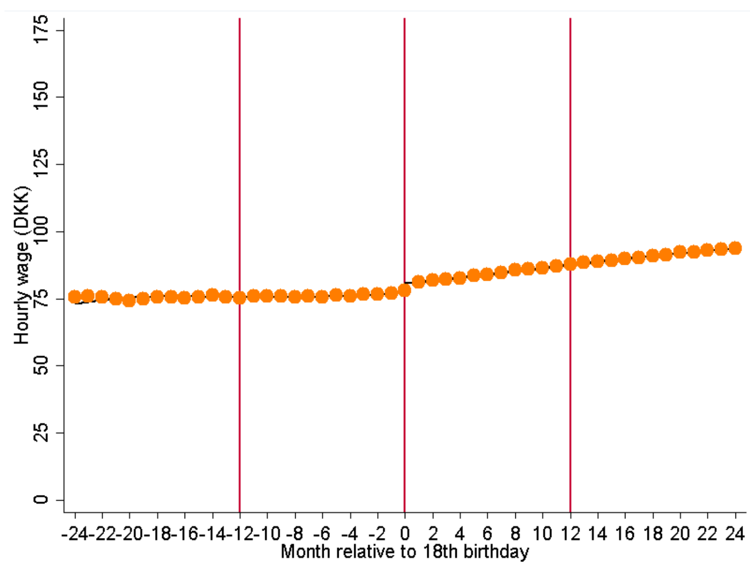
Note: To look for evidence of selection into employment based on wages in a manner that might bias our main results, this figure depicts average imputed hourly wages around the 18th birthday for workers employed continuously from $t = -2$ to $t = 2$ around the 18th birthday. The graph is basically identical to Figure 1a, indicating that our results to not suffer from such selection bias.

Figure A.4: Employment Around Workers' 18th Birthday by (Annual) Birth Cohort



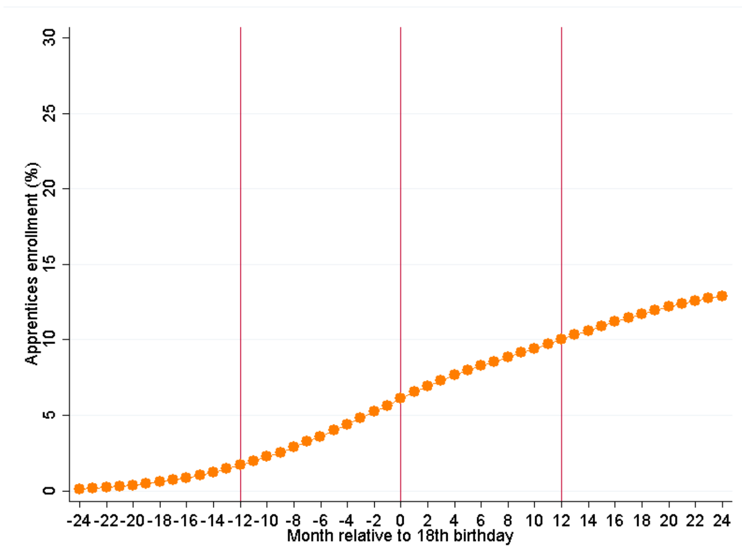
Note: This figure depicts employment around workers' 18th birthday, exactly as in Figure 1b, separately for each annual birth cohort present in our data.

Figure A.5: Average Hourly Wages for Apprentices Around Workers' 18th Birthday



Note: This figure depicts average imputed hourly wages around workers' 18th birthday, exactly as in Figure 1a, but for individuals employed as apprentices, which are exempt from minimum wage rules.

Figure A.6: Employment as Apprentice



Note: The graph depicts employment in skilled apprenticeships around the 18th birthday. We observe no jump in the probability of employment in an apprenticeship at age 18.