

Do Lower Minimum Wages for Young Workers Raise their Employment?

Evidence from a Danish Discontinuity*

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Abstract

We estimate the impact of youth minimum wages on youth employment by exploiting a large discontinuity in Danish minimum wage rules at age 18, using monthly payroll records for the Danish population. The hourly wage jumps up by 40 percent at the discontinuity. Employment falls by 33 percent and total input of hours decreases by 45 percent, leaving the aggregate wage payment almost unchanged. We show theoretically how the discontinuity may be exploited to evaluate policy changes. The relevant elasticity for evaluating the effect on youth employment of changes in their minimum wage is in the range 0.6-1.1.

Keywords: Minimum wage policy, employment, regression discontinuity

JEL: J2, J3, H2

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Minimum wages, set by law or by collective agreement, exist in 3/4 of 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 legislated 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 are confronted with 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. Many US states and cities, including California, Minnesota, South Dakota, Kansas City, Missouri, and Des Moines, Iowa, that have recently increased their minimum wage have debated, and at times legislated or placed on the ballot, an exception for younger workers.¹ Similarly, many European countries with high minimum wages have lower minimum wages for younger workers (OECD, 2015).

The main question we seek to answer is: holding the adult minimum wage fixed at a given level, what is the effect of a change in the minimum wage applying to young workers on their employment? Existing US evidence and most other evidence cannot answer this question as it studies changes in a global minimum wage rather than a youth-specific minimum wage.²

¹A lower minimum wage for young workers exists already in Alaska, the District of Columbia, Connecticut, Illinois, Michigan, Minnesota, Ohio, Pennsylvania, Rhode Island, South Dakota, Vermont, Washington, and California, but the differences between young and adult workers are small. Federal minimum wage rules and some other state minimum wage rules allow workers under the age of 18 to be paid less than the adult minimum wage for the first 90 days of employment. Minimum wage exceptions are often 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>

²For example, the elasticity of youth employment with respect to the minimum wage of 0.075 reported

Our empirical evidence exploits a large discontinuity in Danish minimum wage rules occurring when workers reach age 18. The Danish context is ideal for our purpose. Denmark has large changes in minimum wage rates when workers turn 18 (and no change at any other ages) and a high adult minimum wage comparable to the \$15 level in place in California and under consideration more generally in the US.³ Furthermore, we can study the effect of the age discontinuity using high-quality monthly data on wages, employment, and hours worked for the entire Danish workforce.⁴

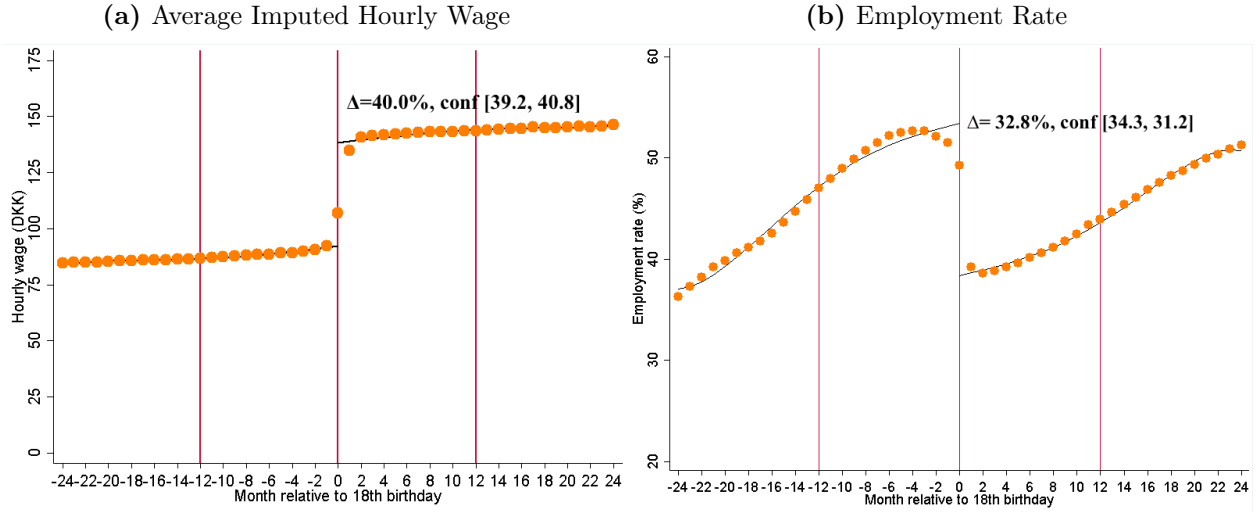
Our main findings are contained in Figure 1, which shows that the age discontinuity in minimum wages has a large impact on employment around age 18. We explain the details behind the construction of the data set, measurement issues, and the source of identifying variation below. Figure 1a plots average hourly wages, imputed by dividing reported monthly wages by reported hours worked for each individual, as a function of age (measured in months), for two years before and after their 18th birthday. 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. For comparison, note that the wage and employment rates develop smoothly when individuals turn 17 and 19 years old, and that it takes two years before the employment rate is back at

by the US Congressional Budget Office is based on changes in a global minimum wage (Congressional Budget Office, 2014).

³Using 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, 2016a), the minimum wage for adult workers over 18 in Denmark is comparable to a US wage rate of about \$14.50.

⁴Our results complement recent studies exploiting Danish tax return data to identify responses to tax-transfer policies (e.g. Chetty et al., 2011; Kleven et al., 2014; Kreiner, Leth-Petersen and Skov, 2014, 2016).

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



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. We observe no changes when workers turn 17 and 19 years old. The percent change in the dependent variables and the fitted black line are taken from the estimation of a regression described in Section 3. See also Table 2.

the level it attains just before the jump downwards at age 18. Subsequent analyses reveal that the drop in employment when workers turn 18 reflects a discrete change in job loss without any discrete change in hiring (we do observe a small anticipatory slow-down in hiring as workers approach age 18). A simple estimate of the employment elasticity (the extensive margin) with respect to the wage change is obtained by dividing the estimates of the percentage changes in employment and hourly wage. This gives an elasticity around -0.8. 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 a total hours worked elasticity around -1, not depending on the measurement of hourly wages.

We use economic theory to motivate our empirical specification and to show that, under reasonable assumptions, the estimated employment 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 model in which the elasticity we estimate using the age 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. According to this 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 using our estimated elasticity. This calculation gives a 15 percentage point drop in youth employment, corresponding to 33 percent of initial employment.

A model with downward sloping labor demand for low-skilled work would instead suggest that there are cross-worker effects, implying that a higher youth minimum wage may increase low-skilled adult employment. Such cross-worker effects pose a potential threat to the identification strategy. However, we show that one can obtain a lower bound for the youth employment elasticity by considering the extreme case of a fixed demand for low-skilled work (implying that the employment effect from the discontinuity analysis is entirely driven by cross-worker effects). The lower bound may be computed from our estimated elasticity and the wage share of younger workers in the low-skilled labor market. We thus compute the wage share of low-skilled workers under age 18, using various definitions of the

low-skilled workers that are perfectly substitutable for workers under age 18. In the most extreme of these calculations, in which only workers aged 18-19 are deemed to be “low-skilled” substitutes for workers under age 18, the lower bound of the youth employment elasticity becomes 0.6. Increasing the minimum wage for young workers up to the level of adult workers would then decrease employment by at least 11 percentage points, or 25 percent of youth employment, which is still a substantial employment effect.

We also embed our simple model in an equilibrium search framework incorporating dynamics for aging. In accordance with the empirical evidence, the model predicts that the drop in employment at age 18 reflects a discrete change in job loss rather than a discrete change in hiring. 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 young workers constitute a low share of total low-skilled employment."

Additional analysis demonstrates that our interpretation of the empirical results is correct and studies heterogeneity in employment effects across workers. Most importantly, we demonstrate that other policies that change when workers turn 18, such as the eligibility for Danish social welfare programs, are not driving our results. We also show that the size of the employment elasticity is only slightly larger for workers of lower ability, as proxied by school GPA in 9th grade or the income of parents. Finally, we provide suggestive evidence that job losses have persistent effects on workers. Two years after the workers' 18th birthdays, the employment rate is about 15 percentage points lower for workers losing their job at age 18 relative to workers who kept their job.

Our paper contributes to the sizable literature on minimum wages and employment, as

reviewed in Card and Krueger (2015), Neumark and Wascher (2008), and Brown (1999). Most of this literature studies employment effects of global minimum wage hikes, while our focus is on the effects of age-specific minimum wages, where evidence is limited. Neumark and Wascher (2004) show that countries with high minimum wages also tend to have high youth unemployment, but, consistent with our results, this correlation is weaker when countries have a lower minimum wage for young workers. A few more recent studies employ difference in differences (DD) designs around age-specific changes in the minimum wage within various countries. Consistent with our results, Yannelis (2014) and Pereira (2003) use administrative data (from Greece and Portugal, respectively), and estimate employment elasticities in the -0.2 to -0.4 range for younger workers. Consistent with the notion that the employment effect should be larger for a youth minimum wage than for a global minimum wage, these estimates are larger than most estimates in the global minimum wage literature. Their estimates are not as large as ours, which might reflect less binding minimum wages or that short-run frictions can attenuate the effects in DD research designs.

One new study, Kabátek (2015), analyzes an age discontinuity, in this case several small age discontinuities in Dutch minimum wages.⁵ The observed changes in wages and employment around workers' birthdays are therefore much smaller and more diffuse than in our context. The implied employment elasticity is slightly smaller than ours. Combining one large discontinuity with thorough theoretical reasoning and rich data allows us to interpret our effects in more detail and to perform credible counterfactual policy exercises.

Our results may make some readers concerned about the impact of global increases in

⁵Two other studies have examined age-related differences in UK minimum wages with discontinuity designs (Dickens, Riley and Wilkinson, 2014; Fidrmuc and Tena, 2013). However, these studies are based on survey data, which substantially decreases their precision.

the minimum wage on employment, a subject of intense ongoing debate. Several DD studies, most famously Card and Krueger (1994), find little to no impact of global minimum wage hikes on employment.⁶ Our estimates of the effect of an increase in minimum wages on employment are much larger than those typically estimated for global minimum wage hikes using DD designs. There are three factors that could explain this difference. First, estimates in existing DD studies might be attenuated by short-run frictions (Baker, Benjamin and Stanger, 1999; Sorkin, 2015; Meer and West, 2015; Aaronson, French and Sorkin, 2017), which are not relevant in our setting. Second, our study is based on a high minimum wage level compared to most previous studies. Minimum wages may not be binding at low levels and, if binding, they may increase employment due to labor market imperfections (Manning, 2003). Third, our results might be driven by cross-age substitution rather than purely a disemployment effect of the minimum wage. The first two of these factors suggest that our results address shortcomings of the existing literature on global minimum wage hikes. However, the third is an important limitation of our study’s ability to speak to this debate. Cross-age substitution would imply that we estimate higher employment elasticity in our setting than would be seen with a global minimum wage change. The extent to which this particular factor drives our large estimate determines the extent to which readers should update their beliefs about the employment effects of global minimum wage hikes. On the whole, therefore, it is difficult to imagine that our findings will make readers *less* concerned about employment effects of high minimum wages, but whether and to what extent they

⁶The empirical literature is not unanimous on this question. For instance, Jardim et al. (2017) find large disemployment effects of the recent, sizable minimum wage hike in Seattle. Recent evidence in Clemens and Wither (2016) also 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.

should be *more* concerned depends on what they believe about the mechanisms behind our results.

