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1 Introduction

In most OECD countries, the share of labor income going to social security contributions (SSCs) exceeds the share going to income taxes.[1] Since SSCs mostly finance public pensions for an aging population, they are projected to consume an increasing share of national income. Economists have long recognized that SSCs and other payroll taxes might be less distortionary than income taxes because there is often a link between SSCs paid in and pension and other benefits received (Burkhauser and Turner, 1985; Liebman et al., 2009). Furthermore, since the link between SSCs and future benefits is often tenuous, there is potential for substantial efficiency gains from tightening this link (Auerbach and Kotlikoff, 1985; Feldstein and Liebman, 2002; Lindbeck and Persson, 2003).

For this reason, many multinational organizations such as the World Bank (e.g. World Bank, 1994) and IMF have advocated tightening the link between current contributions and future benefits by switching from a Defined Benefit (DB) pension system to a Notional Defined Contribution (NDC) system. Many countries have followed these recommendations, including Italy in 1996, Hungary in 1998, and Poland and Sweden in 1999. However, so far no empirical evidence has established that changing the contribution-benefit link has an impact on labor supply many years before the retirement age. Although it is well established that the large implicit taxes from pension systems hinder older age employment (Gruber and Wise, 1999), there is little evidence on the impact of pensions on labor supply far from the retirement age. The responsiveness of labor supply at younger ages to pension incentives is an open question in part because people seem to not always be fully informed of the details of pension systems (Mitchell, 1988; de Mesa et al., 2006). This lack of information potentially impacts the responses to pension incentives (Chan and Stevens, 2008; Bottazzi et al., 2006; Mastrobuoni, 2011; Liebman and Luttmer, 2015).

This paper provides what is, to the best of our knowledge, the first empirical assessment of how changing the link between SSCs and future benefits affects labor supply far from retirement age. We exploit a Polish pension reform in 1999 that introduced an NDC pension scheme. This new pension system retained the pay-as-you-go nature of the previous DB pension system and kept retirement ages constant but introduced many of the incentives associated with Defined Contribution (DC) systems.[2] As emphasized by the architects of

[1] In 19 out of the 37 OECD countries (including Poland), personal income taxes are less than one third of the total tax wedge (the sum of SSCs and personal income taxes).

[2] In particular, in the NDC system, working-age individuals contribute to the system and fund the benefits of current retirees, while the link between benefits and contributions is altered by introducing a proportionality between each individual's contributions and the benefits they receive. Furthermore, similarly

this policy change, one of the most important elements of the reform was to "introduce a strong link between contributions and benefits" (see page 59 in Chlon et al., 1999).

An advantage of the setting we study is that the Polish reform switched from a DB scheme to an NDC scheme, leaving other features of the pension scheme (such as the retirement age, private pensions and funding status) largely unaffected around the discontinuity, whereas reforms in other countries usually changed several pension features all at once. As a consequence, we can directly assess the incentive effects of future pension benefits on labor supply, holding other features of the pension system constant.

The reform had a considerable impact on work incentives. While work incentives generated by Poland's NDC system differ little throughout the life cycle, the DB system makes earnings at certain ages particularly valuable for pension wealth accrual. A key reason for this difference is that, in the DB system, pension benefits are calculated based on average earnings over a selected subset of "best" years (usually 10) in an individual's earnings history. In the NDC system, benefits are roughly proportional to the (indexed) sum of earnings in all years; thus no prominence is given to earnings in any particular years. This feature of the DB system generates stronger work incentives than the NDC system at points in the lifecycle when wages are high, and weaker incentives when wages are low.

An individual's "best" years depend on that individual's life cycle earnings profile. For those with steeper earnings profiles, pensions in the DB system often depend heavily on earnings near age 50 since these are typically the highest earning years in one's lifetime. For these individuals, reducing labor supply at age 50 has a large impact on the average earnings base that is used to calculate benefits, providing strong labor incentives at that age. Conversely, for individuals with flatter wage profiles, incentives under DB rules diverge less across the lifecycle. We exploit these differences in the change in incentives to identify the effect of changing the link between contributions and future benefits. In particular, we will separately study the effect of the reform in regions with high earnings growth, where individuals have steeper lifecycle earning profiles, and in low earnings growth regions, where individuals' earnings profiles are flatter.

Besides the change in incentives, the new NDC scheme led to a substantial reduction in pension wealth for individuals under the new rule. To isolate the effect of incentive changes from the effect of a reduction in pension wealth, we exploit the fact that the reform caused similar losses in pension wealth in high and low earnings growth regions, while the change in incentives was substantially different across regions. We calculate that the difference in

to a funded DC scheme, the rate of return reflects changes in economic prospects and growth.

the change in the net return to work between high and low growth regions induced by the policy change was 5.2 percent, while the difference in the induced change in pension wealth was only 0.35 percent. Therefore, by comparing responses to the policy in high wage-growth and low wage-growth regions we can capture the effect of changes in incentives net of the effect of changes in pension wealth.

We estimate the employment responses to the pension reform by exploiting the sharp cohort-based discontinuity created by the reform. For men, the reform applied only to those who were born after December 31st, 1948 and so were younger than 50 years old at the time of the policy's implementation.[3] This sharp cohort-based discontinuity implied that two individuals born just a few minutes apart faced radically different pension systems from age 50: the older one would still participate in the traditional DB system while his slightly younger counterpart was ushered into the new NDC system.

Using a regression discontinuity design (RDD) and the full population of tax returns linked to the Polish population registry, we estimate labor supply responses occurring between 2000 and 2002.[4] Our empirical design identifies the effect of the policy change by comparing individuals who were born only a few days apart and face a similar labor market and economic environment but are assigned to different pension schemes.

We find that, as a result of the reform, the employment rate in the high-growth regions, which saw the largest decrease in work incentives, fell by around one percentage point (or two percent) more at ages 51-53 than that in the low-growth regions. Importantly, given our interest in identifying effects at ages distant from typical retirement ages, these responses are observed between 15 and 11 years before these individuals reach the full retirement age.[5]

We use our estimates to assess the implied employment elasticity with respect to the net return to work. Since the difference in the change in the effective net return to work between high and low growth regions induced by the policy change is 5.23 percent, while the difference in the employment increase is 2.29 (s.e. 0.95) percent, the employment elasticity with respect to work incentives is $\frac{2.29}{5.23} = 0.44$ (s.e. 0.18). This elasticity is in the range of those typically estimated in the literature (see Chetty et al. 2013; Blundell et al. 2016 for reviews). The novelty of our paper lies in the fact that we estimate the labor supply response to benefits

[3]Since the introduction of the reform was more gradual for women, we focus throughout the paper on men. Nevertheless, in Table A.3 we report estimates for women. In line with the gradual introduction of the reform, we find qualitatively similar results for women with more muted responses.

[4]Our main analysis ends in 2002 due to an unanticipated and substantial change in the old age unemployment benefit program that differentially impacted labor supply incentives of the 1948 and 1949 cohorts.

[5]On average, men ages 50-53 in Poland expect to start collecting their pension payment for the first time at age 63 according to the 2005-2009 waves of SHARE data.

received many years in the future, whereas most of the literature estimates the labor supply response to the contemporaneous return to work. Our results provide constructive evidence that individuals' labor supply responds in a forward-looking way to incentives in the pension formula, suggesting that tightening the link between contributions and benefits has the potential to alleviate labor supply distortions caused by SSCs.

To provide a benchmark against which to compare our forward-looking elasticity, we estimate the labor supply response to an unanticipated radical reform in 2004 that impacted *contemporaneous* work incentives for the same population of workers. The reform changed eligibility for a generous unemployment benefit available to individuals older than 55 years who were laid off from their jobs. This policy change affected the cohorts born in August 1949 and later but not the cohorts born before then. We estimate the labor supply response to the change in access to generous unemployment benefits and find an employment elasticity of 0.58 (s.e. 0.04). This is only slightly larger than our elasticity estimated in response to the pension reform. This suggests that labor supply is only slightly less responsive to changes in discounted future pension benefits than to (net of tax and benefit) earnings. The old age benefit reform changed incentives similarly in high- and low-growth regions. We also find that estimated labor supply responses are similar across regions, suggesting that the populations in high- and low-growth regions respond similarly to contemporaneous incentives. This implies that the differential response to the pension reform in high- and low-growth regions likely reflects the differential change in incentives and not some fundamental difference across the two regions.[6]

We show that our results are robust to alternative ways of implementing the regression discontinuity design, alternative assumptions on calculating the change in incentives, and finer geographic disaggregation. Furthermore, the considerable differences in employment between the 1948 and 1949 cohorts are not found between "placebo" cohorts where there was no change in the policy (those born in 1946 versus 1947, 1947 versus 1948, and so on).

In the final part of the paper, we estimate a lifecycle model to evaluate the impact of pension reforms on labor supply over the whole lifecycle. We estimate the structural parameters of this lifeycle model by matching the regression discontinuity estimates from the reform. We use the estimated model to compare the effects on labor supply, at all ages, of a move from the DB system to a NDC system. Adjusting the NDC system so that

[6]Besides exploring the differential responses across regions to the old age unemployment benefit reform, we also studied responses to a large tax cut instituted in 2009 and studied in detail by Zawisza (2022). We find no statistically or economically significant differences in responses to the tax cut between the high- and low-growth regions. This again supports our key identifying assumption that labor supply elasticities are the same across two types of regions. Results are available for request.

government revenue under both systems is equivalent, we find that altering the age structure of incentives as a result of the switch to the NDC system causes overall labor supply across the lifecycle to fall by two months. This net fall is explained by the fact that the negative labor supply effects at age 50 are only partially offset by positive labor supply effects from earlier in the lifecycle in the NDC system. Contributing to this is the fact that labor supply is less responsive to incentives for those in their 30s than for those at older ages, and so the improved labor supply incentives at earlier ages yield less additional labor supply than that which is lost due to reduced work incentives later in the lifecycle. This highlights that the link between SSCs and future benefits should be strongest at ages when labor supply is most responsive.

Our paper relates to several strands of the literature. A number of papers have examined the savings responses to changes in pension wealth, exploiting differences across cohorts, including Attanasio and Brugiavini (2003) for Italy, Attanasio and Rohwedder (2003) for the UK, and Lachowska and Myck (2018) for the 1999 Polish pension reform which we study. Instead, our paper focuses on labor supply and not savings decisions. Additionally, instead of relying on survey data sample sizes and/or a gradual implementation of a pension reform, we can combine population-level administrative data with a sharp discontinuity in changes in incentives. This allows us to avoid identifying responses by comparing the behavior of cohorts which were distant from each other.

A large literature examines labor supply responses to retirement incentives. That literature, however, focuses almost exclusively on labor supply responses close to the retirement age: see Feldstein and Liebman (2002); Coile (2015); Blundell et al. (2016) for reviews and Fetter and Lockwood (2018); Gelber et al. (2018); Manoli and Weber (2016) for examples. For instance, Liebman et al. (2009) studies the effect of SSC-pension benefit linkage on retirement decisions using the Health and Retirement Study, where the average respondent is almost 60 years old. In contrast, our paper studies the employment responses of individuals who are far from the retirement age, and so our results better reflect how incentives built into the pension system can distort labor supply throughout the lifecycle. A recent working paper by Bovini (2019) finds evidence of forward-looking labor supply responses to a complex pension reform in Italy that impacted accrual rates, pension wealth, and the early retirement age, but does not disentangle the relative importance of each nor does it separate the roles of wealth and incentive effects. There is also some evidence that the pension eligibility age affects labor supply prior to the eligibility age (Jean-Olivier et al. (2010); Carta and De Philippis (2019)). Dean et al. (2020) find that self-employed workers increase

their reported earnings in years that impact their pension base. Bozio et al. (2019) provide evidence that the incidence of SSCs differs from that of taxes whenever there is a tight link between SSC contributions and benefits.

This paper makes two key contributions to this literature. First, the paper estimates the impact of the pension formula on labor supply far from the retirement age by exploiting a radical pension reform. As a result, instead of indirectly inferring the potential impact of switching from a defined benefit to a defined contribution type system, we provide the first direct evidence on this matter. Second, this paper is the first that separates incentive effects from other features of the pension scheme (e.g. wealth effects) when estimating the labor supply responses to future pension benefits. As a result, our estimates can be used to study how reforms of pension calculations will alter behavior throughout the life cycle.

Our paper is related to the literature studying the impact of taxes on labor supply. Most of the literature does not account for how social security contributions impact future benefits, and it thus treats social security contributions as just another tax creating the same type of tax wedge between market work and leisure as any other tax (see e.g. Blundell et al., 1998; Kleven, 2014; Ohanian et al., 2008). Another large labor supply literature goes to the opposite extreme and assumes that individuals fully internalize how their contributions impact future benefits. This includes studies using dynamic structural models of labor supply and retirement (see e.g. French, 2005; van der Klaauw and Wolpin, 2008; O'Dea, 2019; Borella et al., 2019) and an evolving literature on optimal tax policies in dynamic contexts (see e.g. Huggett and Parra, 2010; Golosov et al., 2016; Jones and Li, 2020).

The remainder of the paper is structured as follows. Section 2 presents a simple framework that can be used to measure changes in incentives. Section 3 presents the details of the 1999 reform and introduces the data we use. Section 4 assesses the changes in the contribution-benefit link which arose as a result of the reform. Section E.4 presents the RDD empirical strategy. Section 6 presents our estimation results. Section 7 presents a dynamic model which rationalizes our RDD results in the context of a lifecycle model and simulates the effects of the Polish reform over the entire lifecycle. Finally, Section 8 concludes.

2 The Net Return to Work

Social Security Contributions (SSCs) and other payroll taxes differ from standard income taxes because SSC payments are often linked to future benefits (Burkhauser and Turner, 1985). This linkage, if recognized by the individual, could impact labor supply, mitigating the resultant distortions of payroll taxes.

This section describes a framework for evaluating the labor supply response to changes in the SSC benefit link caused by the NDC reform. To do this, we define the net return to work (relative to staying out of the labor force on out-of-work benefits) under pension scheme $k = \{DB, NDC\}$:

$$nrw_{it}^{k} = (1 - \tau(\tau^{pi}, \tau^{ss})) \cdot w_{it} - u_{it} + E_t(PV_{it}^{\text{Employed}_t,k} - PV_{it}^{\text{Not employed}_t,k}). \tag{1}$$

where w_{it} is individual i's wage at age t. The net return to work includes three components. The first component is the after-tax earnings $(1 - \tau(\tau^{pi}, \tau^{ss})) \cdot w_{it}$, which is a function of the personal income tax rate τ^{pi} and the Social Security tax rate τ^{ss}. The second component is u_{it}, which represents the welfare and unemployment benefits that are lost when the individual works (see Online Appendix C for further details on these). The third component is the increment to the present discounted value of expected pension benefits from work at age t for each pension scheme k. This last term, reflecting the contribution-pension benefit link, is calculated using $PV_{it}^{\text{Employed}_t,k}$, the present value of pension wealth if the individual works in period t given the current wage and entire earnings history, holding future labor supply constant, and $PV_{it}^{\text{Not employed}_t,k}$, the value if the individual does not work in period t, again holding future labor supply constant. The difference between the two is the increment to pension wealth that occurs as a result of working in period t. In the next section, we discuss the two pension schemes in detail and illustrate how the reform changed the pension contribution-benefit link. Throughout the text, nrw_{it}^{k} denotes the net return to work each individual faces, while nrw_{t}^{k} is the sample average net return to work at age t.

The reform we study switched the pension system from a Defined Benefit to a Defined Contribution scheme, so it changed the link between today's contributions and future benefits, and thus the net return to work. We can use this reform to calculate an employment elasticity with respect to the net return to work:

$$\eta \;=\; \frac{(P_t^{NDC} - P_t^{DB})/P_t^{DB}}{\Delta nrw_t / nrw_t^{DB}} \tag{2}$$

where $P_t^{NDC} - P_t^{DB}$ represents the change in the employment rate at age t which arises from changing the contribution-benefit link, and Δnrw_t represents the change in the net return to work from switching from DB to NDC.

Our definition of the employment elasticity is closely related to the standard formula. The main difference here is that the variation in the net return to work is coming from the change in the pension contribution-benefit link rather than from the change in the tax rate,

which was held constant. Because there was no change in tax rates from the reform, the change in net return to work is: $\Delta nrw_t = (E_t[\Delta PV_{it}^{NDC}] - E_t[\Delta PV_{it}^{DB}])$, and so the percent change in the net return to work coming from the pension reform is:

$$\frac{\Delta nrw_t}{nrw_t^{DB}} = \frac{(E_t[\Delta PV_{it}^{NDC}] - E_t[\Delta PV_{it}^{DB}])}{E_t[(1-\tau(\tau^{pi},\tau^{ss}))\cdot w_{it} - u_{it}] + E_t[\Delta PV_{it}^{DB}]} \tag{3}$$

where the expectations are taken over all individuals. We use equation (3) to assess the effect of the reform on incentives to work. Central to this formula is the change in (expected) present value coming from working at age t, $E_t(\Delta PV_{it}^k)$, in pension scheme k. The next section describes the new and old pension schemes and the calculation of the change in the present value of pension benefits.

3 Institutional setup and data

3.1 Institutional setup

The 1999 Polish pension reform. The 1999 pension reform in Poland introduced NDC pensions for those born after 31st December 1948. Those born in 1948 or earlier remained in the DB scheme. In the new system, a virtual account was opened for every individual and a record of all subsequent contributions to this account was kept by the Polish Social Security Administration, named ZUS.[7] These contributions predominantly fund current pension expenditures on a pay-as-you-go basis, as in the previous scheme. As a result, the new system can be described as a *notional* defined contribution system.[8]

Importantly for our empirical strategy, the date-of-birth discontinuity is sharp only for men. For women, the new system was introduced gradually. For instance, only 20% of the pension for women born in 1949 would come from the notional DC account, with gradually increasing amounts for each subsequent cohort. Only cohorts of women born in 1954 or after get the entirety of their benefit under the new rules. Due to this gradual introduction of the NDC system for women, we focus on men, for whom 100% of the pension for those born in

[7] Polish name: Zaklad Ubezpieczen Spolecznych.

[8] The reform also gave the option to accumulate some of the contributions in capital funds managed by private pension funds. Those born between 1949 and 1969 could choose to either accumulate all of their contributions in the state-managed notional account or 38% in a private fund and 62% in the notional account. The default option was opting out from the private fund, and the government suggested that men (women) who were older than 45 (40) years at the time of the reform should not take the risk of opting in. As a result, 93% of the cohort born in 1948 chose to accumulate all their contributions in the state-managed notional account (Leifels et al. (2010)). In the paper, we assume that all workers are fully enrolled in the notional account.

1949 would come from the NDC account.

DB Benefit formulae. The way in which past contributions translate into current pension benefits differs substantially between the DB and NDC systems. In the DB system, pensions are a function of two key variables: (1) the number of years in which an individual made contributions into the retirement system and (2) the individual's earnings relative to the economy-wide average in their best earnings years. At age 65, the monthly after-tax benefit for individual i is calculated according to the formula

$$b_{i65} = (1-\tau^{pi})\Big(\bar{y}_{65}(1-\tau^{ss})\Big)\Big(0.24 + \ 0.013 \cdot c_i \cdot aime_i + \ 0.007 \cdot n_i \cdot aime_i\Big), \qquad (4)$$

where $\Big(\bar{y}_{65}(1-\tau^{ss})\Big)$ is the average monthly salary for everyone in the economy in the year when the beneficiary turns 65 (net of the Social Security tax rate τ^{ss}), c_i is the number of contributory years on retirement, and n_i is the number of "non-contributory years". Non-contributory years are those in which the individual was not contributing for reasons such as being on disability benefit, in higher education, on maternity leave or on sickness leave. Contributory years are those in which the individual was working or receiving unemployment insurance benefits. The variable $aime_i = \frac{1}{\#\text{best}_i}\sum_{j\in\text{best}_i}\frac{y_{ij}}{\bar{y}_j}$ is "Average Indexed Monthly Earnings". To calculate this, we first take the ratio of individual i's annual earnings y_{ij} relative to the economy's average annual earnings $\bar{y}_j$ of the employed, for each year j. We then average this ratio over individual i's best years, best$_i$. The best years period is chosen by the individual as one of two periods, the best 10 consecutive years out of the last 20 prior to the official retirement age, or the 20 best earnings years over their working lives. Because individual earnings are divided by average economy-wide earnings when constructing $aime_i$, the DB formula contributions in the "best" years are implicitly indexed by average earnings.

NDC Benefit formulae. Under the new NDC system, the formula for pension benefits creates a much more direct link between past contributions and the monthly pension amount b_{65} at the retirement age of 65:

$$b_{i65} = (1-\tau^{pi})A_{i65}^{NDC}/(E[T|t=65]) \qquad (5)$$

where A_{i65}^{NDC} is the value accumulated in the notional account at 65, and $E[T|t=65]$ is remaining life expectancy at the retirement age. In the NDC system, capital in the notional account is accrued according to the formula:

$$A_{it+1}^{NDC} = A_{it}^{NDC} \cdot (1+r^{NDC}) + \tau^{ss} \cdot y_{it+1} \qquad (6)$$

where $(1 + r^{NDC})$ is the real uprating factor on accumulated capital and $\tau^{ss} \cdot y_{it+1}$ is the contribution to the notional account.[9] The nominal uprating factor at the time of the reform was CPI inflation plus 0.75 times the growth in real aggregate earnings in the economy.[10]

Under the old DB system, the impact of contributions on pension benefits depends critically on whether an individual is in their best earnings years relative to others in the economy before retirement. In the NDC system, on the other hand, contributions from any year feed directly into the accumulated amount A_{it}^{NDC} in a given period.

Starting capital in the NDC system. Since the reform took effect on 1st January 1999 and affected individuals born in 1949 onward, many of those affected had made significant contributions under the old system. As compensation for these contributions, such individuals were given "starting capital" in their notional accounts, calculated based on their contributions history.[11]

Contribution rates. The social security contribution rate to the pension system τ^{ss} remained the same between the DB and the NDC system, at 0.1952 of the earnings bill, up to a cap of 2.5 times the average earnings in the economy. For those on employment contracts, half of these contributions were paid by the employer, and half were paid by the employee. The self-employed paid a lump sum of contributions equivalent to those paid by

[9]Here the amount τ^{ss} is sum of the "worker" and "employer" social security contributions, which is 0.1952. This is slightly different from the Social Security tax rate of 0.1871 described in equation (1), which includes additional taxes to pay for disability and sickness benefits but does not include employer contributions. For simplicity, we avoid using separate notation here and in equation (1) for τ^{ss}, but when we calculate the net return to work we take into account that these two rates are not exactly the same.

[10]Specifically, in nominal terms:

$$1 + r^{NDC,nom} = \pi_{t-1} + 0.75 \cdot \left(\frac{WageBill_{t-1}}{WageBill_{t-2}} - \pi_{t-1} \right) \tag{7}$$

where π_{t-1} is one plus the rate of increase of the CPI in the year preceding indexation and $WageBill_{t-1} = \bar{y}_{t-1} \cdot e_{t-1} \cdot Pop_{t-1}$ is the total revenue collected by the social security administration in the year preceding uprating. We convert to real terms and take sample means. Unlike the DB formula, therefore, a fall in the total level of contributions coming from a fall in the number of workers in the economy would result in lower indexation of past contributions, even if average earnings in the economy remained constant. In the Appendix, we document that for the years 2000-2013, which are the focus of this study, the uprating factors were similar in both systems.

[11]The formula used was very similar to the DB pension formula:

$$b_{i50}^{start} = 0.24 \cdot \bar{y}_{50} \cdot p_{i50} + \ 0.013 \cdot c_{i50} \cdot aime_{i50} \cdot \bar{y}_{50} + \ 0.007 \cdot n_{i50} \cdot aime_{i50} \cdot \bar{y}_{50} \tag{8}$$

where $c_{i50}, n_{i50}, aime_{i50}$, are respectively the number of contributory years, non-contributory years, and Average Indexed Monthly Earnings at the time of the reform (which was age 50 for the cohort we study), and p_{i50} had the role of increasing starting capital with a weighted average of age and the total number of contributory and non-contributory years at the time of the reform: $p_{i50} = \sqrt{\frac{50-18}{65-18} \cdot \frac{n_{i50}+c_{i50}}{25}}$. Starting capital was then calculated as $A_{i50}^{NDC} = b_{i50}^{start} \times E[T|t = 62]$, where $E[T|t = 62]$ is remaining life-span at 62.

an employee earning approximately the minimum wage.

Information. The reform was widely discussed and highly publicized at the time in Poland. Furthermore, each participant in the new NDC system received an annual statement that included information on their capital account balance and an estimate of the monthly pension benefit under different assumptions about the retirement age (Chlon et al., 1999). Appendix Figure A.1 shows an example of this annual statement.

Exceptions. While most men born on or after 1st January 1949 faced the new NDC system, there were some important exceptions who remained in the DB system. For instance, those who worked in occupations outside of the main state social security system, such as farmers, members of the military, police, judges, teachers, and railway workers, were excluded. Also excluded were those in "special occupations", which included physically demanding jobs in sectors such as mining, energy, metallurgy, construction, logging, transport, the health sector, glass production, artists, and journalists. We estimate that 12% of the population was employed in agriculture and another 5% was employed in the other excluded or special occupations.[12] Although these exemptions could bias our estimated labor supply responses towards zero, we show below that accounting for this has only a small effect.

Minimum pension. For the cohorts we study here, all men were eligible for the minimum pension if they made contributions for at least 25 years and their lifetime earnings were very low. The level of this pension, which is the same for those in both the old and the new system, is set by statute every year and increases by at least the CPI inflation rate. The minimum pension, however, is only binding for a few: fewer than 3% of male pensioners received it in 2019.[13] Thus, the realized pension benefit would be the greater of the minimum and the benefits described in equations (4) and (5) for the DB and NDC schemes, respectively.

Other relevant institutional features. Individuals were eligible for old age unemployment from age 60 if the termination of employment was caused by the employer.[14] In 2002, the age threshold was reduced to age 55, which was in turn repealed in August 2004, at which point it went up again to age 60. As a result, individuals who were born in 1948 and were 55 years old in 2004 were eligible for the old age unemployment benefit, but individuals who were

[12]Unfortunately, we are unable to observe whether someone belonged to an excluded sector or special occupation in our administrative data. We calculate the share of the labor force in special occupations from the Household Budget Survey, and the share of farmers from the Labor Force Survey. Our administrative data, described below, excludes those in agriculture. Thus, our estimated labor supply responses are only for the non-agricultural sector.

[13]In line with that, we find in our simulations that the minimum pension applies to only a very small fraction of men.

[14]The old age unemployment benefit was called "swiadczenie przedemerytalne" in Polish. Those who received were eligible to get the unemployment benefit until they reached the normal retirement age.

born in 1949 and who only reached age 55 after August 2004 were not eligible anymore. This created a large discontinuity in eligibility for the old age unemployment benefit between the 1948 and 1949 cohorts from 2004 onward. Moreover, in 2003, the 1948 cohort was eligible for the old age unemployment benefit because of having reached age 55, while the 1949 cohort was not. To ensure that our estimates do not capture the differential effect of the old age unemployment benefit on the two cohorts, we focus on the years 2000-2002 in our main analysis.

3.2 Data

Our data consists of the entire population of anonymized income tax records filed in Poland. All non-agricultural workers are required to file taxes if their annual income (including pension benefits) is above a certain threshold (2,296zł in 2000, which is equivalent to US $547). These reported earnings are used to calculate SSCs and pension benefits. Agricultural income is not included in the tax data. However, workers in agriculture belong to a separate pension fund and are unaffected by the pension reform. Our employment responses are therefore estimated for the non-agricultural workers impacted by the reform.

We also have access to the population register in Poland, which we can merge into the administrative tax data. This allows us to identify, for each member of the population, whether he/she filed a tax return. Our measure of employment is an indicator for whether the individual had employment or self-employment income exceeding the earning threshold required to file a tax return. Since self-employed individuals might simply respond to the policy change by changing their reporting behavior, we also report estimates separately for the employed and self-employed.

We use data for the years 2000-2002 for estimating the employment response to the switch from a DB to an NDC scheme. We end the analysis in 2002 to make sure that we do not pick up the effect of changes in eligibility for old age unemployment benefits. When we directly study the impact of the old age unemployment benefit, we use the data from 2005-2007. Finally, we exploit the full data range 2000-2013 when we estimate the earnings process, which we use for measuring incentives generated by the different pension systems across the lifecycle (we describe this procedure in the next section). Our administrative data covers information on date of birth, gender, marital status, residence,[15] as well as reported income from employment and self-employment. For the baseline regression discontinuity analysis, we have 1,363,922 individual-year observations between 2000 and 2002.

[15] If an individual did not file taxes in a given year, we have access to the region they were most recently formally registered in, as well as the previous region in which they filed taxes.

In Appendix Table B.5 we show that the employment rate calculated in our administrative data lines up well with the employment rate calculated using two representative household surveys: the Polish Household Budget Survey (HBS) and the Polish Labor Force Survey (LFS). The fraction of individuals in non-agricultural employment for the 1948 and 1949 cohorts is 48% in the LFS (based on 9,485 observations), which is very similar to our estimate in the administrative data (49% based on 1,669,539 observations). The estimated total employment rate (including agriculture workers) for the 1949 and 1950 cohorts is 60% in the LFS and 61% in the HBS.[16] Problems of underreporting do not appear to be of serious concern in our administrative data.

4 The Effect of the Reform on the Net Return to Work

In this section, we describe how we calculate the net return to work in the DB and NDC pension systems. In the DB system, work incentives depend heavily on whether an individual was experiencing one of their best earnings years in the period preceding retirement. Conversely, in the NDC system, best years do not play such a prominent role.

To illustrate this, consider the change in the expected replacement rate at age of an individual in their early 50s who is deciding whether or not to work. Because the DB pension benefit formula uses income in the best 10 consecutive years, the increase in the replacement rate from working is very small in all but the 10 highest wage years. However, in those best 10 years, the increase in the replacement rate is potentially very large if wages in these 10 best years are much higher than at other ages. On the other hand, an individual in the NDC system will experience a similar change in the replacement rate, irrespective of age. This highlights a key difference between DB and NDC schemes: both schemes provide work incentives, but at different ages. The DB scheme provides strong incentives to work in a narrow set of ages whereas the NDC scheme provides weaker incentives but at all ages.

To calculate the reform's impact on the net return to work for the full population, we calculate the increase in the present discounted value of pension benefits from working at each age following the existing literature (e.g., Attanasio and Rohwedder, 2003):

[16] The employment rate between age 50-54 in Poland is around 65%, which is lower than the OECD average at 84% (source: OECD Dataset: LFS - Sex and Age composition). The lower employment rate is partially explained by the fact that the old-age unemployment to population ratio is a bit higher in Poland (12%) than in other OECD countries (4%) in this period. Furthermore, the participation rate is around 71%, which is lower than the OECD average (87%). The lower participation rate is due to the fact that some workers with a long working history in special occupations (such as metal workers or teachers) can retire already in that age range. These workers are unaffected by the reform and so our main empirical results are relevant for workers not employed in these special occupations.

- We calculate retirement benefits according to the legislation in effect in the year of observation. We take into account any reforms and future uprating rules that have been legislated up to the time of observation. We assume that people expect the current legislation to persist.
- We assume that, when forming their expectations, people take their current residence as given and fixed.
- We account for longevity uncertainty using year, age, and gender specific survival probabilities for the cohort aged 50 in 1999. We assume age and gender specific mortality do not change after 2016. The maximum attainable age is fixed at $T_{death} = 100$.
- We assume that individuals expect to retire at the male normal retirement age of 65.
- We assume that aggregate wage growth, interest rates, and benefit uprating factors are constant over time. We estimate these by taking averages over the post-reform period.
- We extend the framework in Attanasio and Rohwedder (2003) by also allowing for wage and unemployment risk. We estimate both from the data.

Making these assumptions, the change in present discounted value of benefits under each system k is:

$$\begin{aligned} E_t(\Delta PV_{it}^k) &= \left(\frac{1}{1+r}\right)^{65-t} \sum_{s=65}^{T_{death}} S_{s|t} \left(\frac{1}{1+r}\right)^{s-65} (b_{is}^{\text{Employed}_t,k} - b_{is}^{\text{Not employed}_t,k}) \qquad (9) \\ &= \left(\frac{1}{1+r}\right)^{65-t} \sum_{s=65}^{T_{death}} S_{s|t} \left(\frac{1+r^{index}}{1+r}\right)^{s-65} (b_{i65}^{\text{Employed}_t,k} - b_{i65}^{\text{Not employed}_t,k}), \end{aligned}$$

where $S_{s|t}$ is the probability of being alive at age s conditional on being alive at age t, $1+r$ is the risk free interest rate (and therefore $\left(\frac{1}{1+r}\right)^{s-t}$ discounts benefits earned at time s to time t), $1+r^{index}$ is the yearly indexation of pension benefits after age 65, and $(b_{i65}^{\text{Employed}_t,k} - b_{i65}^{\text{Not employed}_t,k})$ is the difference in age 65 pension benefits between working and not working at age t under the pension scheme k.

The change in (expected) present value of pension benefits has the following components. First, working at age t will increase age 65 pension benefits by $b_{i65}^{\text{Employed}_t,k} - b_{i65}^{\text{Not employed}_t,k}$, which depends on the whole lifecycle path of earnings and the pension formula. Second, once calculated, pensions are indexed by $1+r^{index}$ each year after age 65. Third, pension benefits are only received if still alive. As a result, the present discounted value depends on the probability of being alive at age s conditional on being alive at age t. Finally, all these future payouts are discounted to the present using the risk free interest rate $1+r$.

In the net present formula above, we observe the indexation factor ($r^{index} = 0.0116$), interest rate ($r = 0.0288$), the NDC uprating factor ($r^{NDC} = 0.0381$) and survival probabilities ($S_{s,t}$) in the data; see Online Appendix C for details. Since the pension benefit at age 65, $b_{i65}^{\text{Employed}_t,k}$, depends on earnings throughout the lifecycle, we simulate earnings profiles for individuals around the discontinuity (aged 49-50 on 1st January 1999). In the simulations, we deviate from the existing literature that assumes deterministic earnings profiles (see e.g. Attanasio and Brugiavini (2003), Attanasio and Rohwedder (2003), and Lachowska and Myck (2018)). Instead, we take into account wage and unemployment risks. These risks are important for the DB system as they affect which best years enter the benefit formula.

We estimate the earnings process in the following way. In the first step, we estimate the process for annual wages, w_{it}. In the second step, we estimate unemployment risk. Earnings, y_{it}, are equal to the offered wage w_{it} if working (P_{it}=1) and 0 if not working ($P_{it} = 0$). We assume wages are the sum of a deterministic and a stochastic component:

$$\log w_{it} = \mathbf{x}_{it}^T \kappa + \eta_{it} + \omega_{it} \tag{10}$$

where $\mathbf{x}_{it}$ consists of a fourth order polynomial in age, a linear time trend, an indicator for high growth region, and high growth region interacted with a fourth order polynomial in age and a time trend, and $\eta_{it} + \omega_{it}$ is the stochastic component that we describe below.[17]

Since pension benefits and the change in incentives to work depends on the shape of individuals' lifecycle profiles, we also exploit that individuals' lifecycle profiles vary across locations. In our benchmark specification, we divide the data into regions with below- and above-median wage growth in the years 2000-2013. The time trend and age polynomial interacted with region (controlling for a time trend and age polynomial) in the wage equation (10) capture geographic variation in wage growth over time. This creates variation in the timing of individuals' best earnings years which is important in the DB formula but not the NDC formula. Below, we show our results are robust to finer levels of regional disaggregation. We also confirm that the time trend and age polynomial parameters are robust to alternative methods of estimating the wage equation, including controlling for individual person-effects.