Our work also contributes to the theoretical literature on the effects of minimum wages. Much of the literature attempts to rationalize early DD studies finding small or even positive employment effects using models with monopsony power or other labor market imperfections (Rebitzer and Taylor, 1995; Manning, 2003; Flinn, 2006). Our findings of large, negative employment effects around age-based minimum wages align better with binding minimum wages in a competitive labor market model. The minimum wage literature often assumes that workers/jobs are homogenous with a downward sloping labor demand due to a decreasing marginal product of labor. This is in contrast to the optimal income tax literature normally assuming heterogeneous productivities (Mirrlees, 1971). Our explanations of the empirical findings are based on theory with heterogeneous productivities, similar to other recent minimum wage research (Clemens and Wither, 2016; Clemens and Strain, 2017). The fact that some individuals lose their job when they turn 18, while others keep their job, strongly suggests that heterogeneous productivity is an important aspect of the low-skilled labor market.

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

1 Theory and Empirical Identification

This section develops theory that informs our empirical methodology and justifies our counterfactual policy calculations. We begin with a simple model of the labor market, where we show how the age-discontinuity in minimum wages may be exploited empirically to identify

the effect of a change in the youth minimum wage on youth 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.

1.1 Basic Model and Empirical Approach

A theory needs to explain why some individuals are still employed when they turn 18, while others lose their job, even under the realistic assumption that individuals just above and below 18 are perfect substitutes. This employment pattern is difficult to explain without introducing some kind of worker or job heterogeneity.

We start by considering a simple constant returns to scale model with worker heterogeneity similar to other recent minimum wage research (Clemens and Wither, 2016; Clemens and Strain, 2017). 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 $x_{i,a} = \omega_i + \alpha(a)$, 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

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

Assuming that $F(\cdot)$ is approximately linear in the relevant range of the minimum wage, the employment propensity $\Pr(e_{i,a} = 1)$ may be approximated by a linear probability model. In this case, we may estimate

$$\Pr(e_{i,a} = 1) = \eta \bar{w}_a + \tilde{\alpha}(a), \quad (2)$$

where $\tilde{\alpha}(a)$ is a simple transformation of $\alpha(a)$ in eq. (1), 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 the 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

⁷The 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 and Wither (2016).

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 (2) and use information about statutory minimum wages for regular work in the collective agreements. Another strategy is to estimate the employment equation

$$\Pr(e_{i,a} = 1) = \psi_e 1\{a \geq \hat{a}\} + \tilde{\alpha}(a), \quad (3)$$

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 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.

1.2 Worker Substitutability 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 *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 lowering 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 18 year olds. 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

$$y = f(x), \quad x \equiv \int_0^1 \int_{i(a)}^1 \omega(i) di da, \quad (4)$$

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

$$w_1 = f'(x^*)\omega_1, \text{ for } a \leq \hat{a}, \quad (5)$$

$$w_2 = f'(x^*)\omega_2, \text{ for } a > \hat{a}, \quad (6)$$

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

$$\tilde{\varepsilon} \equiv \frac{de_1/e_1}{dw_1/w_1} = \frac{1 + \epsilon \frac{(1-\hat{a})\omega_2}{x^*}}{1 + \epsilon \frac{(1-\hat{a})\omega_2 + \hat{a}\omega_1}{x^*}} \varepsilon, \quad (7)$$

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 $\tilde{\epsilon} = \epsilon$ without any bias, as in the previous section. The potential bias is largest when overall labor demand is vertical—the discontinuity effect is *entirely* driven by cross-worker substitution—so $\epsilon \rightarrow \infty$, in which case we have

$$\tilde{\epsilon} = (1 - \delta)\epsilon, \tag{8}$$

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 3, we use this insight to obtain a lower bound of the elasticity when accounting for cross-worker effects.

1.3 Dynamics and Search Frictions

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

⁸Note that this parameter is similar but not identical to the wage bill share in Section 2.2, which was also

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 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 they become adults. Thus, empirically we should see a spike in the job separation rate for individuals moving into adulthood (but not in the job finding rate).

Second, a higher youth minimum wage reduces youth employment. The effect on adult employment is ambiguous. Intuitively, a higher youth minimum wage reduces youth employment and thereby reduces 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.⁹

denoted δ . Here, δ is the fraction of workers in the given labor market that are young.

⁹A higher adult minimum wage reduces the employment rate of adults and—perhaps counterintuitively—also reduces 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.

1.4 Labor Supply Effects and Imperfect Competition

We have, so far, considered a fixed labor supply and a competitive labor market. In such a setting, labor demand channels alone determine employment effects of binding minimum wage hikes. The literature often relaxes these assumptions to rationalize positive employment effects of minimum wage hikes. We discuss the relationship between our results and these theories here.

In Appendix A.3, we modify the basic model to allow 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. With this modification, the employment effect we estimate consists of labor supply and demand effects. For the labor supply effect, a higher minimum wage attracts older workers into the labor force and boosts adult employment. For the labor demand effect, as before, young workers with productivity above the old minimum wage and below the new one are no longer employed when they turn 18. These two effects are opposite in sign, so 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.

Finally, we consider the possibility of imperfect competition. As is well-known, imperfect competition 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, such mechanisms may be at play, but if so they are dominated by the other effects pulling towards a negative relationship between the minimum wage level and employment.

2 Institutional Background and Data

2.1 Minimum Wages and Labor Market in Denmark

In Denmark, and many other countries, minimum wages are set by collective wage agreements between trade unions and employers' organizations (OECD, 2015).¹⁰ This is organized by industry sectors nationally. A wage agreement of an industry specifies minimum pay rates, but leaves all employment decisions to the employers (a "right-to-manage" bargaining system). The pay rates may vary with age, experience, qualifications, time of work etc. Collective bargaining agreements effectively cover 80-90 percent of all Danish workers.¹¹ Crucially, the minimum wage level in all collective agreements increases sharply when individuals become adults at age 18. An exception applies to apprentices (similar to technical education in the

¹⁰Other countries include Austria, Finland, Iceland, Italy, Norway and Sweden.

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

US) where wages change according to education length. Some other countries 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, 2016b).

Table 1, panel A describes the minimum wage levels specified in the wage agreement relevant for people working in supermarkets and grocery stores (called “*Butiksoverenskomsten*”) where around 44 percent of the employed 16- and 17-year olds work in 2015 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 workers and adults is approximately 55 percent for all categories. Appendix Table A.1 reports minimum wage levels for young workers 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 workers 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, Carcillo and Zylberberg, 2014).

Danish labor market policy is often characterized as following a “flexicurity” model (Andersen and Svarer, 2007). The labor market is flexible in that hiring and firing costs are quite low in a European context, in particular compared to Southern Europe. Denmark complements this flexibility with generous social security policies, but this component of the

¹²These other countries include Australia, Chile, Ireland, Greece, the Netherlands and the UK. See footnote 1 for more on US state minimum wage rules.

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	86	152	56%
Data, median	85	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.

flexicurity model is not so important in our context because the young workers in our study (age 16-19) do not qualify for UI benefits. Thus, the youth labor market in Denmark is probably not so different from the US by these parameters. It is crucial for our RD design that it is easy for firms to lay off workers (without any change in firing costs around age 18). With high firing costs, the employment response at the age-discontinuity in the wage would not be so sharp and could underestimate the employment effect of the counterfactual policy.

Young workers do not receive severance pay. Adults may receive severance pay, but this depends on seniority and typically requires at least three years of employment in a firm, making it irrelevant for our empirical analysis. It is possible to make temporary employment contracts that expire when the employee turns eighteen years old or have longer contracts, but lay off individuals when they become adults. This does not violate age discrimination laws.¹³ It is also legal for a firm to search explicitly for a young worker or for an adult worker.

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

Certain restrictions apply to the type of work done by younger individuals. Young workers are not allowed to lift more than 25 kilos, to work with certain hazardous material or to work certain large machines, and they are not allowed to handle money in certain ways.¹⁴ Additionally, only adults are allowed to drive a car, and this requires 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. In Section 3.2, we show that our results are not confounded by certain benefits only applying to adults.

2.2 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 a monthly frequency for each employee in Denmark. These administrative data are reported by third parties (employers) to the Danish 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.¹⁵ All of this ensures that the data are quite accurate (Kleven et al., 2011).

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 con-

¹⁴This is described in detail in the law document "*Ungebekendtgørelsen*" available at www.retsinformation.dk/Forms/R0710.aspx?id=29935.

¹⁵More 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.

tains 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) enabling links to other registers. The monthly payroll data has been transferred to a centralized governmental statistical agency, Statistics Denmark, for storage and analysis, and merged with other population register data. For some of the analyses, we use other 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 to Dec 2015 for all individuals in Denmark who are 16-19 years old in a given 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. Roughly half of Danish individuals age 16-19 are employed in a typical month. The figures reveal some seasonal variation, with elevated employment in the summer months and in December. Predictably, average earnings among employed individuals are also higher in the summer, especially in August. 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. Therefore, with some exceptions, 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. The hourly wage rate is imputed by dividing earnings by hours worked. 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 also show 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 lie 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 average of the wage changes at age 18 across the agreements (48% in Table A.1) is very close to the average across sectors observed in the data (46% in Table A.2).

3 Empirical Results

This section presents the empirical results of the paper. We show that the minimum wage hike at age 18 has a strong effect on hourly wages and employment; we provide estimates of the elasticity of youth employment with respect to changes in the youth minimum wage; we analyze potential threats to the identification strategy; consistent with the predictions of the search model, we demonstrate a large spike in job loss at age 18 without any spike in hiring; we provide suggestive evidence of a significant impact of job loss beyond just one month after the 18th birthday; and we study how these employment effects vary by worker characteristics.

3.1 Effects on 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 just as workers turn 18, and no discrete changes when they turn 17 or 19.¹⁶ 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

¹⁶Note 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.

regressions of the following form:

$$E[y_{it}] = \psi \cdot 1\{a_{it} \geq 18\} + \sum_{d=0}^D \alpha_d a_{it}^d + \rho \cdot 1\{a_{it} = 18\}, \quad (9)$$

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. (3) 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 nearly linear.¹⁷ 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:

$$\Delta = \frac{\psi}{\sum_{d=0}^D \alpha_d a_{18}^d + \frac{\psi}{2}}, \quad (10)$$

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. (9), 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 individuals (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. (9) and (10).

¹⁷The results do not change much when using lower order polynomials. The employment elasticity in the baseline specification in Table 2 is 0.82. When using lower order polynomials the elasticity becomes higher with 0.97 as the maximum (linear specification).

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

Specification:	(1) Baseline	(2) Month FE	(3) Month & Cohort FE	(4) Month & Cohort FE & dummies for event time -2 to 2	(5) Only event time -1 and +1
Panel A: Hourly wage					
Coefficient (DKK)	46.1	46.1	46.1	49.6	42.5
[95% Conf. Interval]	[45.2,47.0]	[45.4, 46.8]	[45.5, 46.8]	[49.0, 50.2]	[41.3,43.6]
Percent Change (%)	40.0	39.2	39.1	42.0	37.4
	[39.2, 40.8]	[38.6, 39.8]	[38.6, 39.7]	[41.4, 42.6]	[36.5,38.3]
Panel B: Employment					
Coefficient (% points)	-15.0	-15.1	-15.0	-17.8	-12.3
	[-15.7, -14.3]	[-15.6, -14.6]	[-15.5, -14.6]	[-18.4, -17.2]	[-13.1,-11.3]
Percent Change (%)	-32.8	-31.9	-32.2	-38.0	-27.1
	[-34.3, -31.2]	[-33.0, -30.9]	[-33.2, -31.2]	[-39.3, -36.6]	[-29.2,-25.0]
Implied Elasticity	-0.82	-0.81	-0.82	-0.90	-0.72
Panel C: Hours worked					
Coefficient (hrs.)	-7.2	-7.3	-7.2	-8.6	-5.8
	[-7.9, -6.4]	[-7.8, -6.7]	[-7.8, -6.7]	[-9.5, -7.8]	[-6.8,-4.9]
Percent Change (%)	-45.0	-45.1	-44.4	-53.2	-37.0
	[-49.6, -40.4]	[-48.7, -41.7]	[-48.3, -40.5]	[-59.0, -47.7]	[-42.9,-31.0]
Implied Elasticity	-1.13	-1.15	-1.13	-1.27	-0.99
Panel D: Wage Earnings					
Coefficient (DKK)	-40.3	-53.0	-46.2	-125.2	-41.5
	[-125.1, 44.5]	[-118.1, 12.2]	[-115.5, 23.1]	[-237.4, -12.9]	[-61.2,144.2]
Percent Change (%)	-0.02	-0.03	-0.03	-0.07	0.02
	[-0.07, 0.03]	[-0.06, 0.01]	[-0.06, 0.01]	[-0.13, -0.01]	[-0.04,0.08]
Observations	13,130,982	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. 9), and the percent change in the outcome, calculated using the midpoint method (e.g. Δ in Eq. (10)). 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. 9). Subsequent columns add month and birth-year cohort fixed effects to this specification; column 4 also includes 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; while column 5 only uses the month before the workers' 18th birthday and the month after to identify the effects.

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 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.(10) 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 all quantiles of the hourly wage distribution. 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. 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.

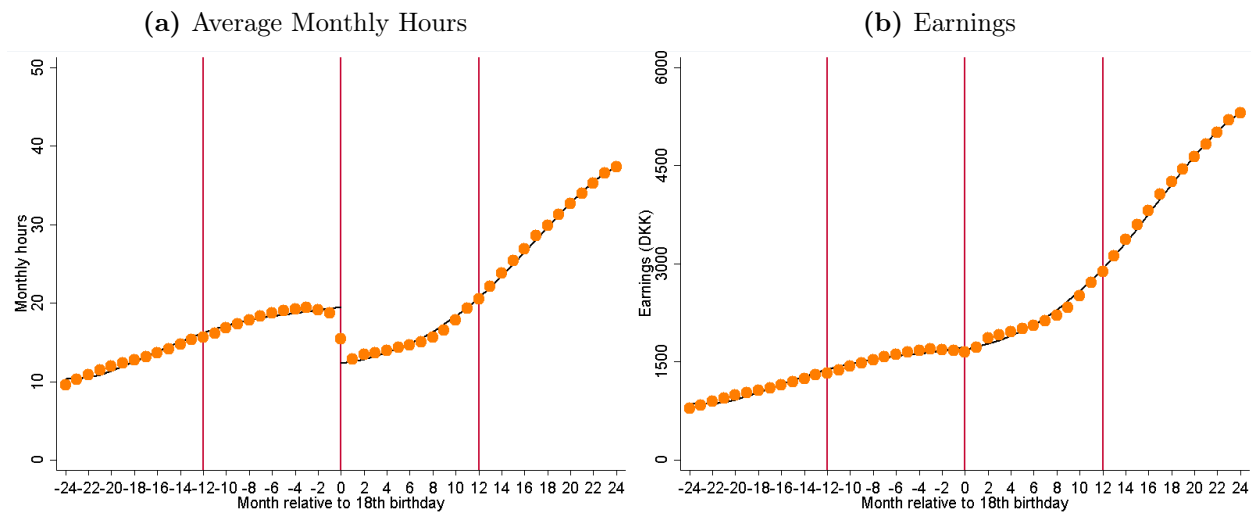
¹⁸It is possible that some of the increase in hourly wages that we observe happens not just because the minimum wage is binding for all workers, but also because workers making above the minimum wage receive a raise when the minimum wage increases, as in Autor, Manning and Smith (2016). Our data are 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.

The remaining 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. Conversely, we may abandon any attempt to account for anticipation and inertia and simply compare wages and employment one month before and one month after workers turn 18 as done in Column (5). In this case, the elasticities are slightly smaller. For example, the elasticity of employment with respect to the minimum wage becomes -0.72. 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. The results above are all conducted using the estimation sample excluding apprentices, but

¹⁹The 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.

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



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. (9).

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. Therefore, mechanically 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 18.²⁰ 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 in Appendix Table A.3, which shows that the estimates of the employment elasticity are almost identical whether we include apprentices or not.

Finally, we conduct additional analyses of various sectors. First Appendix Table A.4 repeats our preferred specification for supermarkets and grocery stores, which is the most important sector for youth with 44 percent of youth employment, and where we have infor-

²⁰This 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.

mation about the relevant collective bargaining agreement as described in Section 2.1. In this sector, both the percent change in wages and the percent change in employment are somewhat larger here than in the entire sample. The estimated percentage change in the hourly wage (53%) is virtually identical to the percentage change in the basic salary in the bargaining agreement (55%), strongly indicating that the minimum wage is binding. The wage increases coincide with a 62 percent drop in employment giving an elasticity estimate of -1.1 or -1.2, depending on the method used to calculate it. Second, Appendix Figure A.7 repeats the analysis in Column (1) of Table 2 with employment in each sector and wages in each sector as the outcome variables for the top 20 sectors for youth employment (see Table A.2). We observe that changes in wages in a sector correlate strongly with changes in employment in that sector, suggestive once again of an overall employment elasticity of around -0.8.

3.2 Potential Threats to Identification

In this section, we address two important concerns with the use of the analysis in the previous section to draw inference about the effect on youth employment from a change in the youth minimum wage. One standard concern with identification in a discontinuity analysis – sorting on the running variable – is not a concern here as workers can exercise no control over the timing of their birthday. We nevertheless report in Appendix Figure A.8 the standard tests for discontinuities in observable characteristics and the density of the running variable at the month of the 18th birthday (McCrary, 2008). Here, we primarily focus on how to account for cross-worker effects in counterfactual policy analysis, and other policies that change at age 18.

Cross-Worker Effects

The most important threat to the identification strategy is the potential for cross-worker effects as described in Section 1. An increase in the youth minimum wage may cause employers to hire more workers over age 18. This possibility would constitute a violation of the Stable Unit Treatment Value Assumption, as the policy change we are interested in would have a direct causal effect on older workers. Nevertheless, we can use the theory to bound the magnitude of the bias in the causal effect of interest—the effect on youth employment of a change in the youth minimum wage—in the presence of cross-worker effects. As shown in formula (8), the true elasticity of youth employment with respect to the youth minimum wage is bounded below by $(1 - \delta)\varepsilon$, 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. This lower bound corresponds to the extreme case of a fixed demand for low-skilled work, so that the discontinuity in youth employment we estimated in Figure 1b is entirely driven by cross-worker effects.²¹ Our estimate of the employment effect at age 18 should thus be a good approximation of the actual effect when the share of workers under age 18 in the low-skilled labor market is plausibly relatively small.

Table 3 contains information on the wage share of workers under age 18, for various definitions of low-skilled work. About 2.8 percent of employed individuals are under age 18, 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 0.3 for young workers. The

²¹The presence of such cross-worker effects also implies that the youth employment effects of changing the youth minimum wage are not the sole determinant of the welfare effect of such a policy change. Our data do not permit us to separate cross-worker effects from real disemployment effects, but we fully acknowledge that cross-worker effects would be important to keep in mind when attempting to set an optimal policy.

last column of Table 3 reports the lower bound for the elasticity of youth employment with respect to the youth minimum wage obtained from plugging in the given wage share as the value of δ and our baseline estimate for the wage elasticity from the discontinuity ($\epsilon = 0.82$). Using a wage share of 0.3 percent results in no meaningful change in the elasticity. However, the theory that gives the bounding result suggests that we should be using the wage share for low-skilled work that is perfectly-substitutable for work by employees under age 18. Various approaches to pin down this number lead to a higher wage share as shown in Table 3. One approach is to use a concept of low-skilled workers that includes workers similar to young workers, based on their sector (e.g. supermarkets), their hourly wage rate, or their education. These definitions lead to wage shares ranging from 1 to 7 percent, which are once again small enough that they have little effect on the implied elasticity. A more conservative method for defining low-skilled work is to suppose that only younger workers are perfectly substitutable for workers under age 18. In an extremely conservative calculation, in which we assume the only substitutes for 16- and 17-year-olds are 18- and 19-year olds, we obtain a wage share of 26.5 percent. This conservative wage share leads to a lower bound of the true elasticity of youth employment with respect to the youth minimum wage of 0.60. With this lower bound elasticity, increasing the youth minimum wage up to the level of adults would decrease youth employment by 24 percent instead of 33 percent, which is still a sizable employment effect.