Appendix Table C.4 reports estimates of wage parameters in equation (10). For the cohorts we study, these estimates imply annual real wages grow 0.75% faster in high-growth

[17] We control for time but not cohort effects in the regression above. As we noted previously, pension benefits under the DB rules are calculated using individual earnings relative to other members of the economy at a point in time. By including time and age effects in our specification, we measure wages of an individual at a point in time relative to other members of the economy. If we were controlling for cohort but not time effects, we would compare wages at different points in an individual's life.

than low-growth regions. The implied difference in growth rates is robust to alternative specifications such as controlling for a full set of time dummies or individual person-effects (the latter is shown in Columns (3) and (4) of Table C.4).[18]

The stochastic components of wages is an AR(1) process η_{it} with an MA(1) innovation:

$$\eta_{it} = \rho\eta_{i,t-1} + \varepsilon_{it}, \quad \varepsilon_{it} \sim N(0, \sigma_\varepsilon^2) \qquad \omega_{it} = \xi_{it} + \theta\xi_{i,t-1}, \quad \xi_{it} \sim N(0, \sigma_\xi^2) \tag{11}$$

The parameters of the age polynomial and time trend are estimated from the administrative data for the years 2000-2013 for men between ages 21-64. We estimate $\rho, \theta, \sigma_\varepsilon^2, \sigma_\xi^2$ using a minimum distance estimator, matching the variance-covariance matrix of wages. We estimate $\rho = .949$ (.001), $\theta = -.235$ (.013), $\sigma_\varepsilon^2 = .059$ (.001), $\sigma_\xi^2 = .027$ (.001). Although we are unaware of any estimates of the dynamic process for wages in Poland, the estimates are similar to those in the US (French, 2005) and many other countries (see the range of estimates cited in Krueger et al. (2010)). To account for unemployment risk, we estimate a first-order Markov process of unemployment spells.[19]

We use the estimated parameters to simulate wage, unemployment, and earnings (the product of wages and employment) histories, and thus benefits. If someone is employed at period t, we calculate $b_{i65}^{\text{Employed}_t,k}$ given the earnings throughout the lifecycle. We also calculate $b_{i65}^{\text{Not employed}_t,k}$ by assuming that the individual faces the same earnings and unemployment history as before but is not working in period t. If someone is unemployed at period t as a result of the simulated unemployment shocks, then we define the net return to work to be zero. In our calculations, we take into account all the details discussed in the institutional section, including the starting capital and the minimum pension.

Our simulations suggest that individuals in high earnings-growth regions were more likely to experience one of their best earnings years when aged 51-54, whereas individuals in low earnings-growth regions were more likely to experience their best earnings years at younger ages.[20] Thus, incentives to work at ages 51-54 under the DB system were greater in high earnings-growth regions than in low earnings-growth regions.

[18]The differential earnings growth between high- and low-growth regions reflects convergence in earnings across regions during the sample period. In 2000, average earnings in high-growth regions were 14.2 percent lower than in low-growth earnings, but by 2013, earnings in high-growth regions were only 3.6 percent lower than in low-growth regions.

[19]We estimate unemployment risk using the Polish Household Budget Survey that has detailed information on transitions from employment to unemployment and vice versa. An individual is considered to be in unemployment if he/she receives unemployment benefits. We estimate transition probabilities for individuals below age 50 and then we extrapolate those for all ages.

[20]The chance that working at age 51 will be part of the best years calculations in the DB system is 47% in high growth regions and 44% in low growth regions.

Table 2 presents the percent change in the net return to work caused by the NDC reform. Using the formula in equation (3), we calculate the average percent change in the net return to work at ages 51-54 for those in the 1949 cohort (who were impacted by the reform) relative to the 1948 cohort (who stayed in the DB system). We present the percent change in the net return to work in high earnings-growth and low earnings-growth regions. Since in high earnings-growth regions the best years were more likely to occur at ages 51-54, the net return to work declined 11.17% in high-growth regions (vs. 5.94% in low-growth regions), a difference of 5.23%.

Besides calculating the change in net return to work, we also calculate the change in present value of pension wealth coming from switching from DB to NDC. For each individual, we take the simulated wage and unemployment shocks and calculate pension benefits (and, using equation (9), the present discounted value of those benefits) under the DB and NDC rules. On average, pension wealth dropped by about 14% in both the high- and low-growth regions. This pension wealth drop exceeds the one predicted by policy makers at the time of the reform, but is in line with simulations of Lachowska and Myck (2018), who studied the same reform. This discrepancy can be explained by the fact that projections at the time of the reform did not take into account the shape of the earnings profile over the lifecycle, which led to a lower than expected starting capital for many individuals.[21]

The reduction in pension wealth provides an incentive to work more, partly offsetting the reduced work incentive from the reform. Nevertheless, the size of the pension wealth drop was similar across locations (14.26% in high-growth vs. 13.91% in low-growth). Therefore, we isolate the effect of incentives from the change in pension wealth by focusing on the difference between high and low-growth regions.[22] In the Appendix Table C.3, we provide further detail on what drives the differential incentives across regions. First, the age polynomial part is very similar across locations and so it plays little role explaining the differential changes in incentives. Second, individuals in high-growth regions have lower earnings and steeper wage growth, which together can explain why incentives have changed more in high-growth regions. Notice that our regression discontinuity design implemented separately for high- and

[21]The pension projections at the time applied a simple deterministic model that abstracts from the shape of the lifecycle earnings profile and wage and unemployment risk (see the assumptions they made on page 36 and 37 in Chlon et al. (1999)). Lachowska and Myck (2018) take into account the shape of the earnings profile, but abstract away from the wage and unemployment risks. We take into account both the shape of the earnings profile and the wage and unemployment risks.

[22]A key identifying assumption is that labor supply responses would be the same across the two types of region. In line with this assumption, we find that responses to the old age unemployment benefit are similar across locations. We also find that workers respond similarly to a large tax cut studied by Zawisza (2022) in the two types of region.

low-growth regions filters out the effect of differential labor market trends on labor supply, as those should have constant effect around the discontinuity.

To summarize, Table 2 shows that the difference in the change in the net return to work between high-growth and low-growth regions was 5.23%, while the difference in the change in pension wealth was only 0.35%. In the next section, we study the response of the labor supply to these changes in incentives.

5 Empirical strategy

To identify the effect of the reform on labor supply, we exploit the sharp discontinuity created by the cohort-based nature of this reform. We apply a regression discontinuity design (RDD) where we compare individuals who were born a few weeks from each other but are covered by different pension schemes. More specifically, we estimate the following regression equation:

$$P_{it} = \alpha + \beta \mathbf{1}\{z_i < 50\} + f(z_i) + \varepsilon_{it}, \tag{12}$$

where P_{it} equals 1 if individual i is employed at time period t, and z_i is the age of the individual on 1st January 1999 (when the reform was introduced). Individuals younger than 50 years old at the time of the reform, $\mathbf{1}\{z_i < 50\}$, were ushered into the new NDC scheme, and so β assesses the impact of switching from the DB pension to the NDC scheme. We follow Hahn et al. (2001) and Lee and Lemieux (2010) and estimate two separate regressions of $f(z_i)$ on each side of the cutoff point. We report estimates with linear regressions and with kernel-weighted local-linear regressions using a triangular kernel. For the local-linear regression, we set the bandwidth at 150 days on either side of the discontinuity. In Online Appendix A, we show that our results are not sensitive to the chosen bandwidth values.

Since our simulations in Section 4 suggest that incentives changed differently for individuals in high earnings-growth and low earnings-growth regions, we also estimate the RDD regression specification separately for these two regions. The standard error on the differential response between high- and low-growth regions is obtained using the delta method, although we obtain the same standard errors if we estimate the differential response between high- and low-growth regions in one regression specification.

In our RDD, the running variable is birth date, which was determined many years before the policy change. Therefore, manipulation in the forcing variable is not possible. Nevertheless, there is a spike in reported births which occurs on the 1st of January of every cohort in our sample. This spike in reported birth is also observed in registry data in 1998,

before the reform implementation. Thus, the spike is not driven by some policy-induced manipulation. Instead, the spike on January 1st likely reflects the fact that many in these cohorts were born at home (and not at hospital) and the dates of birth for these individuals were self-reported. While this reporting behaviour took place 50 years before the pension reform was announced, the characteristics of these switchers may be correlated with the labor-market outcomes we care about.

To deal with this issue, we exclude individuals born between December 17th and January 5th. We pick these thresholds because we see no evidence of under- or over-reporting of births outside of this narrow range. This is sometimes known as a "donut hole" regression-discontinuity design and has been used in other instances of systematic bunching around the cutoff (see e.g. Almond and Doyle, 2011; Barreca et al., 2011). For robustness, we also alternately perform our analysis using no donut hole at all, and using a broader donut hole where we drop all individuals who were born in January or December. Our results are not sensitive to various definitions of donut holes.

We also report estimates relative to the observed discontinuity in the "placebo" sample, born exactly one year later than our main estimation sample. In the placebo sample, we see a similar spike in births on January 1st. We estimate the regression discontinuity net of placebo in the following way. First, we create a stacked data set by appending the main sample containing the 1948 and 1949 cohorts observed in 2000-2002 (our main sample) with a dataset containing the 1949 and 1950 cohorts observed in 2001-2003 (our placebo sample).[23] We denote individuals belonging to the main sample in this stacked data with $M_i = 1$ and individuals belonging to the placebo sample with $M_i = 0$. For the placebo sample we assume that there is a discontinuity between those born on December 31st 1949 and those born on January 1st 1950. Therefore, the discontinuity threshold is age 50 at the time of the reform for individual i in the main sample, formally $k_{M(i)} = 50$, and it is age 49 for individual i in the placebo sample, $k_{M(i)} = 49$. The specification for the net-of-placebo RDD is then:

$$P_{it} = \alpha^P + \beta^P \mathbf{1}\{z_i < k_{M(i)}\} + f^P(z_i) + \left(\alpha^M + \beta^M \mathbf{1}\{z_i < k_{M(i)}\} + f^M(z_i)\right) \cdot M_i + \varepsilon_{it}, \quad (13)$$

where $f^P(z_i)$ and $f^M(z_i)$ are sample-specific controls for the forcing variable (age at the time of the reform) estimated separately on each side of the cut-off. In this regression, β^P estimates the change in employment at the placebo cut-off, while β^M shows the estimated

[23] For the placebo sample, we use years between 2001-2003 to make sure that we have the same age bands in the main and in the placebo samples.

employment change in the main sample relative to the placebo sample and is thus the parameter of interest.

Finally, we also check whether there is a noticeable discontinuity in individuals' observable characteristics at the cut-off. The results of this exercise are presented in Table D.1 in Online Appendix D for all individuals. While there is some evidence of a lower female share, higher rural share and higher local area employment rate among those born after January 1 in our main sample covering 1948-1949 cohorts, that discrepancy is very similar in the placebo sample covering 1949-1950 cohorts. As a result, in our net-of-placebo estimates, we find no indication of any unusual change in the covariates around the January 1st discontinuity. We also show the results for individual-level covariates in the low- and high-growth regions separately, and likewise find no change around the January 1st discontinuity for either.

6 Results

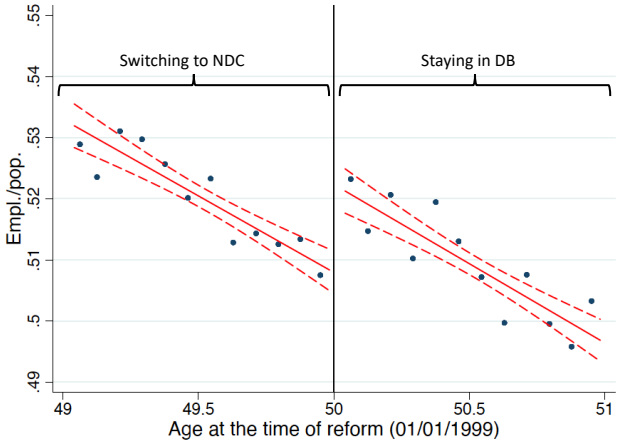
Employment responses. We start our analysis by evaluating the effect of the reform on the employment rate. Panels (a) and (b) of Figure 1 show the average employment rates over the years 2000-2002 by month of birth around the reform discontinuity. The x-axis shows the age of the individual on January 1st, 1999, the date the pension reform was introduced. Therefore, as we move along the x-axis, we show the employment-to-population ratio for cohorts that are successively older. The red vertical line shows the threshold of age 50 on January 1st, 1999, for which the new rules applied. Cohorts younger than the threshold (left of the red vertical line) were ushered into the new NDC scheme, while older cohorts (right of the red vertical line) stayed in the old DB system. As noted in the previous section, we implement a "donut hole" RDD, excluding individuals born right around the discontinuity.

Figure 1 also plots the lines of best fit for individuals both below and above the discontinuity, as well as the 95% confidence intervals. The downward slope of these lines reflects the tendency of employment rates to fall with age at older ages. As we described above, non-agricultural employment rates for men aged 51-54 in Poland were 49% in the period under consideration. Agricultural workers were unaffected by the policy change and are excluded from the data (see Section 3 "Exceptions").

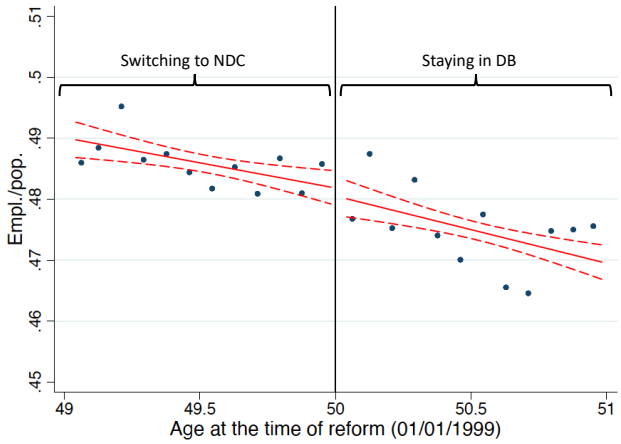
Since the change in incentives was different in high- and low-growth regions, we report estimates separately for the two. Panel (a) shows a 1.5 percentage point decline in the employment rate as a result of switching to the NDC scheme (left to the vertical red line). Using the 52% baseline employment rate in the high-growth regions, this translates to a 2.8 percent drop. This fall reflects the decrease in these individuals' net return to work (shown

Figure 1: Effect of the Pension Reform on Employment: Treatment and Placebo Estimates.

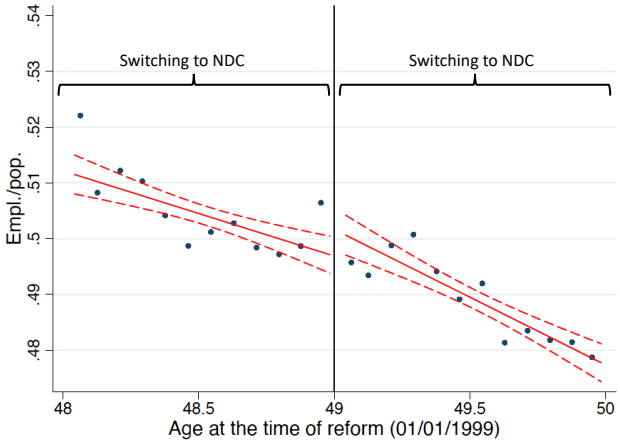
(a) High-growth regions: **reform cohort**



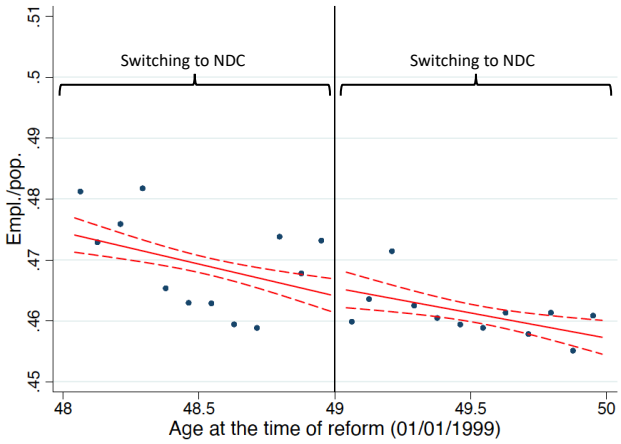
(b) Low-growth regions: **reform cohort**



(c) High-growth regions: **placebo cohort**



(d) Low-growth regions: **placebo cohort**



Notes: This figure plots the fraction of individuals who have positive earnings in a given year by month of birth (measured as the age on 01/01/1999). The top two panels, (a) and (b), show our treatment results. Individuals younger than age 50 on 01/01/1999 are in the new NDC scheme, while older individuals are in the DB scheme. We calculate the fraction having positive earnings for every year and then average them for the years 2000-2002. Panel (a) shows the fraction in high earnings growth regions, while panel (b) shows the fraction in low earnings growth regions. High earnings growth regions are regions with an above median earnings growth rate between 2000 and 2013, while low earning growth regions have below median earnings growth. To deal with the bunching in birth date at each year at January 1st, we apply a donut hole RD design and exclude those born between December 16th and January 5th. The solid lines are OLS lines of best-fit, allowing for different slopes and intercepts on both sides of the cutoff. The 95 percent confidence intervals are also shown. The bottom two panels, (c) and (d), show one of our placebo results. We plot the fraction having positive earnings for individuals born in 1949 and 1950 (age 48 and 49 at the time of the reform) where all individuals were ushered into the new NDC scheme and so there is no policy discontinuity. Panel (c) shows the fraction in high earnings growth regions, while panel (d) shows the fraction in low earnings growth regions. Otherwise, the plots are as in panels (a) and (b).