Other Changes at Age 18

The other important potential threat to our identification strategy is that other discrete changes happening when individuals turn 18 may create a jump in the employment rate. We are aware of two such changes. First, as described in section 2.1, there are a few limitations on the type of work that young workers may carry out: not lift more than 25 kilos, not work

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

Population	Share age 16-17 (%)	Lower bound elasticity
Full population	4.0	
Employment (persons)	2.8	
Employment (hours)	0.8	
Wage income	0.3	0.82
Low-skilled occupations [*]	2.1	0.80
Supermarkets	6.5	0.77
Hourly wage < 95th percentile for 18 yr olds ^{**}	1.0	0.81
Highest Education 9th grade or lower ^{***}	2.2	0.80
Individuals age 16-24	5.6	0.77
Individuals age 16-19	26.5	0.60

Note: This table reports the wage share of workers aged 16 and 17 in selected populations, providing suggestive evidence on the share of younger workers in the low-skilled labor market, and computes the corresponding lower bound elasticity estimate using formula (9). In the baseline calculations, we use data for all Danish employees age 16-65. In the last two rows, we assume that only workers of age 18-24 and 18-19, respectively, may substitute for young workers. ^{*}We identify low-skilled occupations using four-digit ISCO classification. We select the 10 most important occupations/job types for youth, which correspond to $\approx 83\%$ of youth employment. ^{**} We define low-skilled, adult workers as having a wage below the 95th percentile for 18 year olds. ^{***} We count low-skilled workers as all workers over 18 with an education level of 9th grade or lower, together with all 16- and 17-year-old workers.

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 even 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 3 replicates our main results in samples constructed in such a way that we can rule out that the drop in employment at age 18 is driven by either student benefits or social assistance.

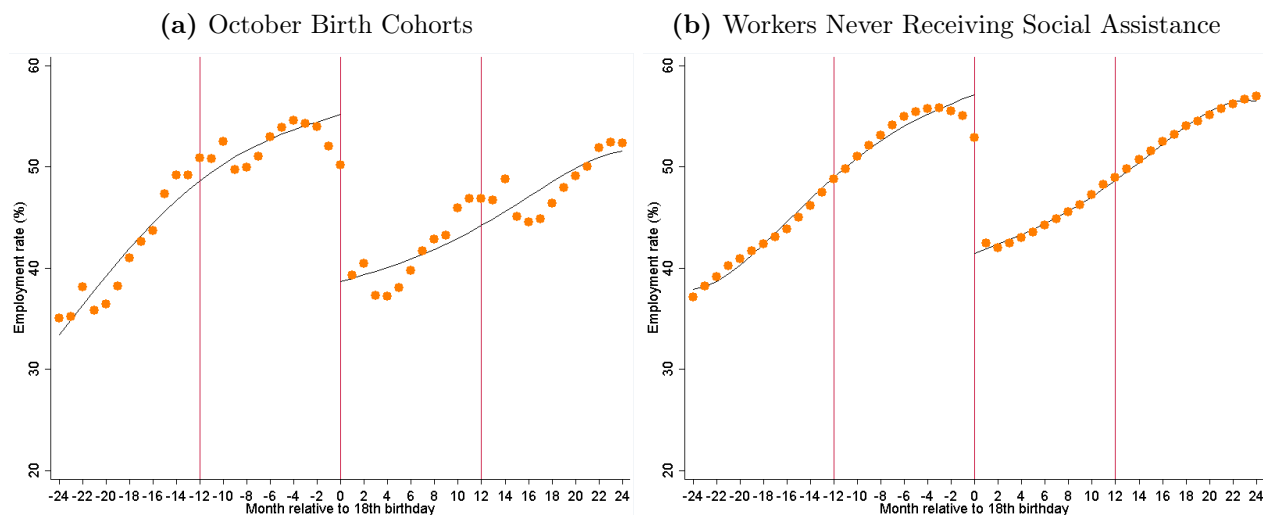
Individuals are eligible for student benefits in the quarter after turning 18 years old, and when receiving student benefits they are allowed to earn DKK 7,500-11,800 per month,²² depending on the type of education, after which student benefits are phased out with the level of your earnings. Importantly, this is computed on an annual basis. In Figure 3a, 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 in January of the next year, 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 can directly observe which individuals receive social assistance. Around 5 percent of 18 year old individuals receive social assistance. In Figure 3b, 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 earn-

²²Level in 2015 obtained from www.su.dk.

Figure 3: 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.

ings 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.

3.3 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 1.3. Figure 4 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 large spike in flows out of employment occurs just after workers turn

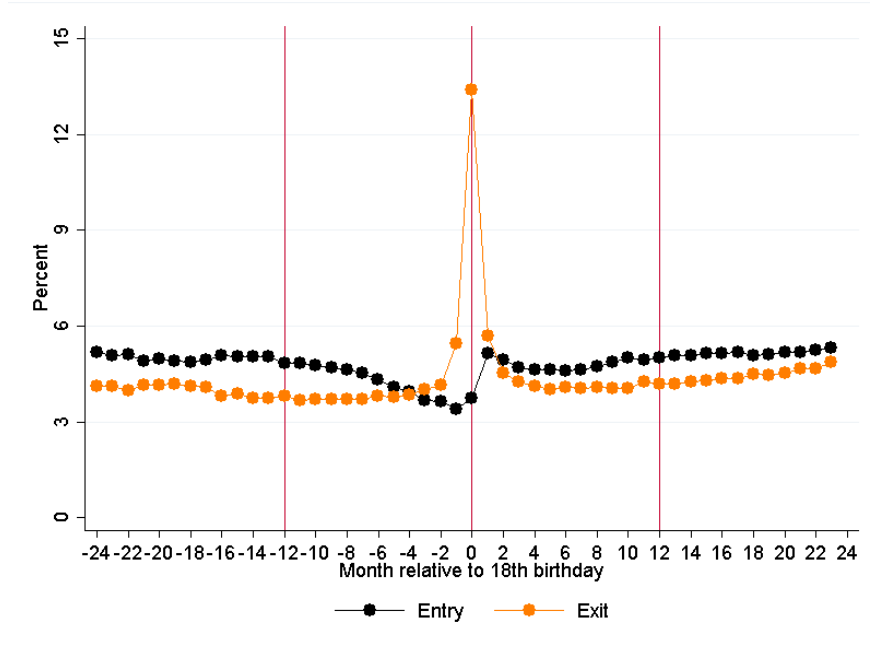
18 as predicted by the search model. This spike drives the drop in employment observed in Figure 1b. The effect is almost entirely concentrated in a three-month period, from the month of the worker's 18th birthday to two months later. We also observe a slight decrease in the flow into employment just 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.²³

3.4 Differences across Groups of Workers

Figure 5a 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. While this difference of about 0.2 in the elasticity is small relative to the overall elasticity, the direction of the change is roughly what one would hypothesize from our basic model: lower ability workers are more likely to lose their job when they turn 18 and are subject to the higher minimum wage. Nevertheless, the elasticity remains large even for students with high GPAs. In Figure 5b, we report equivalent elasticities by deciles of workers' parental income using the average income of individual's parents from age 11 to

²³In 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 4: 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.

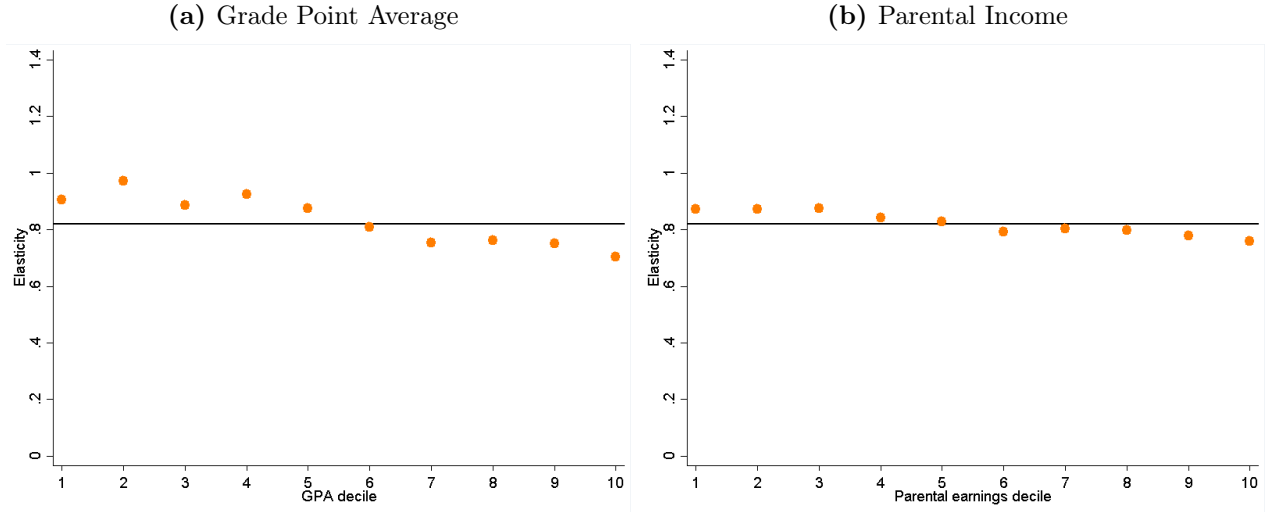
13. Here, we find elasticities that are only very slightly decreasing across the distribution of parental income. The similar elasticities show that a wage increase has a stronger effect on the unemployment risk of young individuals with lower ability, but the differences are relatively small. That our estimated elasticities are nearly unrelated to these broad measures of underlying ability levels is consistent with the search model in Section 1.3 where workers (and firms) are ex ante identical.²⁴

3.5 Consequences of Job Separations

Finally, we present some evidence suggesting 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-

²⁴To complement Figure 5a, Appendix Figure A.9 shows the predicted hourly wage and employment rate at age 18 by GPA and parental income for the low minimum wage and the high minimum wage. The wage rates do not depend on GPA or parental income. The employment rates are increasing in GPA, as may be expected from the theory, but the change in the employment rate is also increasing, so that the percentage change in employment and the elasticity of employment with respect to the wage are roughly constant.

Figure 5: 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 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 that the elasticity is slightly larger for workers with lower GPA or lower parental earnings, but the magnitude of the difference is small relative to the overall elasticity.

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 4 already suggests this is unlikely: the flow into employment does not increase significantly after workers turn 18, as one would expect 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 6a, we look at the rate of employment after turning 18, for workers employed at age 17 years and 11 months that did and did not lose their jobs when they turned 18. These rates of employment are at 0 and 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. Almost 20 percent of individuals leaving employment one month after turning 18 do 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. Two years after turning 18, the difference in employment rates between the two groups is still more than 15 percentage points. 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.²⁵

Figure 6b shows average earnings (including zeros for those not working) for the two groups. The development of earnings mirrors the development of employment. In particular, the job separation event creates a significant earnings gap between the two groups that also exists two years after when the individuals become twenty years old.²⁶

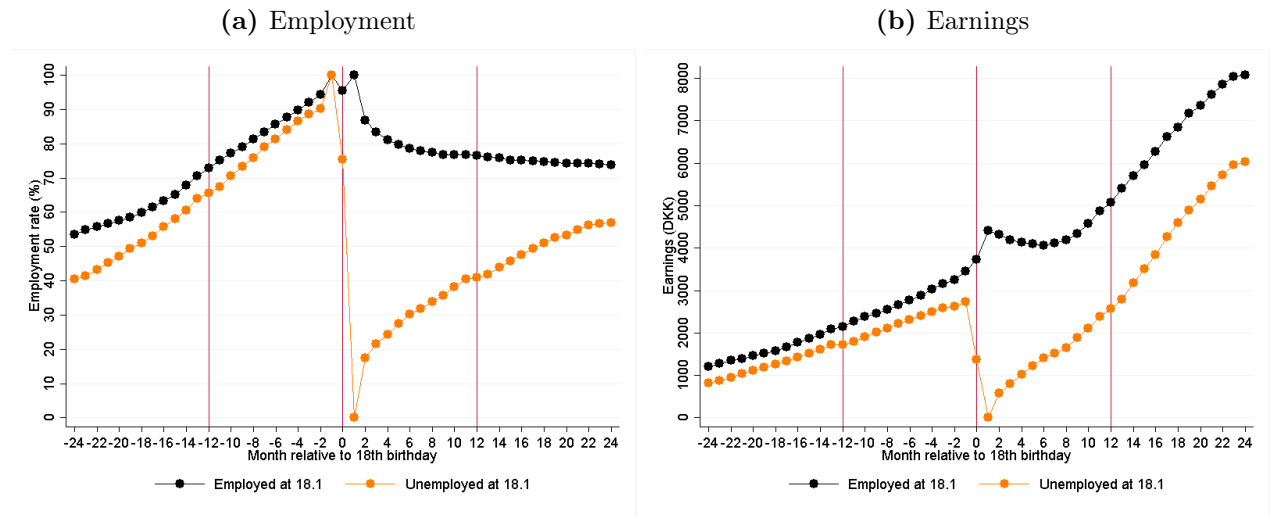
4 Conclusion

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

²⁵This conclusion is confirmed by Appendix Figure A.10, which shows the results from an analysis where we match the group becoming unemployed at an age of 18 years and 1 month to the employment group using propensity score matching based on employment trajectories from age 16 to 17. The employment rates after job loss (from $t = 1$ to 12) mirror Figure 6a, suggesting that the result is not driven by selection.

²⁶One 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. The income loss is to some extent compensated by student benefits as the share of recipients two years after job loss is 3 percentage points higher than for the group not losing the job at age 18. These individuals are enrolled in some form of education, which may create long run benefits. Finally, job losers may also work in the informal labor market and thereby compensate for their income loss. A more fundamental caveat is that the job loss sample, compared to the sample of those continuing being employed, includes individuals who lost their jobs for other reasons than the hike in the minimum wage, e.g. serious injuries. These types of job losses may generate persistent effects not due to the minimum wage and thereby bias the result. However, such job losses are presumably of minor importance compared to the estimated 1/3 reduction in employment caused by the minimum wage hike.

Figure 6: Effect of Job Separations at Age 18 on Future Employment and Earnings



Note: The graphs depict employment (panel a) and labor income (panel b) around the 18th birthday for workers employed in the month before they turn 18. We consider only cohorts born in 1995-96 where we have observations for all months. 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 future employment rates and in earnings between those who stay employed and those who leave employment, even two years after the month workers turn 18.

turn 18, almost all of which 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 in the range of 0.6 to 1.1. 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 differences 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 US. In any event, our results suggest that adopting a lower minimum wage for younger workers would substantially increase youth employment

in US 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.

As discussed in the Introduction, our results do not imply that studies of global minimum wage increases are necessarily underestimating 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, 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. 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, our discussion of cross-worker effects above highlights that 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, the exact process by which jobs for youth and adults are rationed in the presence of binding minimum wages may also matter for the welfare effects of changes to the youth minimum wage (Gerritsen, 2017). Finally, 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 1.2, the full equilibrium search model outlined in Section 1.3 and the extension with endogenous labor supply described in Section 1.4.

A.1 Derivation of Equation (7)

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

$$\Delta w_1 = w_2 - w_1 = f'(x^*)(\omega_2 - \omega_1) \quad (11)$$

$$\Delta e_1 = e_1 - e_2 = i_2 - i_1 \quad (12)$$

where we have used eqs. (5) and (6). The corresponding employment elasticity equals

$$\varepsilon \equiv \frac{\Delta e_1/e_1}{\Delta w_1/w_1} = \frac{(i_2 - i_1)/i_1}{(\omega_2 - \omega_1)/\omega_1}. \quad (13)$$

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 (5), this may be approximated by

$$\Delta w_1 = f''(x^*)\Delta x^*\omega_1 + f'(x^*)\Delta\omega_1. \quad (14)$$

Measured relative to the original wage in eq. (5), this becomes

$$\frac{\Delta w_1}{w_1} = \frac{f''(x^*)x^*}{f'(x^*)} \frac{\Delta x^*}{x^*} + \frac{\Delta\omega_1}{\omega_1}. \quad (15)$$

A Taylor expansion of eq. (4) gives

$$\frac{\Delta x^*}{x^*} = -\frac{\hat{a} \cdot \omega_1}{x^*} \frac{\Delta\omega_1}{\omega_1} - \frac{(1 - \hat{a})\omega_2}{x^*} \frac{\Delta\omega_2}{\omega_2}. \quad (16)$$

A Taylor expansion of eq. (6) 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. (16), 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

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

Inserting this expression into eq. (15) 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

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

where we have used eq. (12). After using the expression for the empirically observed elasticity in (13), we obtain the result in eq. (7).

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 , respectively.

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.²⁷ 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.

The rate at which a vacancy is in contact with a potential employee may be written as

²⁷That firms search for young and old workers separately matches anecdotal descriptions of our Danish institutional setting.

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:

$$c = q_1(\theta_1) \int_{\bar{w}_1}^{\infty} J_1(x) f(x) dx, \quad (17)$$

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

$$J_1(x) = x - \bar{w}_1 + (1 - \lambda - (1 - \delta))J_1(x) + (1 - \delta) \cdot 1\{x \geq \bar{w}_2\}J_2(x). \quad (18)$$

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

$$c = q_2(\theta_2) \int_{\bar{w}_2}^{\infty} J_2(x) f(x) dx, \quad (19)$$

which is similar to eq. (17). The value of a filled job with an adult with productivity x equals

$$J_2(x) = x - \bar{w}_2 + (1 - \lambda - \delta)J_2(x), \quad (20)$$

which is similar to eq. (18) with the exception that aging in this case 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

$$\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))U_1 = (1 - \delta + \lambda)E_1. \quad (21)$$

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

$$\theta_2 q_2(\theta_2)(1 - F(\bar{w}_2))U_2 + (1 - \delta) \frac{1 - F(\bar{w}_2)}{1 - F(\bar{w}_1)} E_1 = (\delta + \lambda)E_2, \quad (22)$$

where the second term reflects that some of the young employed workers are fired when they become adult if $\bar{w}_2 > \bar{w}_1$, noting that $\Pr(x \geq \bar{w}_2 | x \geq w_1) = \frac{1 - F(\bar{w}_2)}{1 - F(\bar{w}_1)}$.²⁸

A.2.4 Solving the Model

From eq. (20), we have

$$J_2(x) = \frac{x - \bar{w}_2}{\lambda + \delta}. \quad (23)$$

By inserting this expression into eq. (18) and simplifying, we obtain

$$J_1(x) = \begin{cases} \frac{x - \bar{w}_1}{1 - \delta + \lambda} & \text{for } \bar{w}_1 \leq x \leq \bar{w}_2 \\ \frac{x - \bar{w}_1}{1 - \delta + \lambda} + \frac{1 - \delta}{1 - \delta + \lambda} \frac{x - \bar{w}_2}{\delta + \lambda} & \text{for } x > \bar{w}_2 \end{cases}. \quad (24)$$

By substituting eq. (23) into eq. (19), we obtain

$$c = q_2(\theta_2) \int_{\bar{w}_2}^{\infty} \frac{x - \bar{w}_2}{\lambda + \delta} f(x) dx. \quad (25)$$

²⁸One can relatively straightforwardly derive similar steady state conditions using U_1 and U_2 and solve the model using these instead.

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 in \bar{w}_2 decreases θ_2 .

By inserting eq. (24) into eq. (17), we get

$$c = q_1(\theta_1) \left[\int_{\bar{w}_1}^{\infty} \frac{x - \bar{w}_1}{1 - \delta + \lambda} f(x) dx + \int_{\bar{w}_2}^{\infty} \frac{1 - \delta}{1 - \delta + \lambda} \frac{x - \bar{w}_2}{\lambda + \delta} f(x) dx \right], \quad (26)$$

which determines labor market tightness in the labor market for the young, θ_1 , for given minimum wages of 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 $\theta_1 q_1(\theta_1)$. 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. (26) and therefore a lower worker match probability $\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))$ of the young.

From eq. (21), the definition of the employment rate $e_1 = E_1/L_1$ and $U_1/L_1 = 1 - e_1$, we obtain

$$e_1 = \frac{\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))}{\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1)) + 1 - \delta + \lambda} = \frac{1}{1 + \frac{1 - \delta + \lambda}{\theta_1 q_1(\theta_1)(1 - F(\bar{w}_1))}}. \quad (27)$$

From eq. (22) and the relationships $U_2 = L_2 - E_2 = (1 - e_2)L_2 = (1 - e_2)(1 - \delta)$, $E_2 = e_2 L_2 = e_2(1 - \delta)$ and $E_1 = e_1 L_1 = e_1 \delta$, we obtain

$$e_2 = \frac{\theta_2 q_2(\theta_2)(1 - F(\bar{w}_2)) + \delta e_1 \frac{1 - F(\bar{w}_2)}{1 - F(\bar{w}_1)}}{\lambda + \delta + \theta_2 q_2(\theta_2)(1 - F(\bar{w}_2))}. \quad (28)$$

Note that this expression is similar to eq. (27) 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. (22) and (24) 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. (26) 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. (27) that e_1 is also decreasing in \bar{w}_1 and \bar{w}_2 .

Third, we see from eq. (28) that an increase in the minimum wage for adults \bar{w}_2 decreases their employment e_2 . We know from eq. (25) 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 directly reduces the second term in the numerator of eq. (28).

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. (28), 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.