Table 1: The Effect of the Pension Reform on Employment And Wages

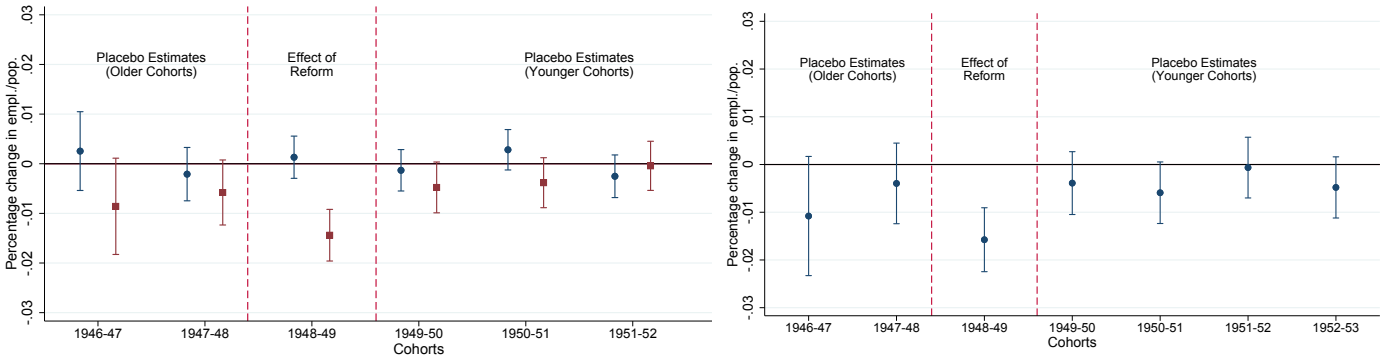
	(1)	(2)	(3)	(4)
Panel A: Change in employment probability				
High-growth	-0.0201***	-0.0148***	-0.0174***	-0.0105***
N = 545,435	(0.0024)	(0.0026)	(0.0050)	(0.0037)
Low-growth	-0.0022	0.0010	0.0027	0.0014
N = 818,487	(0.0020)	(0.0022)	(0.0041)	(0.0032)
Difference (High-Low)	-0.0179***	-0.0158***	-0.0201***	-0.0119***
	(0.0031)	(0.0034)	(0.0065)	(0.0048)
Panel B: Change in log wage				
High-growth	-0.001	-0.005	0.012	0.011
N = 313,720	(0.008)	(0.009)	(0.017)	(0.013)
Low-growth	-0.003	0.005	0.003	0.018
N = 439,545	(0.007)	(0.008)	(0.009)	(0.011)
Difference (High-Low)	0.002	-0.010	0.009	-0.007
	(0.011)	(0.012)	(0.023)	(0.021)
Sample	Full	Donut	Donut	Donut
$f(z_i)$	linear trend	linear trend	local linear	linear trend
net-of-placebo	no	no	no	yes

Notes: This table shows the estimated change in employment (panel A) and log wage (measured as earned income of workers) for those in work (panel B) at the reform discontinuity. Each cell in the table shows the β coefficients of the RDD specification shown in equation (E.4) (Columns (1)-(3)) or in equation (13) (Column (4)). The rows show the estimated employment and wage change for different regions. The first and second rows show the estimated effect in high and low-growth regions, respectively. High-growth regions are regions with above median earnings growth rate between 2000 and 2013, while low-growth regions have below median growth. The third row shows the difference between the high and low-growth regions. In Column (1) we use the full dataset. In Columns (2)-(4) we apply the donut hole RDD specification where we exclude those born between December 17th and January 5th. In Columns (1), (2) and (4) we estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the cutoff. Column (3) estimates a kernel-weighted local linear regression, where we set the bandwidth at 150 days. Column (4) estimates the change in employment at the reform discontinuity relative to the change at the placebo discontinuity as in equation (13). The placebo discontinuity is estimated between the 1949 and 1950 cohorts, both of which switched to the NDC system. We report robust standard errors in parentheses. For the local-linear regression we calculate robust standard errors following Calonico et al. (2014). Significance levels are: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

in Table 2), but it could also reflect the effect of the reform on pension wealth. In Panel (b) of Figure 1, we also show the RDD result for the low-growth regions. In these regions, we do not find a significant difference between the DB and NDC cohorts. There is only a slight change in the employment rate, in line with the smaller decrease in the net return to work shown in our simulations.

Panel A of Table 1 presents the RDD estimates in tabular form. It presents the estimates of β from equation (E.4), which show the effect of being in the younger cohort at the discontinuity. The estimated effects are reported for both the high- and low-growth regions. We also calculate the difference between the two types of regions. The first column presents results from a specification using the main sample of all men born in 1948 or 1949 (who were age 49 or 50 at the time of the reform). The subsequent three columns show the "donut hole" RDD estimates where we exclude individuals born between December 17th and January 5th.

Figure 2: Change in Employment for Various Cohorts



(a) Employment change for high and low growth regions

(b) Employment change, difference (high-low)

Notes: This figure plots the employment discontinuities estimated using the regression discontinuity design (see equation E.4) for pairs of cohorts experiencing the policy discontinuity and for pairs of various "placebo" cohorts. The impact of the reform is estimated based on the sample of the 1948 and 1949 cohorts (individuals who were 49 and 50 years old on January 1st, 1999). Estimates for samples of older placebo cohorts are to the left of the 1948 and 1949 cohort estimates, while estimates for samples of younger placebo cohorts are to the right. We apply the same RDD specification as in Figure 1. Since we only have data from 2000 onwards, the estimates based on the 1946 and 1947 placebo cohorts are for individuals aged 53-54, while the estimates for the 1947 and 1948 placebo cohorts are for individuals who were 52-54 years old. The blue dots with the 95 percent confidence intervals on panel (a) show the estimated change in employment in low earnings growth regions, while the red squares show the estimates for high earnings growth regions. Panel (b) depicts the difference in employment change between high and low earnings growth regions.

The differences between Column 1 and the donut hole RDD estimates are small, suggesting that our results are robust to including individuals bunching right around December 31st.

Columns 2-3 explore alternative assumptions on the functional form of the running variable, $f(z)$, which is estimated separately on both sides of the discontinuity. In Column 2, we estimate a linear trend in birth date, while in Column 3 we estimate a local linear polynomial, with a bandwidth of 150 days. In the latter specification, we apply Calonico et al. (2014)'s method to estimate bias-corrected robust confidence intervals. The estimates in the two specifications are very similar to each other. Moving from DB to NDC leads to a 1.5-1.7 (s.e. 0.3-0.5) percentage point decrease in employment in high-growth regions and a 0.1-0.3 (s.e. 0.2-0.4) percentage point decrease in low-growth regions. In Table A.1 of the Appendix, we also explore the sensitivity of the results to the bandwidth choice and show that the results are robust to the applied bandwidth.

As we discussed previously, the change in employment in high-growth and low-growth regions shows the combined effect of the wealth change and the change in net return (incentive effects). Nevertheless, since the reform affected pension wealth similarly in high- and low-growth regions, the difference in the employment change between high- and low-growth regions reflects the change in incentives net of any reform-induced changes in pension wealth. The difference between high- and low-growth in the last row of Panel A suggests that high-

growth regions experienced a 1.6 (s.e. 0.3) percentage point drop in employment relative to low-growth regions in our specification with a linear trend and donut in Column (2).

We conduct a series of placebo analyses as a test of whether our estimates capture the effect of the reform and not of something else related to the timing of birth or age. Panels (c) and (d) of Figure 1 plots employment rates around a placebo discontinuity in high- and low-wage growth regions, respectively. Our placebo sample consists of those aged 48 and 49 at the time of the reform (i.e., those born in the years 1949 and 1950). We analyze their labor supply in the years 2001-03 so that they are observed at the same age band as individuals in our main sample. Members of the placebo sample were all affected by the reform, regardless of whether they were born in late 1949 or early 1950. Similarly to the main estimates, we exclude individuals right at the discontinuity, (i.e., these estimates incorporate the "donut hole"). Panels (c) and (d) of Figure 1 show that there is no significant difference in employment rates at the placebo discontinuity in either the high- or low-growth regions. The slightly higher employment rate for those born after January 1st in high-growth regions in the placebo sample is of an order of magnitude smaller than that for the cohorts in the main sample affected by the reform.

Figure 2 plots our estimated treatment effect using the 1948-49 cohort discontinuity, where individuals in the younger cohort were affected by the reform and individuals in the older cohort were unaffected. In addition, it plots a battery of placebo estimates using the cohorts 1946-47 and 1947-48 (none of whom were affected by the reform), and 1949-50, 1950-51, 1951-52 and 1952-53 (all of whom were affected by the reform). We also plot the 95% confidence interval for each estimate. We only use individuals aged 51-54 in all cohorts.

Panel (a) of Figure 2 shows estimates for both low- and high-growth regions. The estimate for the 1948-49 main sample for the high-growth regions is statistically significant and large, while all of the placebo estimates for high-growth regions are smaller and statistically insignificant. For instance, our estimate for the 1948-49 main sample is a 1.48 (s.e. 0.26) percentage point reduction in employment, whereas for the 1949-50 placebo sample, we estimate a 0.43 (s.e. 0.26) percentage point reduction.[24] In the low-growth regions, the estimate for the 1948-49 treatment cohort is a 0.10 (s.e. 0.22) percentage point increase in employment, while the estimate for the 1949-50 placebo sample is a 0.04 (s.e. 0.21) percentage point fall in employment. The placebo estimate for the 1946-47 cohort is larger than the other placebo estimates but is imprecisely estimated because it only uses data from 2000. By 2001, the cohort members reach age 55 and thus we do not use them.

[24] These estimates are also reported in column (2) of Table 1 and column (2) of Table A.3.

Table 2: Employment Elasticity

	(1) High-growth	(2) Low-growth	(3) Difference (High-Low)
1. Change in net return to work (%)	-11.17	-5.94	-5.23
2. Change in pension wealth (%)	-14.26	-13.91	-0.35
3. Change in employment (%)	-2.01	0.28	-2.29
	(0.71)	(0.63)	(0.95)
4. Employment elasticity (Row 3) / (Row 1)	–	–	0.44
			(0.18)

Notes: This table shows the effect of the pension reform on the net return to work (row 1), on the pension wealth (row 2), on the change in employment (row 3) and on the resulting employment elasticity (row 4). The percent change in the net return to work is calculated using the formula in equation (3) and further details are in Section 2 and in Online Appendix C. To calculate the percent change in employment, we divide the net-of-placebo estimates of the change in employment from Panel A, Column (4) in Table 1, by the employment rate of the cohorts which were age 50 at the time of the reform and so stayed in the DB system. Columns (1) and (2) show the effects for high and low growth regions, respectively. High-growth regions are areas with above median earnings growth rate between 2000 and 2013, while low growth regions have below median earnings growth. The third column shows the difference between the high (Column (1)) and low-growth (Column (2)) regions. Row (4) shows the employment elasticity, which we calculate by dividing the percent change in employment (row 3) by the percent change in the net return to work (row 1). Robust standard errors are in parentheses.

Panel (b) of Figure 2 shows the difference in the estimate between the high- and low-growth regions for each cohort. For the main sample, we estimate a statistically significant 1.58 (s.e. 0.34) percentage point difference, while all of the placebo estimates are smaller and statistically insignificant at the conventional levels. For instance, we find a statistically insignificant 0.39 (s.e. 0.33) percentage point difference for the 1949-50 placebo sample. Moreover, for women, who experienced a much smaller alteration to their pension system as a result of the reform, we find much smaller, statistically insignificant differences in the employment rate around the 1948-1949 cohort discontinuity (see column (3) of Table A.3). This is evidence that the main effects are only found where the policy discontinuity is present, and we find no indication of a differential effect in other cohorts. See Table A.3 in Online Appendix A for further details on the 1947-1948 and 1949-1950 placebo samples.

Nevertheless, in Column 4 of Table 1, we also present our main results relative to the placebo estimates. We report the β^M from RDD regression equation (13). The estimated impact of switching to NDC on employment is -1.1 (s.e. 0.4) percentage points in the high-growth regions and 0.1 (s.e. 0.3) percentage points in low-growth regions. The difference between the high- and low-growth regions is 1.2 (s.e. 0.5) percentage points. This is very similar to the simple RDD estimates in Column 2 (-1.6 percentage points). We will use these more conservative estimates in the benchmark analysis when calculating elasticities.

Implied elasticity. Table 2 presents our estimated participation elasticity. As we explained in Section 4, row (1) shows the effect of the reform on net return to work in high- and low-growth regions, while row (2) shows the impact of the reform on pension wealth.

Row (3) reports the percentage change in employment as a result of the reform. We use our net-of-placebo estimates of the percentage point change in Column 4 of Table 1 and divide it by baseline employment rates at the discontinuity for the cohort staying in the DB system.

To isolate the effect of the reform on incentives from the effect on pension wealth, we focus on differences between high- and low-growth regions (Column 3 of Table 2). Row (4) reports our estimated employment elasticity. We divide the employment change (row 3) by the percent change in the net return to work (row 1). The estimated elasticity is 0.44 (s.e. 0.18), which is statistically significant at the conventional level. Since the differential change in pension wealth was negligible (0.35%), this elasticity only captures the change in net return to work.

The change in net return to work at a given age has permanent and transitory components, and so our estimated reduced form elasticity is between the Marshallian (fully permanent change) and the Frisch (fully transitory change) employment elasticity. On the one hand, the change in the net return to work depends on whether certain ages belong to the "best years", which introduces some transitory component in the change in net return to work. On the other hand, being in the "best years" in a given year means that the next year will likely also be among the "best years". Therefore, there is some permanence in the change in incentives.

As a result, we can compare our estimates to the reduced form Marshallian and Frisch elasticities often reported in the literature. The Chetty et al., 2013 meta-analysis of these reduced-form micro studies suggest that the Frisch elasticity is around 0.32 while the Marshallian is around 0.25.[25] There is some evidence that older individuals tend to be more responsive to changes in incentives: Blundell et al., 2016 cite several studies where the reported elasticity is greater than 0.5.

Nevertheless, these estimated reduced form elasticities do not immediately translate to interpretable structural elasticities given that participation decisions are not simply governed by one single structural parameter or elasticity and may vary with other characteristics such as age. In Section 7, we use a lifecycle model, estimated to match the employment response to policy reform, in order to obtain a model-based estimate of the Frisch elasticity.

Wealth Effects. Our simulations illustrate the fact that the NDC reform delivered non-trivial declines in pension wealth in each region. While it is not the focus of our paper, we can assess labor supply responses to these wealth changes. To do this, we first need to net out the

[25] Chetty et al., 2013 report the Hicksian elasticity but acknowledge that their Hicksian elasticity is a mix of Marshallian and Hicksian elasticities, as many of the papers in their meta-analysis do not fully account for income effects.

impact of the change in net return to work on labor supply. Table 2 shows that our estimate of the employment elasticity is 0.44. In the low-growth regions the change in the net return to work is 5.94%. Together, these imply that employment would fall (5.94%)(0.44)=2.6% in the absence of wealth effects. Given the observed rise of 0.28% in employment, the implied change in employment due to the wealth effect is (5.94%)(0.44)+0.28%=2.9% (for high growth regions the analogous calculation is $(11.17\%)(0.44) - 2.01\% = 2.9\%$). This is a *percent* change in labor supply; given an employment to population ratio of around 0.5, this corresponds to a 1.45 *percentage point* change in labor supply from the wealth effect.

We can compare this magnitude to some recent estimates of labor supply responses to wealth shocks. Graber et al. (2022) document employment responses to wealth shocks coming from lottery winnings. Their Table 3.2 indicates that a wealth shock that is 2.9 times of the average income in the economy[26] causes employment to decline by 3.7 percentage points. The wealth shocks we study are smaller – the 14% decline in pension wealth that our simulations show is equivalent to a wealth shock 1.5 times the average income in the economy.[27] Scaling our estimated 1.45 percentage point effect to the size of their wealth shock, our estimates would imply an employment change by 2.8 percentage points, which is not far from the 3.7 percentage point estimated in Graber et al. (2022). Furthermore, Lindqvist et al. (2020) finds considerably lower wealth elasticities in the Swedish context, suggesting that our estimated wealth effects are within the range of existing estimates in the literature.

Robustness. Table 3 evaluates the robustness of the estimated benchmark elasticity. Panel A reports the baseline estimate of the implied elasticity derived in Table 2. Panel B shows the implied elasticity under alternative implementations of the regression discontinuity design. We calculate the implied elasticity for alternative estimates on the change in employment: a specification with a linear trend in birth date without applying the donut hole restriction, a specification with a linear trend applying a larger donut hole restriction (namely excluding all individuals born in January and December), and a local-linear specification applying the baseline donut. We provide the net-of-placebo estimates on employment in these specifications, where the placebo estimates come from the 1949-1950 cohorts in 2001-2003. The implied elasticity estimates in all cases are statistically significant from zero. The point estimates vary between 0.66 (local linear, with donut) and 0.35 (with December-January donut) in the various specifications, both of which are close to 0.44 – our baseline.

[26]The shocks are worth $100,000, while their Table 2.1 indicates that average earnings are $34,500.

[27]Our simulation indicate that the present discounted value of pension wealth declined by 34,649 zloty, while average pre-tax earnings are 22,118 zloty.

Table 3: Employment Elasticity, Robustness

	(1) Change in nrw (%)	(2) Change in pension wealth (%)	(3) Change in emp(%)	(4) Employment elasticity
Panel A: Baseline				
1. Linear trend RDD, net-of-placebo,	-5.23	-0.35	-2.29	0.44
donut sample			(0.95)	(0.18)
Panel B: Estimation methods				
2. Linear trend RDD, net-of-placebo,	-5.23	-0.35	-2.99	0.57
full sample			(0.88)	(0.17)
3. Linear trend RDD, net-of-placebo,	-5.23	-0.35	-1.85	0.35
Jan-Dec donut sample			(1.04)	(0.21)
4. Local-linear RDD, net-of-placebo,	-5.23	-0.35	-3.40	0.66
donut sample			(1.80)	(0.34)
Panel C: Calculation of net return to work				
5. AR(1) wage process	-5.31	-0.40	-2.29	0.43
(parameters from French (2005))			(0.95)	(0.18)
6. AR(1) + White Noise wage process	-5.12	-0.23	-2.29	0.45
			(0.95)	(0.19)
7. Actuarially fair uprating	-5.57	-0.35	-2.29	0.41
of NDC contributions			(0.95)	(0.17)
8. Wage process with individual	-6.04	-0.05	-2.29	0.38
fixed-effects			(0.95)	(0.16)
Panel D: Interest rate				
9. $r = 0.04$	-4.46	-0.35	-2.29	0.51
			(0.95)	(0.21)
10. $r = 0.06$	-3.30	-0.35	-2.29	0.69
			(0.95)	(0.29)
Panel E: Definition of employment				
11. $2000 p.a. threshold	-5.23	-0.35	-2.02	0.39
			(0.95)	(0.18)
Panel F: Elasticity Formula				
12. Alternative adjustment for	-5.23	-0.35	-2.54	0.48
unaffected workers			(1.05)	(0.20)
Panel G: Employment change between 2005-2007				
14. Estimate at age 56-59	-4.80	-0.35	-3.69	0.77
			(1.56)	(0.32)

Notes: Panel A reports the benchmark elasticity in Table 2. Panel B shows robustness of the elasticity to the estimation method of the change in employment. Row 2 reports RDD estimates when using a linear trend (and not applying the donut hole restriction), row 3 when applying a broader definition of the donut hole (omitting everyone born in January and December), and row 4 when using a local-linear RDD on the baseline donut sample. Panel C explores robustness to the calculation of the net return to work. Row 5 uses the AR(1) parameterization from French (2005) instead of the AR(1) + MA(1) process used in our benchmark calculation (see Equation (10)) when calculating the net return to work. Row 6 uses an AR(1) process with White Noise, where we estimate the parameters by a GMM procedure described in Section 2. Row 7 assumes that pension indexation in the NDC system is actuarially fair – an additional 1 zloty contribution leads to 1 zloty higher present discounted value of pension benefits in equation (9) instead of applying the actual risk free interest rate, pension indexation, and survival rates. Row 8 applies the AR(1) + MA(1) process but estimates the deterministic components of wages based on fixed effects regression, shown in Appendix Table C.3. In Panel D, rows 9 and 10 explore the effect of changing the real interest rate from our baseline of 2.88% to 4% and 6%. Panel E explores changing the definition of employment we use as our dependent variable. Rows 11 shows robustness to increasing the threshold of earnings above which individuals are deemed to be in employment to increase to $2000 p.a., from our baseline of $547. Panel F explores an alternative adjustment for unaffected workers described in detail in C.2. Finally, panel G explores the effect of pension system at later ages. All estimates take the difference in the estimated employment change between high-growth and low-growth regions to isolate the effect of changes in net return to work. Robust standard errors are in parentheses.