A.3 A Model of Endogenous Labor Supply

Here, we extend the simple model in subsection 1.1 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. (1) 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. (1) becomes:

$$\Pr(e_{i,a} = 1) = l(\bar{w}_a, a)[1 - F(\bar{\omega}_a)], \quad \bar{\omega}_a = \bar{w}_a - \alpha(a). \quad (29)$$

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. (29) around the threshold age \hat{a} and the minimum wage applying to adults \bar{w}_2 to obtain a regression equation:²⁹

$$\begin{aligned} \Pr(e_{i,a} = 1) &= l(\bar{w}_2, \hat{a})[1 - F(\bar{\omega}_2)] \\ &+ \underbrace{\{l_{\bar{w}}[1 - F(\bar{\omega}_2)] - l(\bar{w}_2, \hat{a})F'\}}_{\eta}(\bar{w}_a - \bar{w}_2) \\ &+ \{l_a[1 - F(\bar{\omega}_2)] - l(\bar{w}_2, \hat{a})F'\alpha'\}(a - \hat{a}), \end{aligned} \quad (30)$$

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 1.1, 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. The labor supply effect, a higher minimum wage attracts workers into the labor force, is represented by the first component of η in eq. (30). The labor demand effect, as before, young workers with productivity above the old minimum wage and below the new one are no longer employed,

²⁹As 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.

is represented by the second component of η in eq. (30). 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.³⁰

³⁰Similar 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.

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)		Deviation from mean (%)		Difference btw. age 17 and 18 (%)
		17 year	18 year	17 year	18 year	
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 computed using the mid-point method. The information about minimum wage rates for youth in different collective bargaining agreements is obtained from the webpage www.jobpatruljen.dk.

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

Sector	Share of youth employment	Average hourly wage (DKK)		Deviation from wtd. mean		Difference btw. age 17 and 18
		17 year	18 year	17 year	18 year	
1. Retail - grocery	29.3%	86	151	4%	4%	54%
2. Non-specialized retail	14.8%	99	144	9%	1%	37%
3. Restaurants	8.4%	86	155	5%	7%	58%
4. Bakeries	2.9%	90	135	0%	7%	40%
5. Retail - clothing	2.3%	82	140	9%	4%	52%
6. Postal and courier service	1.7%	81	136	10%	6%	51%
7. Public service	1.6%	65	126	28%	13%	63%
8. Sports clubs	1.5%	106	158	18%	9%	39%
9. Café, pubs and clubs	1.1%	111	141	23%	3%	23%
10. Hotels	1.1%	113	140	25%	3%	22%
11. Cinemas	1.1%	96	149	6%	3%	43%
12. Retail - construction	1.0%	90	128	1%	12%	35%
13. Retail - homeware	1.0%	86	150	4%	3%	53%
14. Gas stations	0.9%	82	143	9%	1%	54%
15. Retail - gift items and handicraft	0.9%	84	134	7%	7%	46%
16. Newspaper routes	0.8%	74	130	17%	10%	55%
17. Retail - bread and pastries	0.8%	108	147	20%	2%	30%
18. Retail - sports equipment	0.7%	74	127	18%	13%	53%
19. Sports clubs	0.7%	82	138	10%	5%	51%
20. Sports facilities	0.7%	92	146	2%	1%	45%
Other	26.6%	99	144	10%	1%	37%
Sum / weighted average	100	90	145	7%	4%	46%

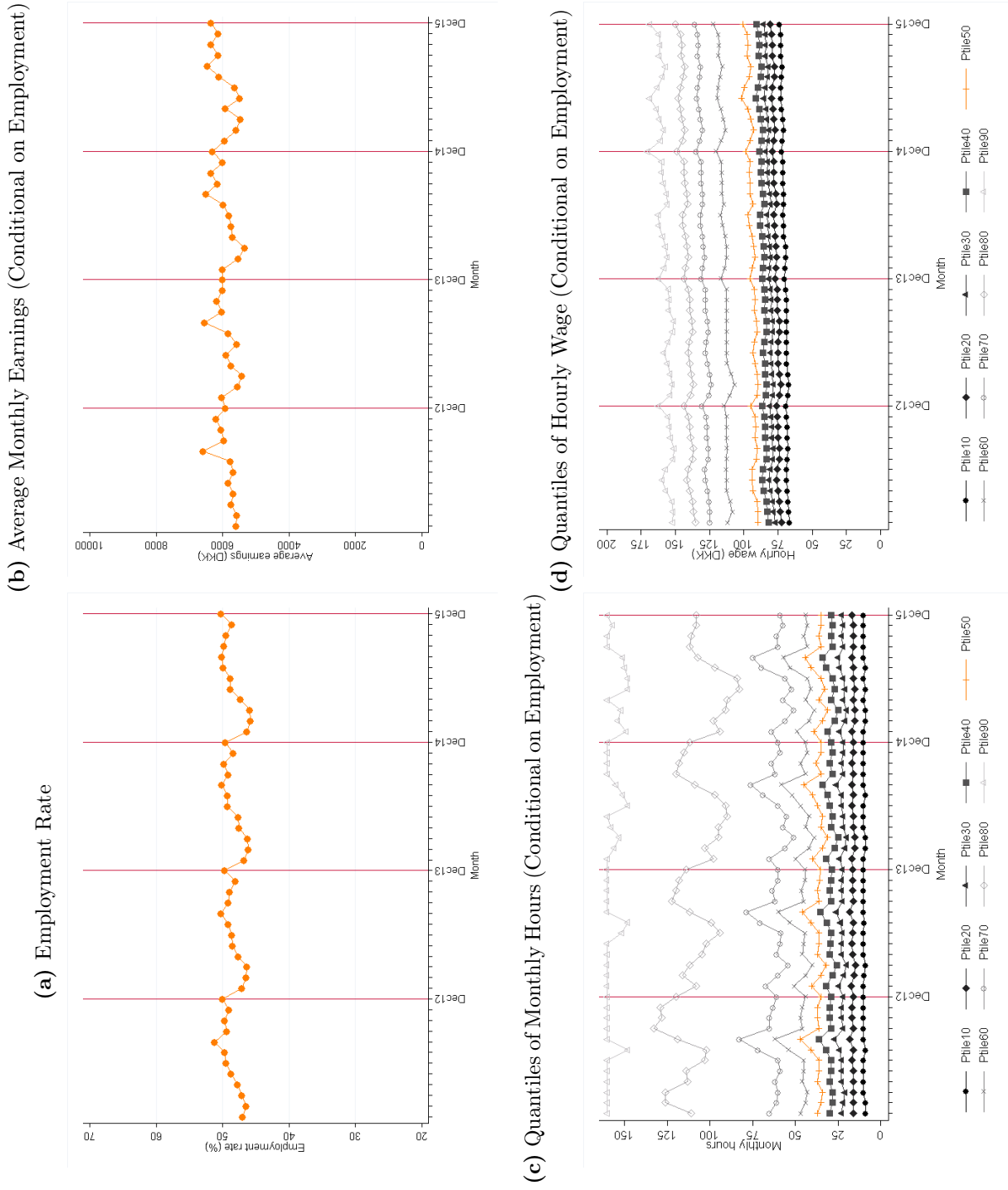
Note: The table reports the average hourly wage for 17- and 18-year-olds by sector in 2015 and the share of youth employment (age 16-17) of each sector. We include the 20 most common sectors for youth employment and an "other" category for workers in other sectors. We also report how much the sector average wage deviates in percent from the overall weighted average (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 (computed using the mid-point method). The weighted average in the last row is weighted with the number of observations in each sector. 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, Including Apprentices

Specification:	(1)	(2)	(3)	(4)
	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

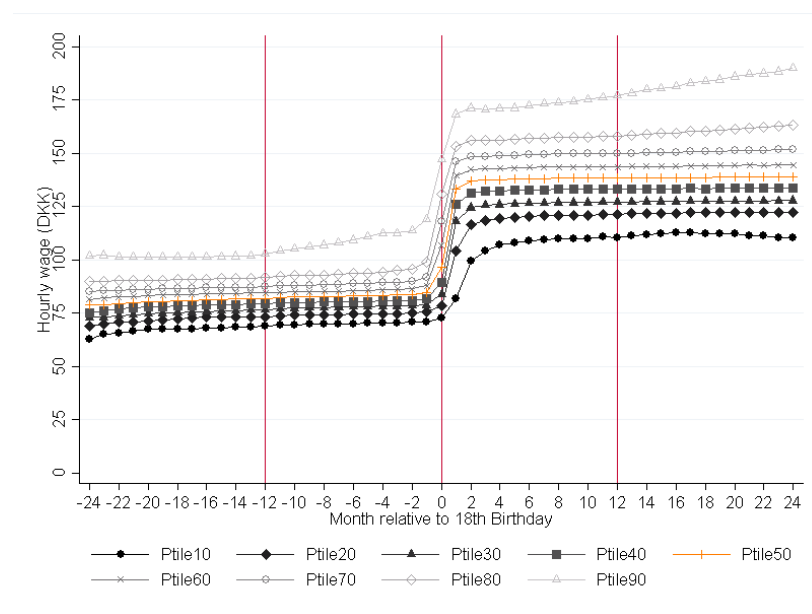


Note: This figure provides simple time series of key variables of interest for our analysis over our sample period. Panel a depicts employment defined as having positive earnings in a month. Panel b depicts average earnings conditional on employment. Panels c and d show the evolution among employed individuals of deciles of hours worked and hourly wage rates. The hourly wage rate is imputed by dividing earnings by hours worked.

Table A.4: Estimates for Supermarkets and Grocery Stores

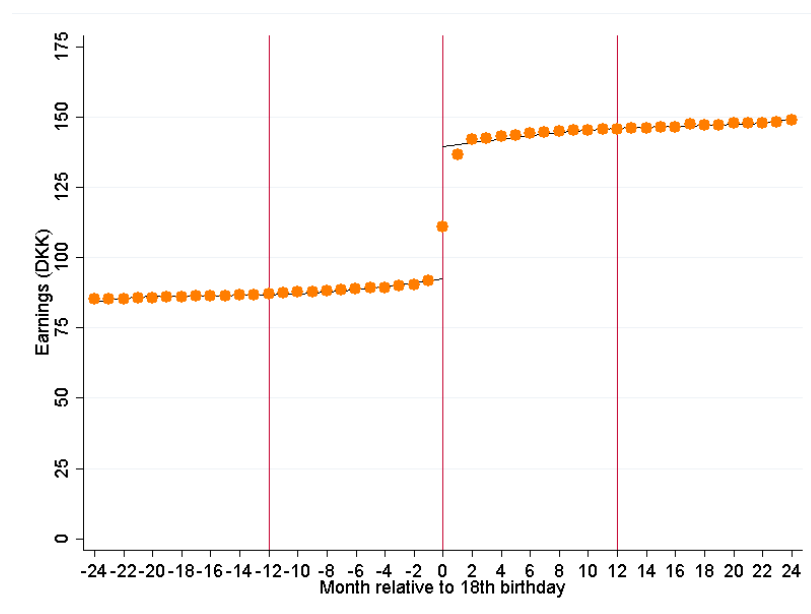
Share of Youth Employment (%)	44.1
Percent Change in Bargaining Agreement Wage (%)	55.2
Percent Change in Imputed Hourly Wage (%)	52.6
[95% Conf. Interval]	[51.2, 54.1]
Percent Change in Employment (%)	-62.2
[95% Conf. Interval]	[-66.0, -58.4]
Elasticity Implied by Bargaining Agreement Wage	-1.13
Elasticity Implied by Imputed Wage	-1.18

Note: This table reports for 2015 the size and the effects of the discrete change in minimum wages occurring at age 18 in supermarkets and grocery stores on average hourly wages, employment and hours worked. The specification for employment and imputed hourly wage is identical to that of Column (1) of Table 2 (see also eqs. (9) and (10)). We report 95 percent confidence intervals, calculated from standard errors clustered by (monthly) birth cohort, in square brackets below these point estimates. We also report the percent increase in minimum wages implied by the pertinent collective bargaining agreement, along with the implied employment elasticity. The percent change in hourly wages obtained here is slightly different from the one in Table 1, because the estimates here are based on an estimation of (9) and the numbers in Table 1 are simple averages by age.

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

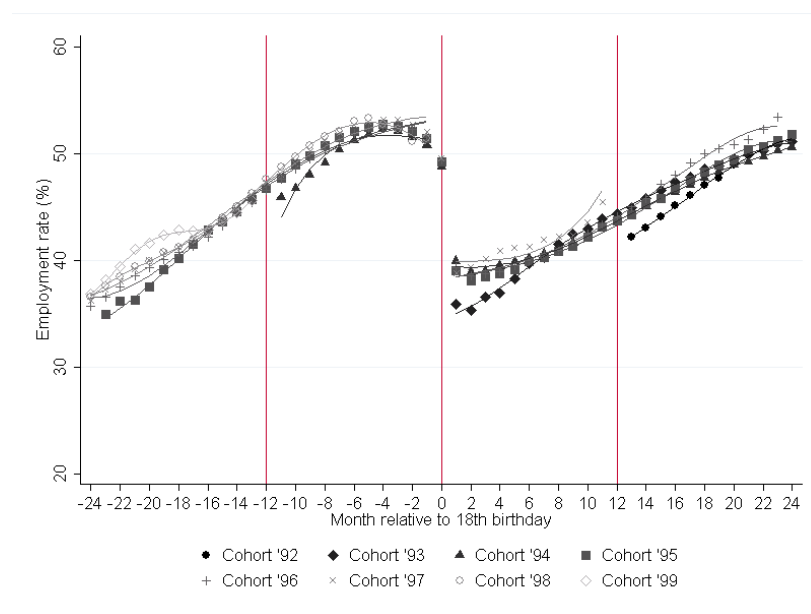
Note: This figure depicts quantiles of imputed hourly wages around workers' 18th birthday. We observe a sharp increase in the distribution of hourly wages at all quantiles.

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



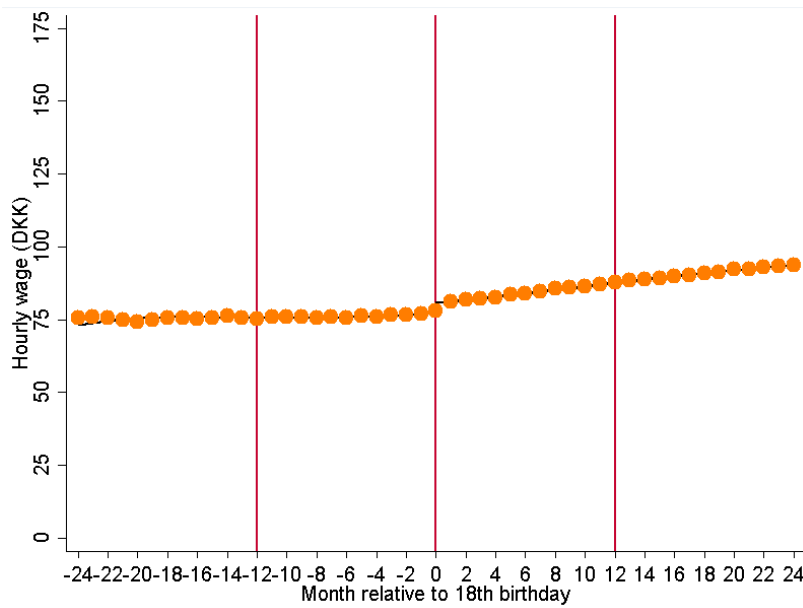
Note: To look for evidence of selection into employment based on wages in a manner that might bias our main results, this figure depicts average imputed hourly wages around the 18th birthday for workers employed continuously from $t = -2$ to $t = 2$ around the 18th birthday. The graph is basically identical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

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



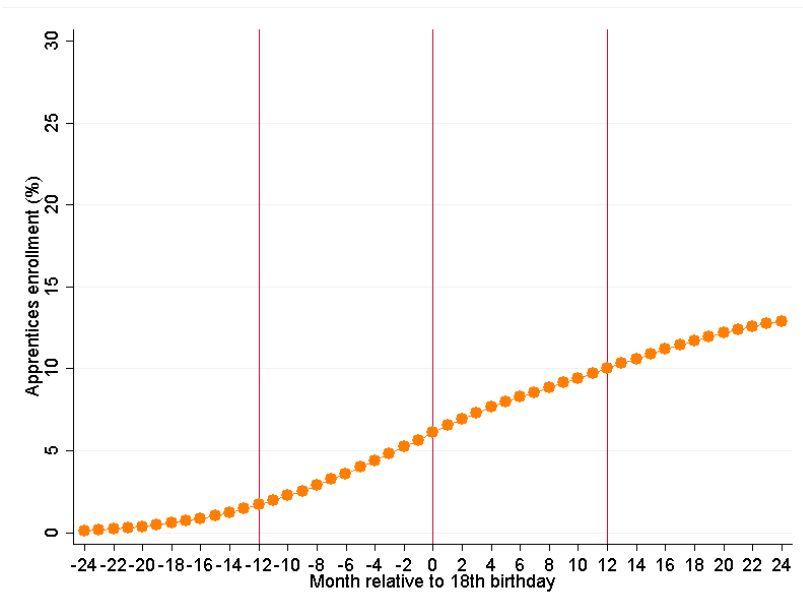
Note: This figure depicts employment around workers' 18th birthday, exactly as in Figure 1b, separately for each annual birth cohort present in our data.

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



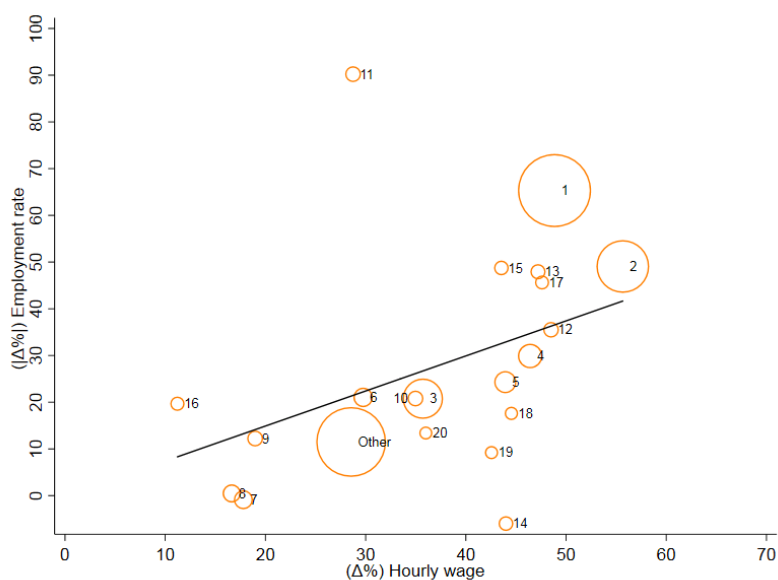
Note: This figure depicts average imputed hourly wages around workers' 18th birthday, exactly as in Figure 1a, but for individuals employed as apprentices, which are exempt from minimum wage rules.

Figure A.6: Employment as an Apprentice



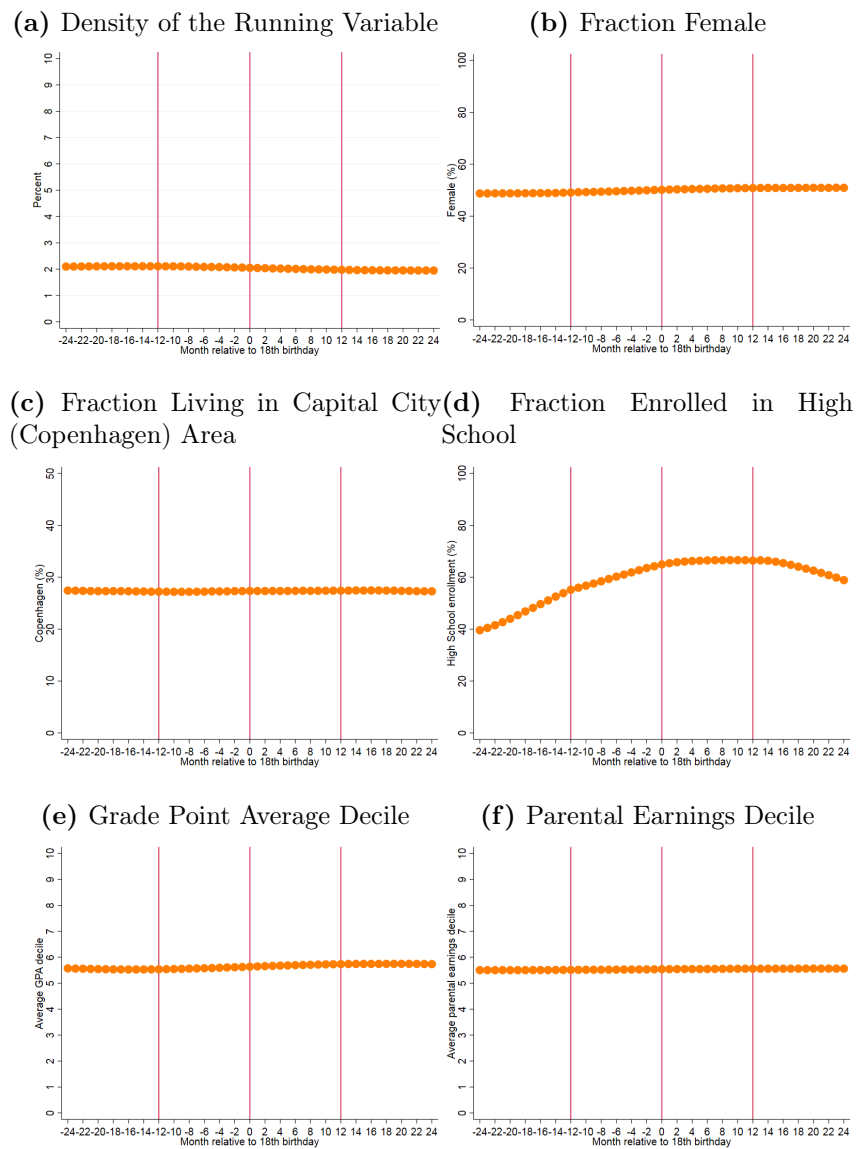
Note: The graph depicts employment in skilled apprenticeships around the 18th birthday. We observe no jump in the probability of employment in an apprenticeship at age 18.