In Panel C, we assess the robustness of the results to alternative assumptions made in calculating the net return to work. In particular, we explore how the implied elasticities change if we apply alternative wage processes in our simulations. In the first row, we use a wage process applying the parametrization and estimates in French (2005) using data from the U.S. Panel Study of Income Dynamics. The second row in Panel C uses simulations where the estimated stochastic component of the wage is an AR(1) process with White Noise instead of an AR(1)+MA(1) process as in our benchmark specifications. In both cases, the change in net return to work is almost identical to the change calculated in our benchmark specification and thus the implied employment elasticities (0.43 with the French (2005) parametrization and 0.45 with the AR(1) process with White Noise) are almost identical to the benchmark estimate (0.44) also. These estimates highlight that our main results are robust to alternative assumptions made in our simulation of incentives.

In the third row of Panel C of Table 3, labeled "actuarially fair", we explore an alternative assumption on the uprating factor, r^{NDC} (see equation 6). In the benchmark specification, we calculate the present discounted value of pension benefits in equation (9) by using the actual uprating factor on accumulated capital, r^{NDC}, the indexation factor r^{index}, interest rate r, and survival rate probabilities ($S_{65|t}$). This discounting implies that a contribution of 1 Polish złoty increases the present value of the NDC account by 0.7 Polish złoty. As a robustness check, we increase the uprating factor on accumulated capital, r^{NDC}, to ensure that 1 Polish złoty contributed to the NDC account increases the present value of benefits by 1 złoty, and so the pension scheme is actuarially fair. The implied elasticity in this case is modestly smaller (0.41 instead of 0.44 in the benchmark case). This highlights that our estimates are not very sensitive to alternative assumptions on the parameter values of the NDC system. In the final row of Panel C, we include individual fixed-effects in the deterministic component of the wage process. In this case, the simulated change in incentives is very similar and consequently so is our elasticity at 0.38, which shows that our estimates are robust to controlling for all time-invariant factors such as cohort effects.

In our analysis, we assume that individuals equally value the after-tax wage and the increase in the expected present discounted value from pension benefits from working. Furthermore, we have assumed that individuals discount future benefits at an interest rate of 2.88%, which is the rate for government bonds over the period 2000-19. However, households might discount future benefits more heavily if they are borrowing constrained, face high interest rates, are myopic, or lack full information about their pension incentives. In Panel D of Table 3, we consider alternative higher interest rates when calculating the net return to

work (equation (3)) to investigate sensitivity to assumptions about discounting. We explore how the implied elasticity varies when the interest rate is 4% and 6%. With higher interest rates, we find that the implied elasticity is somewhat larger. For instance, if 4%, then the implied elasticity is 0.51. If the interest rate is 6%, the implied elasticity is 0.69.

In our baseline specification, we consider someone to be employed if he/she filed a tax return and so his/her annual income is at least \$547. In Panel E, we show that we get very similar results if we use alternative definitions of employment, namely earning above $\$1,000$ annually or $\$2,000$ annually, the latter of which is equivalent to the annual earnings of someone earning the minimum wage. As can be seen, our estimates of the elasticity are the same under both definitions at 0.39, slightly lower than our baseline estimate.

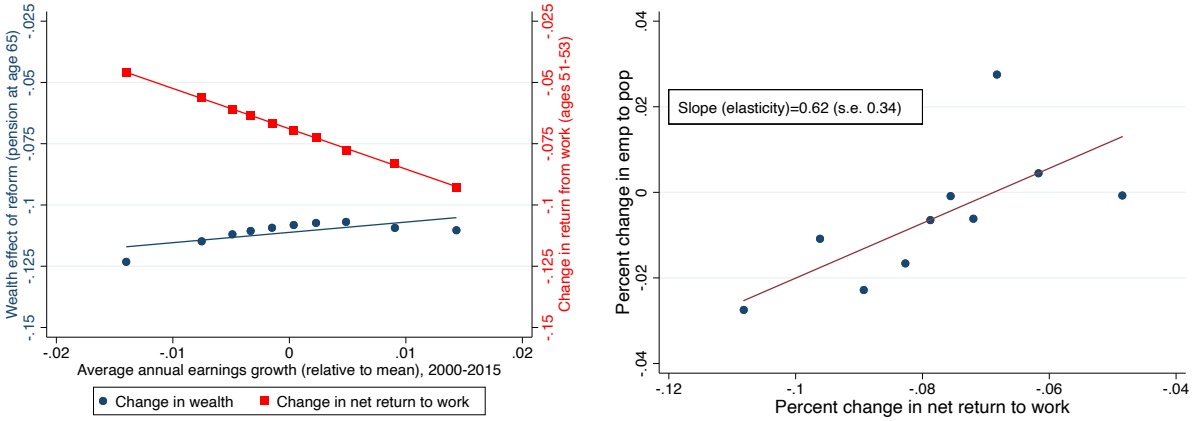
Some individuals at the age discontinuity were in either an excluded sector or a special occupation and were thus unaffected by the reform. Failure to account for the fact that not all men were affected by the reform could bias our estimate of the responsiveness of labor supply towards zero. In Panel F, we adjust our elasticity estimates by applying an upper bound on the number of workers in excluded sector following the procedure described in Appendix C.2. Because the vast majority of men were affected by the reform, accounting for those who were not affected raises the estimated elasticity only slightly, to 0.48.

Elasticity estimates by finer regions. Our main estimates so far compared the employment change, the change in incentives and the change in pension wealth between high and low earnings-growth regions. In panel (b) of Figure 3, we assess the changes at a finer regional level. We calculate pension incentives over 2000 small administrative local areas in Poland.[28] The change in incentives is tightly linked to local area-level earnings growth, while the change in pension wealth varies very little across regions (see panel (a) of Figure 3). Thus, as before, we use regional variation to identify the impact of changes in work incentives on employment separately from the effect of changes in pension wealth.

In panel (b) of Figure 3 we plot the non-parametric bin-scattered relationship between the estimated RDD employment change at the reform discontinuity (net-of-placebo estimates based on equation (13)) and the percent change in net return to work. There is a clear positive relationship between the change in work incentives as a result of the pension reform and the estimated effect of the reform on employment outcomes. The figure also shows that the best linear fitting line is clearly upward sloping. The slope shows the relationship between the percent change in employment and the percent change in incentives and is therefore an

[28] We calculate the change in incentives at each local area separately. For each local area, we use the economy-wide lifecycle earnings profile but adjust the earnings growth rate to reflect the local-area level earnings growth between 2000 and 2013.

Figure 3: The Percent Change in Employment and in Work Incentives Across Locations



(a) Percent Change in Work Incentives and Pension Wealth Across Locations

(b) Percent Change in Employment and Work Incentives Across Locations

Notes: Panel (a) shows the non-parametric bin-scattered relationship between the percent change in net return to work and the average annual earnings growth (red squares) and between the percent change in pension wealth and the average annual earnings growth (in blue dots) across 2000 local areas. The annual earnings growth for each location is calculated between 2000-2013. We group the 2000 administrative local areas to 10 equally-sized bins based on their change in annual earnings growth (x-axis). The percent change in the net return to work is calculated according to equation (3). Panel (b) shows the non-parametric bin-scattered relationship between the estimated employment change at the reform discontinuity (net-of-placebo estimates based on equation (13)) and the percent change in the net return to work across the 2000 local areas. We estimate the employment changes for each local area separately by applying the local-linear RDD specification with the baseline donut (y-axis). We also plot a linear fit line using OLS. The slope of the linear fit in panel (b), reported in the top left of the panel, shows the relationship between the percent change in employment and the percent change in incentives across areas and so is an estimate for the employment elasticity.

estimate of the employment elasticity. We estimate that the slope is 0.62 (s.e. 0.34), which is close to the benchmark 0.44 elasticity.

Overall, the finer regional-level analysis underscores our benchmark results. The employment changes are tightly linked to the percentage change in incentives. The elasticity obtained at the finer regional level is very close to the elasticities obtained from comparing the response in high-growth regions relative to low-growth ones, though the estimates are more imprecise. This highlights that the estimated difference between high and low earnings-growth regions are not sensitive to the specific cutoff used to define those regions.

Intensive margin responses. In Panel B of Table 1, we present the RDD results for observed log wages among those reporting positive earnings. The estimates are small and insignificant, and the sign of the estimates is sensitive to the estimation method used. For this reason we focus on the extensive margin estimates, which are robust.

Table 4: Elasticity Estimates using Contemporaneous Incentives

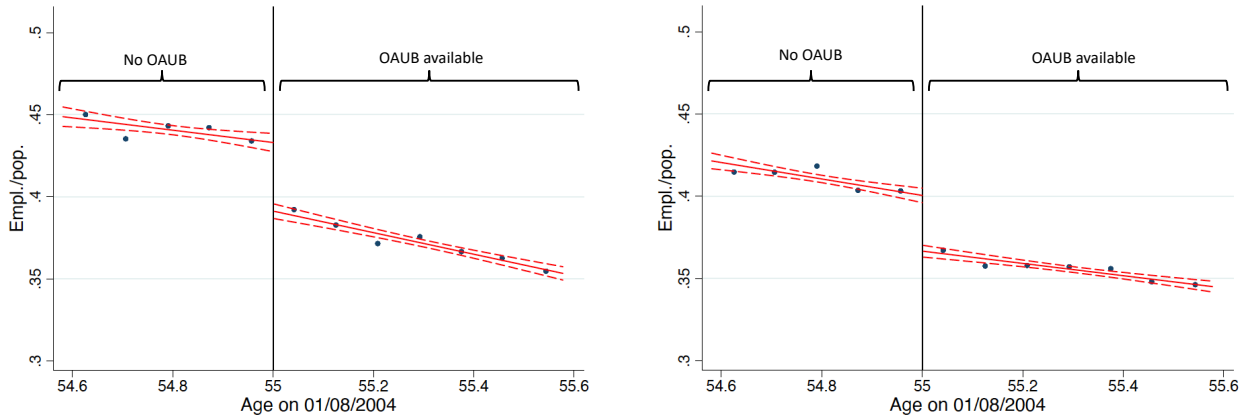
Region	(1) All regions	(2) High-growth	(3) Low-growth
1. Change in net return to work	25.13	24.97	25.31
2. Change in net wealth	0.0	0.0	0.0
Fraction eligible: **40%**			
3. Change in employment (%)	22.03	24.03	21.20
	(1.31)	(2.07)	(1.81)
4. Implied elasticity (Row 3) / (Row 1)	0.88	0.96	0.84
	(0.052)	(0.083)	(0.072)
Fraction eligible: **60%**			
5. Change in employment (%)	14.68	16.02	14.13
	(0.87)	(1.38)	(1.21)
6. Implied elasticity (Row 5) / (Row 1)	0.58	0.64	0.56
	(0.035)	(0.055)	(0.048)

Notes: This table shows the effect of the old age unemployment benefit reform (OAUB) on the net return to work (row 1), on the net wealth (row 2), on the change in employment (row 3 and 5) and on the resulting employment elasticity (row 4 and 6). The change in the net return to work is a result of the change in out-of-work benefits at the policy discontinuity. The percent changes in employment when 40% and 60% were eligible are shown in row 3 and 5, respectively. The employment elasticity is shown in row 4 and 6, respectively.

Employment vs. self-employment. In Appendix Table A.4, we study separately the effect of the reform on self-employed workers and workers with employment contracts. A potential concern with our elasticity estimates is that they only pick up reporting responses that mainly affect self-employed workers (Kopczuk, 2012). Nevertheless, the results in Appendix Table A.4 highlight that the change in employment is mainly driven by changes in employment rates of people in paid employment, while the change in self-employment is limited. Jobs in paid employment feature third party reporting, and so tax evasion is less prevalent in those type of jobs (Kleven et al., 2011). Therefore, our estimates on employment change pick up real responses to the policy and not simply changes in reporting behavior.

Future versus contemporaneous change in incentives. The estimated labor supply responses shown above are to benefits received in the future. These responses depend on both the responsiveness of labor supply to incentives and the way that individuals value future benefits relative to current benefits. To attempt to disentangle the responsiveness of labor supply from people's valuation of future benefits, we estimate the labor supply response to a subsequent reform that impacted contemporaneous work incentives for the same population of individuals.

Figure 4: Effect of the Old Age Unemployment Benefit (OAUB) Program on Employment



(a) High earnings growth regions

(b) Low earnings growth regions.

Notes: Fraction of individuals employed in a given year by month of birth (with age measured in months on the date of the OAUB reform, 01/08/2004). Individuals younger than age 55 on 01/08/2004 ceased to be eligible for the OAUB program, while older individuals could still claim the OAUB if they satisfied the eligibility criteria. We calculate the fraction employed in each year and then average this for the years 2005-2007. Panel (a) shows the fraction in high earnings growth regions, while panel (b) shows this for low earning growths regions. High growth regions are regions with an above median earnings growth rate between 2000 and 2013, while low growth regions have below median earnings growth. The solid lines are OLS lines of best-fit, allowing for different slopes and intercepts on both sides of the cutoff. The 95 percent confidence intervals are also shown.

We exploit a radical change in eligibility for an old age unemployment benefit program which provided generous benefits to individuals whose employment was terminated by the employer. On 1st August 2004, a reform raised the eligibility age for this benefit from 55 to 60. Individuals could therefore take up the benefit if they reached age 55 by 1st August 2004 and demonstrated that their employment was terminated by the employer. This created a cohort-based discontinuity in access to the benefit: individuals born before 1st August 1949 were potentially eligible for the benefit, and individuals born after were not eligible. In Appendix Section E.1, we provide further details and analysis of the benefit program.

We exploit a RDD strategy to estimate the labor supply response to the reform. Figure 4 shows employment rates for men over the years 2005-2007 by age of the individual (in months) on 1st August 2004.[29] We compare individuals who were slightly younger than 55 on 1st August 2004 to individuals who were slightly older than 55. As we move along the x-axis, we show the employment-to-population ratio for increasingly older cohorts. The vertical line shows the eligibility threshold. Cohorts younger than the threshold (left of the vertical line) did not have access to the generous old age unemployment benefit program at

[29]In our data, we only observe yearly earnings. As a result, even if someone stops working in the middle of the year, we will see positive earnings for that individual in that year. That is why we focus in this analysis on the years between 2005 and 2007. Outcomes in 2004 are excluded because this would include information prior to the reform.

age 55, while older cohorts (right of the vertical line) had access to the benefit. The figure shows a clear change in the employment rate around the discontinuity in both low- and high-growth regions. We find that employment changes are similar across regions, with 3.3 and 4.1 percentage point changes in employment in low- and high-growth regions, respectively. When pooling all regions, the estimated drop is 3.8 percentage points.

To calculate the employment elasticity implied by these employment changes, we calculate the percent change in the net return to work as a result of the reform, which we show in row (2) of Table 4. The net return to work is:

$$nrw_{it}^{l} = (1 - \tau(\tau^{pi}, \tau^{ss})) \cdot w_{it} - u_{it}^{l} + \cdot E_t(PV_{it}^{\text{Employed}_t, NDC} - PV_{it}^{\text{Not employed}_t, NDC}),$$

where l here reflects whether someone has access to old age UI (l = OAUB) or not (l = NOAUB). The change in net return to work is coming from the change in outside option, $nrw_{it}^{\text{NOAUB}} - nrw_{it}^{\text{OAUB}} = -(u_{it}^{\text{NOAUB}} - u_{it}^{\text{OAUB}})$.

We calculate the implied elasticity as calculated as $\frac{(P_t^{\text{OAUB}} - P_t^{\text{NOAUB}})/P_t^{\text{OAUB}}}{-(u_t^{\text{OAUB}} - u_t^{\text{NOAUB}})/nrw_t^{\text{OAUB}}}$ where $P_t^{\text{OAUB}} - P_t^{\text{NOAUB}}$ is the change in employment among workers who were eligible for the OAUB program and workers who lost that eligibility. This employment elasticity exploits the change in net return to work coming from the change in *contemporaneous* out-of-work benefits.[30]

Table 4 summarizes the key estimates and calculates the implied employment elasticity. We calculate that the percent change in incentives was around 24.97% in high-growth and 25.31% in low-growth regions. The reform had no direct effect on individuals' wealth. To translate the estimated employment change around the discontinuity to an employment elasticity, we need to take into account the fact that, besides reaching age 55, there were other eligibility criteria for the OAUB program. Most notably, individuals needed to have a sufficiently long employment work history and the termination of the job must have been involuntary. While we do not directly observe the fraction of people who satisfy these criteria, we can use survey data to infer this information. We calculate that the eligible population in this age group in Poland would be between 40% and 60%, with 60% being our preferred rate. We provide details on how we arrive at these numbers in Online Appendix E.

When the eligible fraction of the population is 40%, then the estimated change in employment at the discontinuity translates to a percent change in employment among the eligible population that is 22% when averaging over all regions, with a 21% change in low-growth regions and a 24% change in high-growth regions. The implied employment elasticity

[30] These individuals were age 49 at the time of the 1999 NDC pension reform, so they were covered by the NDC scheme.

is between 0.84-0.96, depending on region. This employment elasticity is almost double the estimated elasticity coming from the pension reform. This would imply that even if workers are responsive to the incentives built into the pension formula, they are less responsive than to contemporaneous changes in incentives.

When the eligible fraction of the population is 60%, the implied employment elasticity is 0.56-0.64, depending on region. Our preferred estimate averages over the two regions, giving an estimate of 0.58. This is 1.32 times larger than our baseline estimate on the pension reform (though the estimates are not statistically different from each other). Overall, these findings suggest individuals are somewhat less responsive to changes in future pension benefits than to changes in the contemporaneous return to work, which is consistent with modest discounting of future benefits above and beyond standard discounting for time and mortality.