Figure A.7: Percent Changes in Wages and Employment by Sector

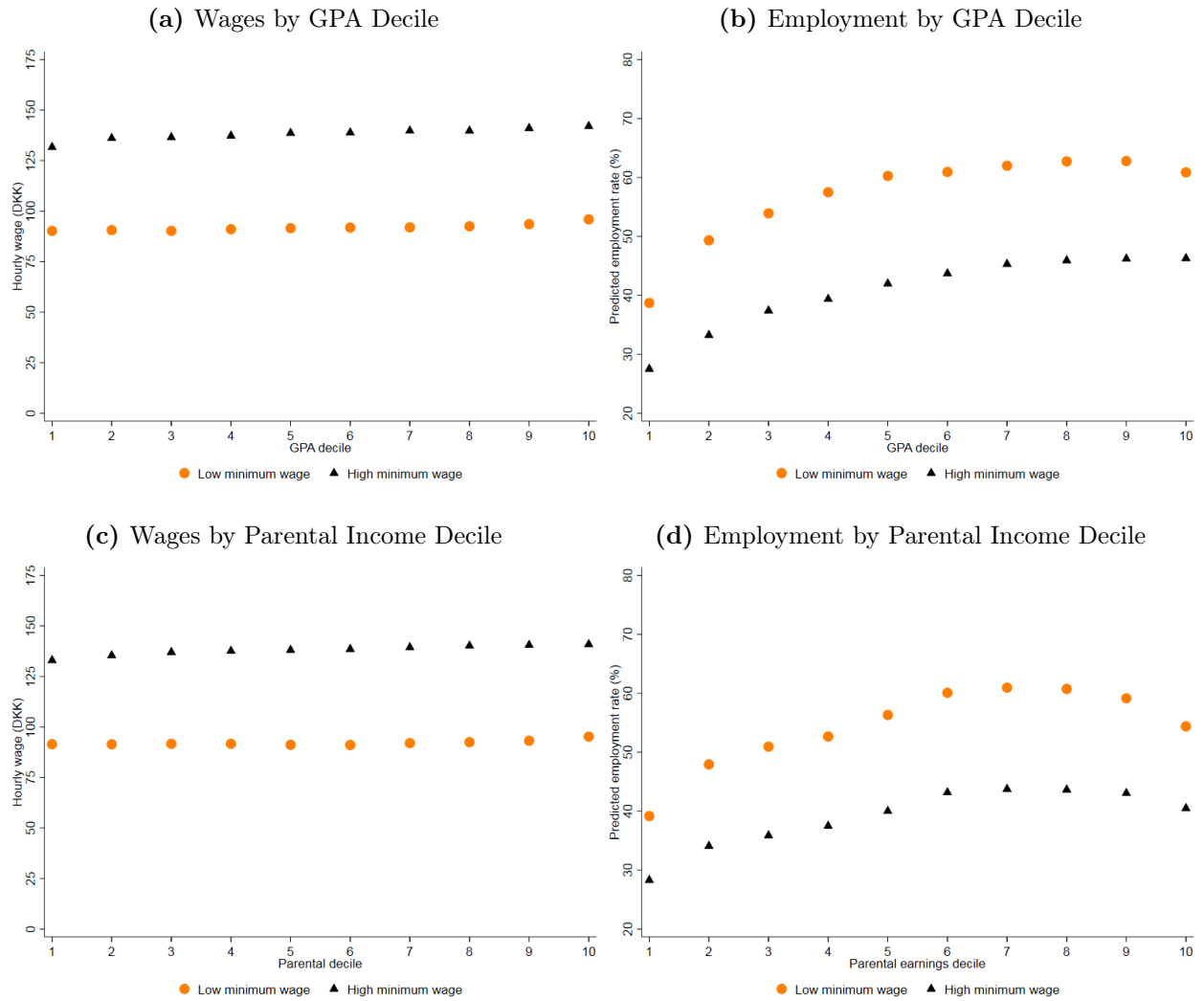


Note: The graph depicts the percent change in wages and employment by sector. We repeat the analysis in the first two panels of Table 2 Column (1) with employment in a specific sector as the outcome variable. We then plot the percent drop in employment on the y-axis and the percent change in hourly wages on the x-axis. The numbers labelling these sectors are the same as those in the first column of Table A.2, and the area of the circle is proportional to youth employment in that sector. The fitted line has a slope of 0.8, which is to be expected as this should match the employment elasticity we report in Table 2. We observe that most sectors follow the fitted line fairly well, though of course not perfectly. The notable outlier sector is cinemas (sector 11), in which, consistent with some anecdotal evidence we encountered, almost all young employees lose their job when they turn 18.

Figure A.8: Additional Tests of RD Validity: McCrary (2008) and Continuity of Observables

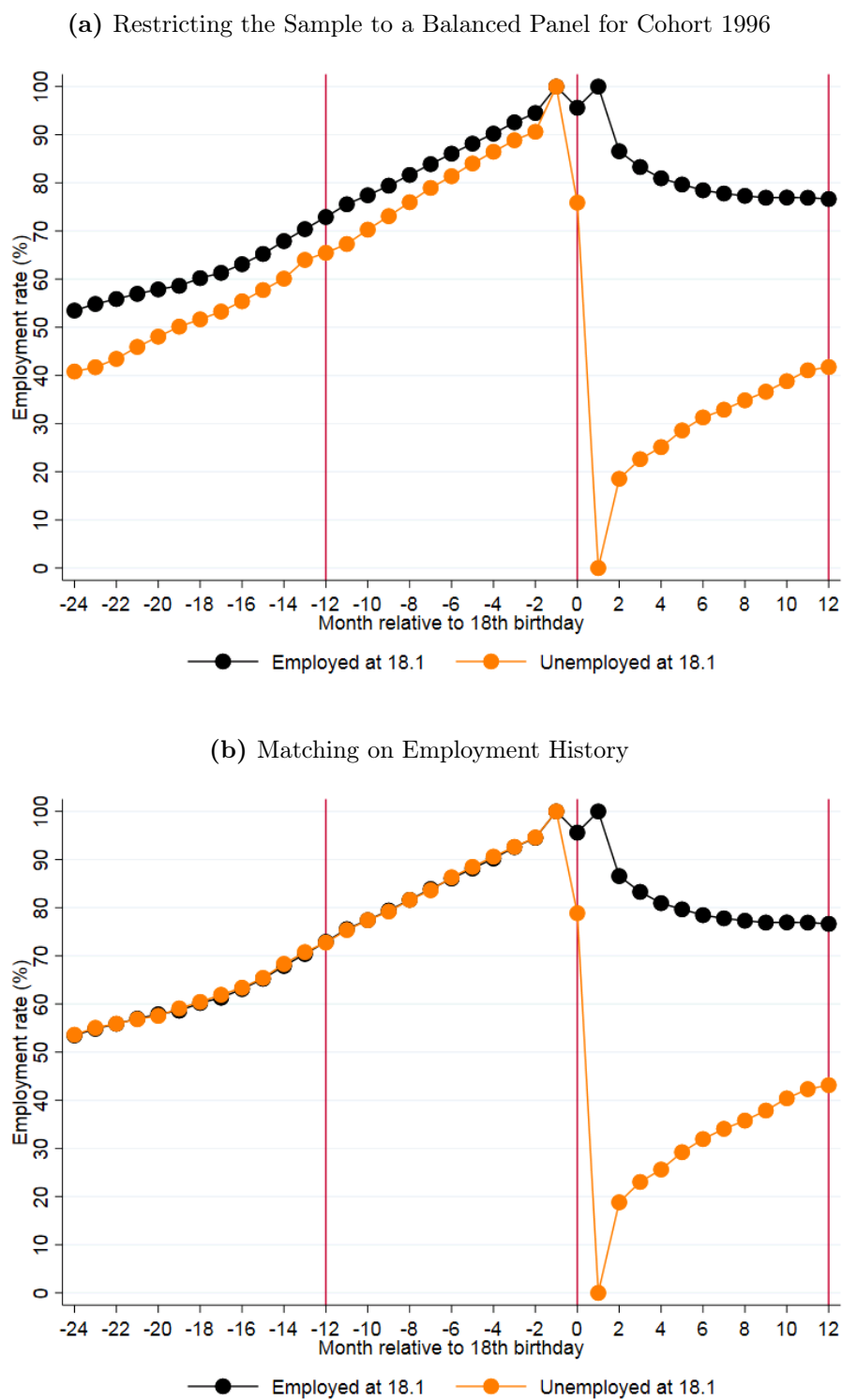


Note: This figure shows that the density of the running variable and the distribution of observable characteristics exhibit no discontinuity, which suggests that sorting on the running variable, month relative to 18th birthday, is not a concern in our setting.

Figure A.9: Differences in Age and Employment Across Groups of Workers at Age 18

Note: This figure complements Figure 5. To construct the first (last) two graphs, we split the sample by grade point average deciles (parental income deciles) and run the baseline regression for each subsample. We then predict the wage rate and the employment rate at age 18 for the low minimum wage applying below 18 and the high minimum age applying above age 18.

Figure A.10: Effect of Job Separations at Age 18 on Future Employment: Accounting for Selection



Note: To carry out the matching analysis based on employment trajectories from age 16 to 17, we restrict the sample to the cohort born in 1996, which we can follow in the full event window from -24 to 12 (balanced sample). The first panel repeats the analysis in Figure 6a and shows that the graph is very similar for this subsample. In the second panel, we match the group becoming unemployed at an age of 18 years and 1 month to the employment group using nearest neighbor propensity score matching with replacement. The propensity score is estimated using a probit regression on the full set of dummy variables of employment in event time -24 to -2. The employment rates after job loss (from $t=1$ to 12) are basically the same in the two graphs suggesting that the effect is not driven by selection.