We calculate similar changes in incentives for high- and low-growth regions and also estimate similar changes in employment across the two regions. This suggests that labor supply reacts similarly to contemporaneous changes in incentives for the two types of regions. The fact that the estimated elasticity does not vary much by region supports our assumption that the differential employment responses to the pension reform for high- and low-growth regions documented before reflect the differential change in incentives, not a differential responsiveness of labor supply across regions.

Employment change between age 56-59. In the Panel G of Table 3 we show the estimated incentive change, employment change, and the elasticity closer to the retirement age between age 56 and 59.[31] To make sure that our estimates are not contaminated by the OUAB reform we focus here on the unaffected cohorts who were born before 1949 August 1st. We assess that the change in incentives (between the high- and low-growth regions) is 4.80%, while the change in wealth is again very small. The estimated employment change is somewhat larger than for baseline estimates which leads to an 0.77 (s.e. 0.32) employment elasticity. As we see in section 7 below, the larger employment responses closer to the retirement age are consistent with the prediction of our structural model.

The estimates after age 55 could in principle be influenced by the interaction between the OUAB and the different pension system for the 1948 and 1949 cohorts. As we describe in detail in Online Appendix E, OUAB affects differently pensions under the DB and the NDC rules. Nevertheless, these interactions are similar for both the high-growth and low-growth

[31]The early retirement rules changed differently at age 60 for the 1948 and 1949 cohorts due to a constitutional court decision in 2008 and so we cannot incorporate ages 60 or later in our analysis. Similarly, due to eligibility for OAUB at age 55 of the 1948 cohort in 2004, but not the 1949 cohort at the DB-DC disconinuity, we cannot include age 55 and the year 2004 in our analysis.

regions. Therefore, if we compare the incentive and employment changes between high and low-growth regions, we net out the interactions between the OAUB and the different pension systems, and isolate the effect of the differential incentives operating through the pension systems. Further discussion on this is provided in Online Appendix E.

7 Effects over the lifecycle

Motivated by the sharp discontinuity in work incentives induced by the reform at age 50, our empirical work has focused on labor supply behavior near that age. However, pension reforms potentially impact labor supply at *all* ages. To place our results into this broader context, in this section we develop a parsimonious lifecycle model, estimate its parameters using our quasi-experimental variation for identification, and use the estimated model to evaluate the effects of the type of reform we study across the whole lifecycle. In the following three subsections, we outline the model, give our estimates, and show the implications of the reform for labor supply over all ages. Further details are given in Online Appendix F.

7.1 Model

The model is one in which heterogeneous agents, who are subject to uncertainty over earnings and survival, make consumption, saving and labor supply choices over their lifecycle.

Choices. Individuals make two choices each period – an extensive margin labor supply choice ($P_{it} = \{0, 1\}$), and a choice between consumption and saving.

Preferences. Individuals have preferences over consumption and leisure that can be represented by the following utility function:

$$U(c_{it}, l_{it}; \nu_i) = \frac{(c_{it}^{\nu_i} l_{it}^{1-\nu_i})^{1-\gamma}}{1-\gamma}, \tag{14}$$

where c and l are, respectively, consumption and leisure. The quantity of leisure consumed is given as $1 - hP$, which is equal to an endowment of leisure (normalized to 1) less a share of that endowment (h, set to 0.3) foregone in periods when the agent works. We assume that the weight each agent places on consumption in the utility function (ν) is constant across time but is heterogeneous in the population, and distributed as $\nu_i \sim N(\mu_\nu, \sigma_\nu^2)$.

Agents discount the future geometrically at rate β.

Demographics. Agents start working life at the age of 25 and face mortality risk. Conditional on surviving to t, the probability of surviving to period $t+1$ is s_{t+1}.

Earnings, Income and Assets. In each period, each agent has an earnings potential

w_{it}. This has a deterministic component that evolves with age and a stochastic component that follows an AR(1) process. We allow the deterministic component to vary with region of residence. This allows the model to be used to study the implications of the differing change in incentives across individuals with different wage growth over the lifecycle.

Agents get a job offer each period with a probability that follows a first-order Markov process. After observing the job offer and potential wage, they make a labor supply choice. If they work, their actual earnings, similarly to the treatment in Section 2, are $(1-\tau(\tau^{pi}, \tau^{ss}))w_{it}$: their potential wage net of taxation. If they do not work, their earnings are zero and they instead receive a welfare payment of u.

Pension Systems To be consistent with our previous simulations of the net return to work, we measure pension accrual as an increment to income. In each period, agents accrue an increment to their income which is proportional to their wage and depends on each of a) which system is prevailing (DB or NDC), b) whether they work, c) their age and d) their region. This captures the key dimensions of variation relevant for pension wealth accrual in our setting. Full details of how we model pension wealth accrual are given in Appendix F.1.

Agents save in a risk-free asset a_{it}, which earns a return of r. They cannot borrow. The budget constraint is:

$$a_{it+1} = (a_{it} + y_{it} - c_{it})(1 + r), \quad a_{it+1} \geq 0 \tag{15}$$

where y_{it} is income. Prior to retirement (age 65), income is equal to after-tax wage income if working and is equal to unemployment benefits when not working. In addition, we model additional returns to work from pension accrual as an increment to their income in a method similar to that used in French and Jones (2011). Thus, the difference between income from work and income from not work is the same net return to work as in equation (1) and is the same concept used earlier in the paper. After age 65, the individual retires.

Model Solution and Summary. This model contains six state variables which we collect in the vector: $\mathbf{X}_{it} = \{\text{region}_i, \nu_i, t, a_{it}, \text{offer}_{it}, w_{it}\}$. Two of these – the agent's region of residence $\text{region}_i \in \{\text{low growth, high growth}\}$ and their consumption weight (ν_i –their 'type') – represent permanent heterogeneity, and four of which – age (t), assets (a_{it}), the presence (or otherwise) of an employment (offer_{it}) and wages (w_{it}) – vary across the lifeycle. Agents maximize

$$V_t(\mathbf{X}_{it}) = \max_{\{c_{it}, P_{it}\}} U(c_{it}, l_{it}; \nu_i) + \beta\Big(s_{t+1}\mathbb{E}_t V_{it+1}(\mathbf{X}_{it+1})\Big) \tag{16}$$

subject to the asset accumulation equation (15), leisure of $l_{it} = 1 - hP_{it}$ and the determinants

Table 5: Parameter Estimates, Model Fit, and Policy Evaluation

Panel A: Parameterization	Value	
Interest Rate (r)	0.0288	
Discount Factor (β)	0.972	
Risk aversion (γ)	4	
Panel B: Estimated parameters	**Estimate**	**SE**
Consumption Weight Mean (μ_ν)	0.485	(0.037)
Consumption Weight St. Dev (σ_ν)	0.145	(0.068)
Panel C: Model fit		
Matched moments	Data	Model
Labor supply at age 50 (%)	64.7 (s.e. 0.01)	64.7
Reform labor supply effect, low-growth (%)	0.28 (s.e. 0.63)	1.37
Reform labor supply effect, high-growth (%)	-2.01 (s.e. 0.71)	-0.80
Implied difference in reform effect		
Reform labor supply effect, difference (high-low) (%)	-2.29 (s.e. 0.95)	-2.17
Panel D: Effect of switching from DB to NDC	**Effect**	
Net change in lifecycle labor supply, all	-1.8 months	
Net change in lifecycle labor supply, low-growth	-0.4 months	
Net change in lifecycle labor supply, high-growth	-3.3 months	
Panel E: Frisch Employment Elasticity	**Elasticity**	
Frisch Employment Elasticity at age 30	0.52	
Frisch Employment Elasticity at age 40	0.57	
Frisch Employment Elasticity at age 50	0.68	
Frisch Employment Elasticity at age 60	0.90	

Notes: Panel A reports parameters set prior to estimation. Panel B reports structural parameters estimated Indirect Inference. Panel C shows the three moments that the model targets. The final row of Panel C shows the difference in employment change between high and low growth regions. Panel D summarizes the overall net change in labor supply over the lifecycle as a result of switching from the DB system to the NDC system, using the estimated model to predict behavior for a cohort that spent their whole working life in the DB system and compare it to a cohort that spent their entire working life in the NDC system. To isolate the reform effect on changing the net return to work from the effect operating through a reduction in the overall generosity of the pension system, we scale down the accruals in the DB system (proportionally) to ensure that the two pension systems are revenue-equivalent. Panel E gives Frisch Employment Elasticities, calculated by perturbing individual wages at each age by 20% and calculating the percentage change in labor supply and dividing by 20%.

of income described in Appendix F.1. We solve the model using value function iteration. Appendix F.2 gives more details on the decision problem and Appendix F.3 gives further details on our solution method.

7.2 Parameterization and Estimation

Our approach to estimation of the model follows a two-step procedure. First, we set model parameters which can be identified external to the model or set with reference to the literature. These are given in Panel A of Table 5, and our choices are discussed in Section F.4. The parameters of the deterministic and AR(1) components of the earnings process are those in the simulation (see equation (10)). The Markov process governing unemployment is also that in the simulation, discussed in Section 4 and with parameter values given in Table C.2.

In a second step, we estimate the two parameters of the model which are most directly linked to the labor supply decisions of our population. These are the mean and variance of the distribution of the consumption weight in the utility function, which we denote by parameter vector χ (where $\chi = (\mu_\nu, \sigma_\nu^2)$). We estimate these using Indirect Inference, matching labor supply at the age of 50 and our baseline estimated employment response to the reform.

To estimate these parameters, we first solve the model and simulate behavior for a cohort who stayed in the DB system. We then solve and simulate for a cohort who, like those born just after the year-of-birth discontinuity, were moved to the new system at age 50. The reform reduces the net return to work and wealth for our modeled agents differentially by region in a manner that mimics the falls described in Section 4. The solution to our model allows us to predict, at any candidate vector of parameters, what the effects of these changes will be on labor supply. We choose parameters to best match the model-implied employment response to the reform in each region (in addition to matching the employment rate at age 51 (64.7%))[32]. This gives us three moment conditions and two parameters to estimate.

Our identification of the parameters of the structural model therefore leverages our causal estimates of the policy reform. The variance of the leisure weight is identified by the responsiveness of labor supply to the reform. When the variance of the leisure weight is greater, there is more dispersion in reservation wages. When reservation wages are more dispersed, there are fewer people near the employment margin, and thus labor supply is less responsive to the reform.

Panel B of Table 5 gives our structural estimates and their associated standard errors. Panel C shows the moments that the model targets, with all modeled moments lying within 95% confidence intervals of their empirical analogues. The model-implied wealth effects on labor supply are larger than the empirical effects, and so the model overpredicts the employment response to the loss of wealth due to the reform. However, the model very closely matches the difference in the employment effect between high- and low-growth regions, which we use in Section 6 to calculate our headline elasticity. The estimated difference is -2.29 versus a model implied value of -2.17. Recall that it is these cross-region differences that capture the intertemporal substitution effect, which is the focus of this study.

7.3 Results

To evaluate the effects of the incentives from different pension systems on labor supply across the whole of the lifecycle, we first use our estimated model to predict behavior for a

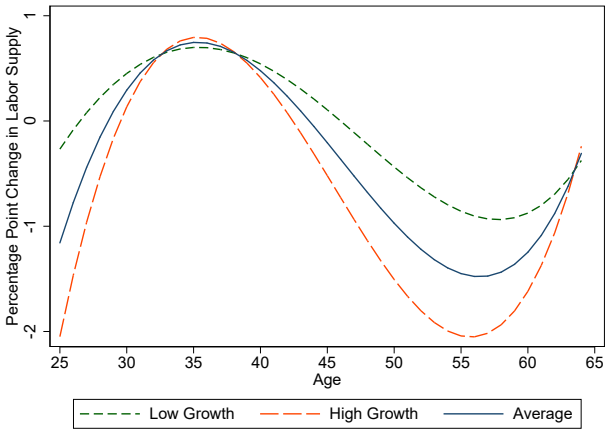
[32]See the discussion at the end of Section 3.2 and Table B.5.

cohort that spent their whole working life in a system with NDC work incentives. We then compare their employment to a cohort who spent their entire working life in a system with DB work incentives. To focus on the role played by changes in the net return to work we ensure that the two systems we are comparing are revenue-equivalent by scaling down the value of pension accrual for those in work under the DB system proportionally at each age by a factor that ensures revenue equivalence (Online Appendix F has further details on the implementation of this counterfactual experiment). We are comparing behavior under two systems which are equally costly to implement but which spread work incentives across the lifecycle in different manners.

Figure 5 shows the reform-induced change in labor supply (in percentage points) across the lifecycle in each region. The model-predicted effect of the reform at age 50 is similar to our estimated effect. This is partly by design (the model was estimated to target those), although the experiment here – the implementation of an NDC system over the whole lifetime – differs from the impact of the NDC reform on the transition cohorts. Hence, agents in the modeled 'steady-state' cohorts can adjust their behavior at all ages. The model also predicts negative effects on labor supply at the very start of working life. In these periods, when earnings are at their lowest, the DB system provides strong work incentives through the fact that a period of work adds to the number of 'contributory' years which multiplies the base for pension calculation (see the pension benefit formula in equation (4)). That base will be substantially higher than current earnings, which means that these years are a 'cheap' time to accrue benefits under the DB system relative to the NDC system. In contrast, pension wealth accrual under the NDC system in these years is proportional to (low) earnings. When agents are in their 30s, on the other hand, the NDC system provides better incentives since NDC accrual is proportional to (now higher) earnings.

Figure 5 illustrates that switching to the NDC scheme increases labor supply at some ages and reduces labor supply at other ages. Panel D of Table 5 shows that, averaged over the lifecycle and over both low- and high-growth regions, employment would, on average, be reduced by almost two months under the NDC scheme, compared to an equally-costly DB scheme. For those living in low-growth regions, increases in labor supply among those in their 30s and the falls at other ages almost exactly offset (with a net fall in average labor supply of less than half a month). For individuals in high-growth regions, however, labor supply over the lifeycle falls by over three months, with the large falls at the start and end of the career only partially offset by modest increases when those agents are in their 30s. This change for those in the high-growth regions is non-trivial. For instance, existing studies

Figure 5: Effect of Switching to an NDC on Labor Supply Over the Lifecycle



Notes: This figure plots the percentage point change in the employment-to-population ratio at each age coming from switching from the DB pension scheme to the NDC scheme. We predict behavior for a cohort that spent their whole working life under DB work incentives and compare it to a cohort who spent their entire working life under NDC work incentives. To isolate the reform effect on changing the net return to work from the effect operating through a reduction in the overall generosity of the pension system, we scale down the accruals in the DB system (proportionally) to ensure that the two pension systems are revenue-equivalent. The dashed green line shows the effect of the reform for individuals with low earnings growth, the red dashed line shows the effect for individuals with high earnings growth, and the blue line shows the average of the two. We smooth the responses using a 4th order polynomial.

suggest that extending the early retirement age by one year extends work by roughly three months, depending on the country, institutional environment, gender, and data, with some studies suggesting more than three months (e.g., Lalive and Staubli 2015) and some studies suggesting less (e.g., Cribb et al. 2016).

An important reason why the negative effects dominate is that the estimated labor supply elasticities are greater at older ages (when the NDC reform reduced work incentives) than they are in their 30s (when the reform improved incentives). We calculate Frisch employment elasticities to be 0.52 at age 30, 0.57 at age 40 and 0.68 at age 50.[33] For those in their 50s, there is a greater mass of agents close to the participation margin than for those their 30s, when (male) labor supply is very high.[34] Ages around 30 are, therefore, an expensive time

[33]See Appendix F.7 for details on how we calculate these elasticities and Figure F.2(b) for a profile of elasticities across the lifecycle. These elasticities are calculated for an anticipated change in wages at those ages, implying opportunities for inter-temporal substitution of labor supply across the whole lifecycle. The elasticity we estimate using our quasi-experiment was for an unanticipated change in the net return to work, which limits the opportunities for inter-temporal substitution of labor supply and results in a smaller elasticity. This pattern of increasing elasticities across the lifecycle is also found by those applying extensive margin labor supply models to US data. For example, French (2005) finds employment elasticities of between 0.19 and 0.37 at age 40 and between 1.04 and 1.33 at age 60. Fan et al. (2019) (Figure 5) estimate elasticities that are lower than 0.2 for those at younger ages and that rise to 1 around retirement ages.

[34]At the very start of the lifecycle, when earnings are lowest and the therefore the value of the model's outside option (welfare) is highest, there is also a large mass of individuals close to the participation margin.

for the work incentives to be sharpened from a government revenue standpoint: labor supply is high, and so extra work incentives from higher pension accrual have substantial revenue implications, and responsiveness is lower, so revenue gains from increased labor supply are modest. Targeting incentives at those ages where labor supply will be most responsive is a consideration that policy-makers need to consider carefully when designing policies that have implications for work incentives across the lifecycle.

8 Conclusion

This paper shows that individuals' labor supply is responsive to changes in the link between *current* social security contributions and *future* pension benefits, even 10-15 years before the expected retirement age. We demonstrate this by exploiting the 1999 Polish pension reform, which switched a DB system to an NDC system. Under the DB system, earnings in a small number of years – those in which earnings were at their peak – were particularly important in determining pension benefits. On the other hand, in the NDC system, all years are roughly equally important. In line with these changed work incentives, we find changes in labor supply that imply an employment elasticity with respect to the net return to work (which includes both the wage and the gain in expected pension benefits) of 0.44 (s.e. 0.18).

Our estimates, therefore, show that the incentives built into the pension calculation formula matter, and so the design of pension systems can have implications for labor supply throughout working life. Nevertheless, as demonstrated by our lifecycle model, how much these incentives matter varies over the lifecycle. Tightening the link between pension benefits and contributions might not have the desired impact if the changes in incentives do not target individuals for whom labor supply is most responsive.

It is worth emphasizing that pension design needs to consider more than labor supply. Tightening the link between current contributions and future benefits has implications for the distribution of living standards of retirees and could increase inequality among pensioners (Diamond and Gruber, 1999). Recent evidence highlight the importance of that trade-offs (see e.g. (O'Dea, 2019; Haller, 2019; Kolsrud et al., Forthcoming)). Therefore, even if our estimates can be used to quantify the potential efficiency gains from considering such reforms, the distributional aspects of such policies should be also taken into account. Balancing efficiency and distributional concerns should be a central focus for future research and policy discussion.

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Online Appendix A Additional Figures and Tables

Figure A.1: Polish Social Security Authority (ZUS) Annual Letter to those in NDC Scheme

Informacja o stanie konta ubezpieczonego w Zakładzie Ubezpieczeń Społecznych

III. Suma na Twoim koncie i subkoncie

1. Konto	294 601,34 zł
2. Subkonto	31 501,06 zł
Razem:	**326 102,40 zł**

IV. Składki należne i wpłacone (bez waloryzacji)

Subkonto:	
1. Składki należne - czyli te, które wynikają z dokumentów przysłanych do ZUS	9 193,67 zł
2. Składki wpłacone na subkonto	9 193,67 zł
Otwarty fundusz emerytalny:	
1. Składki należne - czyli te, które wynikają z dokumentów przysłanych do ZUS	18 400,19 zł
2. Składki odprowadzone do otwartego funduszu emerytalnego	18 400,19 zł

V. Hipotetyczna (prognozowana) wysokość Twojej emerytury

Twój wiek emerytalny to 65 lat

Emerytura obliczona na podstawie konta

Podajemy ją w dwóch wariantach:

Wiek, w którym przejdziesz na emeryturę	**Wariant I** Pracujesz do emerytury i składki wpływają średnio w tej samej wysokości co do tej pory	**Wariant II** W 2019 roku przestajesz pracować i do emerytury nie wpływają już nowe składki
65 lat	1 718,99 zł	1 348,91 zł

Ważne! Jeśli przekroczyłeś wiek emerytalny i nie masz jeszcze ustalonej emerytury, to jej prognozowaną wartość podajemy dla Twojego rzeczywistego wieku oraz dla kolejnych pięciu lat.

Emerytura obliczona na podstawie konta i subkonta

Podajemy ją w kolejnych wariantach:

Twój wiek emerytalny	**Wariant III** Pracujesz do emerytury i na konto i subkonto wpływają składki średnio w tej samej wysokości co do tej pory	**Wariant IV** W 2019 roku przestajesz pracować i do emerytury nie wpływają już nowe składki na konto i subkonto
65 lat	1 964,96 zł	1 493,14 zł

Ważne! Pamiętaj, że na 10 lat przed Twoim wiekiem emerytalnym środki z OFE będą co miesiąc wpłacane na Twoje subkonto w ZUS. Przy prognozie emerytury nie uwzględniliśmy tego, co masz jeszcze w OFE.

Co dają Ci ubezpieczenia społeczne już teraz

Ubezpieczenia społeczne poza emerytalnym obejmują także:

- ubezpieczenie chorobowe,
- ubezpieczenie wypadkowe,
- ubezpieczenia rentowe.

Ważne! Dzięki nim możesz uzyskać jednorazowe, okresowe lub stałe świadczenia w razie choroby, urodzenia dziecka i rodzicielstwa, wypadku przy pracy, niepełnosprawności, niezdolności do pracy.

Na Platformie Usług Elektronicznych na www.zus.pl możesz sprawdzić, jakim ubezpieczeniom podlegasz.

Świadczenia, które Ci przysługują, jeśli masz ubezpieczenie chorobowe

Zasiłek chorobowy w razie niezdolności do pracy z powodu choroby

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Notes: An example of the annual letter sent to all individuals in the NDC system after the 1999 reform. It states the total accumulated funds in the notional account, the retirement age of the individual, and the anticipated pension at age 65 under two scenarios: 1) working until retirement age at current earnings level and 2) stopping work in the current year and not making further contributions to the NDC account.

Table A.1: The Effect of the Pension Reform on Employment And Wages, Robustness to Bandwidth Choice of the Local-Linear Regression

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Change in employment probability						
High-growth	-0.0174***	-0.0263**	-0.0208***	-0.0153***	-0.0155***	-0.0209***
N = 545,435	(0.0050)	(0.0130)	(0.0067)	(0.0041)	(0.0036)	(0.0058)
Low-growth	0.0027	0.0085	0.0032	0.0001	0.0004	0.0040
N = 818,487	(0.0041)	(0.0106)	(0.0055)	(0.0034)	(0.0029)	(0.0061)
Difference (High-Low)	-0.0201***	-0.0348***	-0.0240***	-0.0154***	-0.0159***	-0.0249***
	(0.0065)	(0.0168)	(0.0087)	(0.0053)	(0.0046)	(0.0084)
Panel B: Change in log wage						
High-growth	0.0119	0.0867*	0.0093	0.0073	-0.0012	0.0118
N = 545,435	(0.0174)	(0.0459)	(0.0233)	(0.0144)	(0.0125)	(0.0251)
Low-growth	0.0029	0.0117	0.0063	-0.0093	-0.0119	0.0135
N = 818,487	(0.0145)	(0.0378)	(0.0194)	(0.0120)	(0.0105)	(0.0260)
Difference (High-Low)	0.0090	0.0750	0.0030	0.0166	0.0107	-0.0017
	(0.0226)	(0.0595)	(0.0303)	(0.0187)	(0.0163)	(0.0361)
Sample	Donut	Donut	Donut	Donut	Donut	Donut
$f(z_i)$	local-linear	local-linear	local-linear	local-linear	local-linear	local-linear
net-of-placebo	no	no	no	no	no	no
Bandwidth	150	50	100	200	250	Calonico et al.

Notes: This table shows robustness of the local-linear regression estimate (shown in Column 3 in Table 1) for various choices of the bandwidth, measured in days, on each side of the discontinuity. We show the estimated change in employment (panel A) and log wage (measured as earned income of workers) for those in work (panel B) at the reform discontinuity. Each cell in the table shows the β coefficient of the RDD specification in equation (13). The rows show the estimated employment change for different regions. The first and second row show the estimated effect in high and low-growth regions, respectively. High-growth regions are regions with above median earnings growth rate between 2000 and 2013, while low-growth regions have below median growth. The third row shows the difference between the high and low-growth regions. In each column we report a kernel-weighted local linear regression, where we set the bandwidth at different levels. In Column (1) we set the bandwidth at 150 days as in Table 1. In Columns 2-5 we apply values of bandwidth between 50 and 250 days. Column (6) chooses bandwidth according to the methodology in Calonico et al. (2014), and it is 87 days for the low-growth and 120 days for the high-growth regions. In each column we apply the donut hole RDD specification where we exclude those born between December 16th and January 5th. We report robust standard errors in parentheses following the recommendation in Calonico et al. (2014). Significance levels are: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.2: The Effect of the Pension Reform on Employment And Wages, Robustness to Donut Size

	(1)	(2)	(3)	(4)
Panel A: Change in employment probability				
High-growth	-0.0149***	-0.0105***	-0.0145***	-0.0073
N = 545,435	(0.0026)	(0.0037)	(0.0031)	(0.0044)
Low-growth	-0.0018	0.0014	-0.0027	0.0022
N = 818,487	(0.0023)	(0.0030)	(0.0025)	(0.0036)
Difference (High-Low)	-0.0131***	-0.0119***	-0.0119***	-0.095**
	(0.0035)	(0.0048)	(0.0040)	(0.0056)
Panel B: Change in log wage				
High-growth	-0.0055	0.0095	-0.0196*	-0.0007
N = 313,720	(0.0092)	(0.0130)	(0.0108)	(0.0153)
Low-growth	-0.0043	0.0176	-0.0210**	0.0215*
N = 439,545	(0.0077)	(0.0109)	(0.0091)	(0.0128)
Difference (High-Low)	-0.0012	-0.0081	0.0014	-0.0222
	(0.0120)	(0.0170)	(0.0141)	(0.0199)
Sample	Donut (base.)	Donut (base.)	Donut (Jan-Dec)	Donut (Jan-Dec)
$f(z_i)$	linear trend	local-linear	linear trend	local-linear
net-of-placebo	no	yes	no	yes

Notes: This table shows robustness to the change in the size of the donut in the benchmark regression specification (shown in Table 1). The table shows the estimated change in employment (panel A) and log wage (measured as earned income of workers) for those in work (panel B) at the reform discontinuity. Each cell in the table show the β coefficients of the RDD specification shown in equation (E.4) (Column 1 and 3) or in equation (13) (Column 2 and 4). The rows in Panel A show the estimated employment change for different regions. The first and second row show the estimated effect in high- and low-growth regions, respectively. High-growth regions are regions with above median earnings growth rate between 2000 and 2013, while low-growth regions have below median growth. The third row shows the difference between the high- and low-growth regions. In Column (1) and (2) we apply the benchmark donut hole RDD specification where we exclude those born between December 16th and January 5th. In Column (3) and (4) we apply a broader donut hole where we exclude everyone who was born in January or December. In Columns (1) and (3) we estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the cutoff. In Column (2) and (4) we estimate a kernel-weighted local linear regressions, where we set the bandwidth at 150 days. Column (2) and (4) estimates the change at the reform discontinuity relative to the change at the placebo discontinuity as in equation (13). The placebo discontinuity is estimated between the 1949 and 1950 cohorts, both of which switched to the NDC system. We report robust standard errors in parentheses. For the local-linear regressions we calculate robust standard errors following Calonico et al. (2014). Significance levels are: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.3: Placebo Estimates on Employment and Wages

	(1)	(2)	(3)
	men	men	women
	1947-1948	1949-1950	1948-1949
Panel A: Change in employment probability			
High-growth	-0.0058	-0.0043	0.0043
	(0.0033)	(0.0026)	(0.0036)
N	395,819	647,006	1,349,940
Low-growth	-0.0018	-0.0004	-0.0000
	(0.0027)	(0.0021)	(0.0029)
N	590,418	977,555	2,002,716
Difference (High-Low)	-0.0040	-0.0039	0.0043
	(0.0043)	(0.0033)	(0.046)
Panel B: Change in log wage			
High-growth	-0.013	-0.016	0.004
	(0.011)	(0.009)	(0.013)
N	290,184	314,948	598,753
Low-growth	-0.007	-0.022*	0.016
	(0.010)	(0.008)	(0.011)
N	281,750	445,816	859,847
Difference (High-Low)	-0.001	-0.008	-0.012
	(0.015)	(0.012)	(0.017)
Sample	Donut	Donut	Donut
$f(z_i)$	linear trend	linear trend	linear trend
net-of-placebo	no	no	yes

Notes: This table shows the estimated change in employment (panel A) and log wage (measured as earned income of workers) for those in work (panel B) at three "placebo" discontinuities. Each cell in the table shows the β coefficients of the RDD specification shown in equation (E.4). Column (1) shows the employment and wage change between two cohorts (those born in 1947 and 1948), neither of whom were impacted by the reform, Column (2) shows between two cohorts (born in 1949 and in 1950) who were both impacted by the reform, while Column (3) shows the employment and wage change for women between two cohorts (those born in 1948 and 1949, net of placebo), who were much less affected by the reform at the net discontinuity. We estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the cutoff. We also apply the donut hole RDD specification where we exclude those born between December 16th and January 5th. We report robust standard errors in parentheses. Significance levels are: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.4: The Effect of the Pension Reform on Employment And Wages, by Employment and Self-Employment

	(1)	(2)	(3)	(4)	(5)
Panel A: Change in employment probability					
High-growth	-0.0204***	-0.0156***	-0.0175***	-0.0098***	0.0005
N = 545,435	(0.0024)	(0.0026)	(0.0050)	(0.0037)	(0.0018)
Low-growth	0.0013	0.0048	0.0038	0.0056*	-0.0033
N = 818,487	(0.0020)	(0.0021)	(0.0040)	(0.0030)	(0.0015)
Difference (High-Low)	-0.0217***	-0.0204***	-0.0213***	-0.0154***	0.0038
	(0.0031)	(0.0033)	(0.0064)	(0.0048)	(0.0023)
Panel B: Change in log wage					
High-growth	-0.014*	-0.016*	-0.011	-0.001	0.061
N = 313,720	(0.008)	(0.009)	(0.016)	(0.012)	(0.042)
Low-growth	-0.014**	-0.017**	-0.005	0.009	0.027
N = 439,545	(0.007)	(0.007)	(0.014)	(0.010)	(0.035)
Difference (High-Low)	0.000	0.000	-0.006	0.009	0.035
	(0.010)	(0.011)	(0.021)	(0.016)	(0.054)
Sample	Full	Donut	Donut	Donut	Donut
$f(z_i)$	linear trend	linear trend	local linear	linear trend	linear trend
net-of-placebo	no	no	no	yes	yes
Type of employment	Empl.	Empl.	Empl.	Empl.	Self-empl.

Notes: This table shows the estimated change in employment (panel A) and log wage (measured as earned income of workers) for those in work (panel B) at the reform discontinuity by category of employment. Columns 1-4 shows the estimated employment change when the outcome variable is 1 only if the worker is in employment (and not in self-employment). In column 5, the outcome variable is 1 if the worker is in self-employment. Each cell in the table shows the β coefficient of the RDD specification shown in equation (E.4) (Columns 1-3) or in equation (13) (Column 4). The rows show the estimated employment change for different regions. The first and second row show the estimated effect in high and low-growth regions, respectively. High-growth regions are regions with above median earnings growth rate between 2000 and 2013, while low-growth regions have below median growth. The third row shows the difference between the high and low-growth regions. In Column (1) we use the full dataset. In Columns (2)-(4) we apply the donut hole RDD specification where we exclude those born between December 16th and January 5th. In Columns (1), (2) and (4) we estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the cutoff. Column (3) estimates a kernel-weighted local linear regression, where we set the bandwidth at 150 days. Column (4) estimates the change in employment at the reform discontinuity relative to the change at the placebo discontinuity as in equation (13). The placebo discontinuity is estimated between the 1949 and 1950 cohorts, both of which switched to the NDC system. We report robust standard errors in parentheses. For the local-linear regression we calculate robust standard errors following Calonico et al. (2014). Significance levels are: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Online Appendix B Household Survey Data

Beyond our administrative data, we use two additional data sources: the Polish Household Budget Survey (HBS) and the Polish Labor Force Survey (LFS). Both of these data sources are large representative household surveys. However, they are many times smaller than our administrative data and have too few observations from each cohort for us to apply the RDD empirical strategy to study the labor supply responses to the NDC reform.

The HBS includes a rotating panel where a household is interviewed in two consecutive years. This allows us to observe individuals' transitions between unemployment and employment across years, where unemployment is measured as receipt of unemployment benefits. Moreover, the HBS has detailed information about the type of income individuals receive. We make use of this to estimate the fraction of individuals who receive retirement pensions before the full or early retirement ages, and who are therefore in excluded sectors and special occupations not affected by the pension reform.

The LFS is a large survey studying employment outcomes in the Polish population. Since the LFS captures all types of employment, including agricultural labor which does not appear in our administrative data, we are able to estimate employment rates with and without agricultural workers (see Appendix Table B.5). The data also contain some information on tenure, firm size and the type of employment contract for individuals in work. We exploit this information to estimate whether an individual was eligible for old age unemployment benefit(s) following the 2004 reform (see Online Appendix E).

Table B.5: Employment Rate for Men at Various Ages in the Administrative Data, Labor Force Survey and Household Budget Survey, 2000-2002.

	(1)	(2)	(3)	(4)	(5)
	Non-Agricultural Empl./Pop.		Total Empl./Pop.		Unempl./Pop.
	Admin. Data	LFS	LFS	HBS	LFS
1. Age 51 (cohorts: 1949-1951)	0.51	0.52	0.65	0.66	0.11
Number of Observations	890,620	5,141	5,141	2,299	5,054
2. Age 51-54 (cohorts: 1948-1949)	0.49	0.48	0.60	0.61	0.10
Number of Observations	1,669,539	9,485	9,485	4,254	9,410
3. Age 21-64 (cohorts: all)	0.56	0.56	0.68	0.68	0.12
Number of Observations	11,662,286	64,143	64,143	30,959	63,539
4. Age 50-54 (cohorts: all)	0.50	0.52	0.65	0.63	0.09
Number of Observations	3,907,140	7,771	7,771	10,811	7,678

Notes: This table compares the estimated employment rate for men in our administrative data with the employment rates in representative household surveys using the years between 2000 and 2002. Row 1 reports the employment to population rate for those who were 51 years old between 2000 and 2002, row 2 for those who were between 51 and 54 years old and born around the discontinuity (the 1948 and 1949 cohorts) and row 3 for those who were between age 21 and 64. We focus on non-agricultural employment as we do not observe agricultural employment in the administrative data. Note that agricultural workers belong to a separate pension system and are unaffected by the pension reform. Column (1) reports total non-agricultural employment divided by the total population for all males. Column (2) reports the same using the Labor Force Survey (LFS), the largest household study in Poland that provides the official measures of employment and unemployment. Columns (3) and (4) calculate total employment (including agricultural workers) divided by the total population in the LFS and Household Budget Survey (HBS) for the different age groups.

Online Appendix C Net Return to Work Calculation

C.1 Change in net return to work from DB to NDC switch

In this section we provide a detailed description of how we calculate the net return to work. The percent change in net return to work (which is also shown in equation (3)) is:

$$\frac{\Delta nrw_t}{nrw_t^{DB}} = \frac{d\cdot(E_t[\Delta PV_{it}^{NDC}]-E_t[\Delta PV_{it}^{DB}])}{E_t[(1-\tau(\tau^{pi},\tau^{ss}))\cdot w_{it}-u_{it}]+d\cdot E_t[\Delta PV_{it}^{DB}]}. \tag{C.1}$$

We calculate $E_t[(1-\tau(\tau^{pi},\tau^{ss}))\cdot w_{it}-u_{it}]$ as follows.

Poland has a flat income tax rate that has changed only slightly since before the reform we study, and so we set $\tau^{pi}=0.19$. There is a higher marginal tax rate for those making approximately 2.5 $\times$ average earnings. However, at a similar earnings level the individual hits the cap on social security contributions, making the tax function effectively linear. Income taxes apply to income net of social security contributions (paid by the employees). As a result, the after-tax income if working is:

$$w_{it}(1-\tau(\tau^{pi},\tau^{ss})) = w_{it}(1-\tau^{pi}(1-\tau^{ss})-\tau^{ss}). \tag{C.2}$$

We calculate average after-tax wages of workers in equation (C.2) using our administrative data in the years between 2000 and 2002. The average out of work benefit, $E_t[u_{it}]$, is calculated as follows. Those working last period are eligible for an unemployment benefit for the first six months of unemployment, which is a flat taxable benefit equaling 40% of the average wage income of workers. After six months, the individual receives a flat untaxable welfare benefit equaling 30% of the average wage income of workers. Given that our model is an annual one, we assume that if they worked last period, the individual receives unemployment for 50% of the year and welfare for 50% of the year, so $u_{it}=[(1-\tau^{pi})\cdot 0.5\cdot 0.4\cdot \overline{w}_t]+[0.5\cdot 0.3\cdot \overline{w}_t]$. Those not working last period receive a welfare benefit of $u_{it}=[0.3\cdot \overline{w}_t]$. The actual numbers of the tax formula that we use are presented in Table C.1.

We calculate the $E_t[\Delta PV_{it}^{NDC}]$ and $E_t[\Delta PV_{it}^{DB}]$ as follows. First, we simulate 2,000 life cycle earnings profiles following the procedure described in Section 4. In the first step, we simulate wages according to equation (10). This equation has a deterministic component capturing the age profile of wages and a stochastic component of AR(1) + MA(1) as specified in equation (11). In the second step, we simulate unemployment spells according to a Markov process. The parameter values of the benchmark simulation are shown in Table C.2. Table 3 shows that our estimated labor supply elasticity is robust to different parameter values for the wage process.

For each individual, we calculate the pension benefit at age 65 given their lifecycle earnings and the pension rules. To determine $b_{i65}^{\text{Employed}_t,NDC}$, we calculate the starting capital at age 50 and then apply the pension formulas described in equations (5) and (6). Panel C of Table C.1 shows the parameter values for the pension uprating rate r^{NDC} and life expectancy $E[T|t=65]$ that we used for the calculations. We calculate $b_{i65}^{\text{Not Employed}_t,NDC}$ using individual i's life cycle profile but assuming they were not working at age t.

To calculate $b_{i65}^{\text{Employed}_t,DB}$, we apply the pension formulas described in equation (4). As before, we calculate $b_{i65}^{\text{Not Employed}_t,DB}$ by taking the life cycle profile but assuming that the individual is not working

at age t. For both pension systems, we apply the minimum pension if someone's pension level is below that threshold (Panel B of Table C.1 shows the value of the minimum pension).

Once we have the difference in pension benefits if an individual works at age t, $b_{i65}^{\text{Employed}_t,k} - b_{i65}^{\text{Not Employed}_t,k}$, with $k \in \{DB, NDC\}$, we apply equation (9). The real pension uprating rate r^{index} and the real risk free interest rate r are shown in Part D of Table C.1. The survival rates $S_{s|t}$ at age t are calculated from the survival probabilities in official life-tables. The figure shows at each age the probability of surviving one more year, s_t. Then we calculate survival rates as $S_{s|t} = \prod_{l=t}^{l=s} s_l$.

Once we calculate ΔPV_{it}^k for each individual, we take the average across individuals to obtain $E_t[\Delta PV_{it}^{NDC}]$ and $E_t[\Delta PV_{it}^{DB}]$.

In Appendix Table C.3, we also provide further detail on what drives the differential incentives across regions. In Column (1) we simulate the change in the incentives if we keep the initial wage at age 30 and the trend (wage growth) the same across regions but allow the shape of age profiles to differ. Since the shape of age profiles is very similar across locations the differential change in incentives is close to zero. In Column 2, we also allow initial wages to differ, but assume the wage growth is the same across locations. We see that the initial differences in wages contribute to the incentives differences between locations. In Column (3) we report the benchmark estimates allowing differential initial wages, trend, and shape of age profile. The table shows that the difference in the change in net return to work is driven partly by different levels of wage between high- and low-growth regions, and partly by differences in the estimated time-trend parameters. Finally, Column (4) shows that the incentive change is similar if we estimate the wage process with individual fixed effects.

Table C.1: Parameter Values Used for Calculating the Net Return to Work

Panel A: parameters of the tax function	**Value**	**Source**
τ^{pi} (income tax)	0.19	Official tax
τ^{ss} in eq. (4) (soc. sec. worker cont. rate)	0.1871	and social security rates
τ^{ss} in eq. (6) (total pension cont. rates)	0.1952	
u_{it} (unemployment benefit and welfare,	$(1-\tau^{pi}) \cdot 0.5 \cdot 0.4 \cdot \bar{w}_t$	Official rates
working previous period)	$+0.5 \cdot 0.3 \cdot \bar{w}_t$	
u_{it} (welfare, not working previous period)	$0.3 \cdot \bar{w}_t$	
Panel B: parameters of the pension system		
r^{index} (pension uprating rate)	0.0116	Off. rates, (2000-20)
Minimum pension	$0.2 \times \bar{w}_{65}$	Off. rates &
		administrative tax data
Panel C: NDC-specific parameters		
r^{NDC} (NDC contribution uprating rate)	0.0381	Off. figures, (2000-17)
$E[T\|t=65]$ (life expectancy at age 65)	209.5 months	Off. life-tables
Panel D: discounting parameters		
r (risk-free rate)	0.0288	10-year gov. bonds (2000-19)
$S_{s\|t}$ (survival probability)		Off. life-tables

Notes: This table shows the parameter values used for calculating the net return to work defined in equation (1).

Table C.2: Parameter Values Used for Simulating the Earnings Process

Parameter	Value		Source
Panel A: region-specific deterministic wage component			
	Low	High	
constant	-2.4688	-3.2599	Estimation of (10)
age	1.0433	1.1344	(dataset: administrative tax data)
age^2	-0.0328	-0.0370	
age^3	4.58E-04	5.34E-04	
age^4	-2.41E-06	-2.89E-06	
t	0.04338	0.0517	
Panel B: stochastic wage component			
ρ	0.9496		GMM estimation of (11)
θ	-0.2353		(dataset: administrative tax data)
σ_ε^2	0.0591		
σ_ξ^2	0.0276		
Panel C: unemployment process			
$Pr(UI_{it} = 1 \mid P_{it} = 1)$	0.0340		Estimation of Markov process
$Pr(P_{it} = 1 \mid UI_{it} = 1)$	0.4031		(dataset: HBS)

Notes: This table shows the parameter values used for simulating the lifecycle earnings profiles. Panel A shows the region-specific deterministic wage component of the wage process (see equation (10)). We estimate these values from the administrative tax data between 2000 and 2013. Panel B shows the parameter values of the stochastic components in the wage equation (see equation (11)). We estimate these values using a GMM estimator from the administrative tax data between 2000 and 2013. Panel C shows the parameter values of the unemployment process. These values are estimated from the Household Budget Survey (HBS), where we directly observe unemployment.

Table C.3: Change in net return to work (%) under different parameterizations of deterministic component of wage process.

	(1)	(2)	(3)	(4)
1. High-growth	-9.59	-9.59	-11.17	-12.10
2. Low-growth	-8.93	-5.94	-5.94	-6.06
3. Difference (High-Low)	-0.66	-3.68	-5.23	-6.04
Differential shape of age-profile	Yes	Yes	Yes	Yes
Differential level		Yes	Yes	Yes
Differential shape of time-trend			Yes	Yes
Individual fixed-effects				Yes

Notes: This table shows the effect of the pension reform on the net return to work for different hypothetical parameterizations of the deterministic component of the wage process. The purpose of columns (1)-(3) of this table is to illustrate what part of the wage process drives the difference in the change in the net return to work between the high and low-growth regions. Column (1) shows the net return to work in a scenario in which the high-growth and low-growth regions share the same trend rate of growth - assumed to be that estimated for the low-growth region in both cases - but have the different parameterizations of the age polynomial, which is set to their estimated values. The intercept of the low-growth wage process is adjusted such that individuals in the two regions have the same wages on average over the lifecycle. Column (2) shows the net return to work in which the high-growth and low-growth regions share the same trend rate of growth but have the estimated intercept and parameters of the age polynomial. Column (3) shows the net return to work in which the high-growth and low-growth regions differ in terms of time trend, the intercept, and parameters of the age polynomial, which are assigned their estimated values. This is also our baseline wage process. Finally, column (4) shows the net return to work in which the high-growth and low-growth region parameters were estimated using an individual fixed-effects specification, where the level of fixed effects is chosen to match the average observed earnings of the 1948-1949 cohorts in 2000-2002.

Table C.4: Region-specific deterministic wage component parameters for different specifications of the wage regression.

Parameter	(1)	(2)	(3)	(4)
	Baseline		Individual FE	
constant	-2.4688	-3.2599	–	–
	(0.0626)	(0.0714)		
age	1.0433	1.1344	0.9362	0.9901
	(0.0066)	(0.0076)	(0.0080)	(0.0093)
age^2	-0.0328	-0.0370	-0.0286	-0.0309
	(0.0003)	(0.0003)	(0.0003)	(0.0004)
age^3	4.58E-04	5.34E-04	4.07E-04	4.51E-04
	(4.19e-06)	(4.80e-06)	(4.94e-06)	(5.70e-06)
age^4	-2.41E-06	-2.89E-06	-2.20e-06	-2.49e-06
	(2.51e-08)	(2.93e-08)	(2.87e-08)	(3.38e-08)
t	0.04338	0.0517	–	–
	(0.0001)	(0.0001)		
Region growth type	Low	High	Low	High
Implied annual wage growth	3.34	4.09	2.93	3.56
Difference (High-Low)	0.75		0.63	
Individual FE	No	No	Yes	Yes
N	6,692,578	4,887,578	6,689,495	4,885,520

Notes: This table shows estimates of the parameter values of the deterministic component of the wage process for different estimation methods. Columns (1) and (2) show the parameter estimates for the low and high-growth regions, respectively, under our baseline specification (see equation (10)), while columns (3) and (4) show the parameter estimates for the low and high-growth regions, respectively, from a fixed-effects regression. Here, the coefficient on the time trend is not identified separately from the coefficient on the first element of the age polynomial, and so only the latter is reported. The table also shows the real annual wage growth for the 1948-1949 cohorts between ages 21 and 64 implied by these parameter estimates. This shows that the implied annual wage growth is higher by a similar amount both under the levels and fixed effects specification, demonstrating that higher wage growth in high-growth regions is not driven by changes in the composition of the labor force with age. Standard errors are reported in parentheses.

C.2 Employment Elasticity Calculations: Accounting for those Unaffected by the Reform

We are interested in the employment response to the NDC reform for those affected by the reform. However, some individuals at the reform discontinuity were unaffected by the reform because they were either in an excluded sector or special occupation, and thus remained in the DB scheme. In our benchmark elasticity formula (presented in Equation (2)) we abstract away from this issue. Here we discuss how the presence of unaffected workers affects the calculation of the employment elasticity.

There are two groups of workers unaffected by the reform. First, agricultural workers are unaffected by the reform and their employment is not observed in our administrative data. The indicator variable $A_{it} = 1$ denotes that someone is working in the agriculture sector. Besides agricultural workers, we also have individuals working in excluded occupations. While these workers' employment is observed in our administrative data, we do not observe whether someone is in an exempted occupation or not. We denote (non-agricultural) workers in excluded occupations with $E_{it} = 1$. The pension reform affects workers in the non-agricultural sector, $A_{it} = 0$, and in non-exempted occupations, $E_{it} = 0$.

The employment elasticity for the affected groups can be written as:

$$\eta = \frac{\frac{P_t^{NDC} - P_t^{DB}}{P_t^{DB}}}{\Delta nrw_t / nrw_t^{DB}} \tag{C.1}$$

where now $P_t^{NDC} = Pr(P_{it} = 1 | A_{it} = 0, E_{it} = 0, z_i < 50)$ is the probability of work among those now facing the NDC scheme, $P_t^{DB} = Pr(P_{it} = 1 | A_{it} = 0, E_{it} = 0, z_i > 50)$ the probability of work facing the DB scheme (but also not in an excluded occupation), P_{it} is a binary variable (working or not working) and so we can express its (conditional) expected value as a conditional probability, $E[P_{it} | A_{it} = 0, E_{it} = 0, z_i] = Pr(P_{it} | A_{it} = 0, E_{it} = 0, z_i)$, for $z_i \in \{z_i < 50, z_i > 50\}$. The numerator of equation (C.1) is thus the percentage change in employment conditional on being affected by the reform.

The baseline employment probability under the DB system conditional on being in sectors or in occupations affected by the reform, $Pr(P_{it} | A_{it} = 0, E_{it} = 0, z_i > 50)$, is the following:

$$Pr(P_{it} = 1 | A_{it} = 0, E_{it} = 0, z_i > 50) = \frac{Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 0) | z_i > 50)}{Pr(A_{it} = 0 \cap E_{it} = 0 | z_i > 50)}, \tag{C.2}$$

where $Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 0) | z_i > 50)$ shows the probability that individual i is employed at time t ($P_{it} = 1$) and is in a non-agricultural and non-exempted occupation ($A_{it} = 0 \cap E_{it} = 0$) and older than age 50.

Our regression discontinuity estimates in equation (E.4) identify the change in non-agricultural employment at the discontinuity, formally:

$$\beta = \Pr(P_{it} = 1 \cap A_{it} = 0 | z_i < 50) - \Pr(P_{it} = 1 \cap A_{it} = 0 | z_i > 50), \tag{C.3}$$

where β is the estimated parameter from the regression equation (E.4), $\Pr(P_{it} = 1 \cap A_{it} = 0 | z_i < 50)$ is the probability of working in the non-agricultural sector for the younger cohorts (which contain both affected workers ushered into the new NDC pension system and exempted workers who stayed in the DB pension

scheme) and $\Pr(P_{it} = 1 \cap A_{it} = 0 | z_i > 50)$ is the probability of working in the non-agricultural sector for the older cohorts, all of whom stayed in the DB pension scheme. The change in non-agricultural employment at the discontinuity can be rewritten as

$$\begin{aligned}
&\Pr(P_{it} = 1 \cap A_{it} = 0 | z_i < 50) - \Pr(P_{it} = 1 \cap A_{it} = 0 | z_i > 50) = \\
&= \Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 0) | z_i < 50) + \Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 1) | z_i < 50) - \\
&\quad - [Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 0) | z_i > 50) + \Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 1) | z_i > 50)] \\
&= \Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 0) | z_i < 50) - \Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 0) | z_i > 50) \\
&= [Pr(P_{it} = 1 | A_{it} = 0, E_{it} = 0, z_i < 50) - Pr(P_{it} = 1 | A_{it} = 0, E_{it} = 0, z_i > 50)] \times \\
&\quad \times Pr(A_{it} = 0 \cap E_{it} = 0), \qquad \text{(C.4)}
\end{aligned}$$

where the second equality uses the fact that young workers stayed in the DB system only if they worked in an exempted occupation and so for them $\Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 1) | z_i < 50) = \Pr(P_{it} = 1 \cap (A_{it} = 0 \cap E_{it} = 1) | z_i > 50)$. The third equality uses the definition of conditional probability (similarly to Equation (C.2)) and that the probability of being in an exempt occupation or of being an agricultural worker is unlikely to differ at the discontinuity and so $Pr(A_{it} = 0 \cap E_{it} = 0 | z_i < 50) = Pr(A_{it} = 0 \cap E_{it} = 0) Pr(A_{it} = 0 \cap E_{it} = 0 | z_i > 50)$.

Inserting equations (C.4) and (C.2) into the percentage change in employment conditional on being in sectors or in occupations affected by the reform (the numerator of equation (C.1)) yields:

$$\begin{aligned}
&\frac{Pr(P_{it} = 1 | A_{it} = 0, E_{it} = 0, z_i < 50) - Pr(P_{it} = 1 | A_{it} = 0, E_{it} = 0, z_i > 50)}{Pr(P_{it} | A_{it} = 0, E_{it} = 0, z_i > 50)} = \\
&= \frac{Pr(P_{it} = 1 \cap A_{it} = 0 | z_i < 50) - Pr(P_{it} = 1 \cap A_{it} = 0) | z_i > 50)}{Pr(P_{it} | A_{it} = 0, E_{it} = 0, z_i > 50) \times Pr(A_{it} = 0 \cap E_{it} = 0)} \\
&= \frac{Pr(P_{it} = 1 \cap A_{it} = 0 | z_i < 50) - Pr(P_{it} = 1 \cap A_{it} = 0 | z_i > 50)}{Pr(P_{it}^{DB} = 1 \cap A_{it} = 0 \cap E_{it} = 0 | z_i > 50)} \\
&= \frac{\beta}{Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 0 | z_i > 50)}. \qquad \text{(C.5)}
\end{aligned}$$

Equation (C.5) shows that to obtain the employment elasticity for the affected population, we need to divide the estimated percentage point change in non-agricultural employment around the discontinuity, β (which is what is recovered by our RDD estimator) by the fraction of the population working in non-agricultural and non-exempted occupations, $Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 0 | z_i > 50)$. This latter object is not directly observed in the administrative data, as we do not know who is exempt because they work in a special occupation. We calculate this object by first using the Law of Total Probability and rearranging:

$$\begin{aligned}
&Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 0 | z_i > 50) = \qquad \text{(C.6)} \\
&= Pr(P_{it} = 1 \cap A_{it} = 0 | z_i > 50) - Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 1 | z_i > 50).
\end{aligned}$$

The administrative data shows that the fraction of people working in the non-agricultural sector is $Pr(P_{it} = 1 \cap A_{it} = 0 | z_i > 50)$= 49%.

We infer the fraction of the population that is working in the non-agricultural sector in an excluded occupation (and thus exempt from the reform, regardless of age), $Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 1 | z_i > 50) = Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 1 | z_i < 50)$, in the following way. Workers born in 1949 were exempt from the switch to the NDC system if they worked long enough in a special occupation (e.g. metal workers, teachers etc.) and claimed retirement benefits before 2008. Using the Household Budget Survey, we estimate that 11% of the 1949 cohort (who were 49 years old at the time of the reform) claimed retirement benefits by 2008. These are the individuals who were exempt from the pension reform since they would have otherwise been unable to collect benefits. We then determine what fraction of these individuals were employed over the 2000-2002 time period – the period used for estimating employment response to the policy change. We estimate that 6% of the younger cohort were already drawing retirement benefits and were not employed in 2002. We do not know if the remaining 5% who began drawing retirement benefits between 2002 and 2008 were employed or not in 2002. In the benchmark case, we assume that *none* of these workers were employed, meaning that $Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 1 | z_i < 50) = 0$, and so we get $Pr(P_{it}^{DB} = 1 \cap A_{it} = 0\% \cap E_{it} = 0 | z_i < 50) = 49\%$ according to equation (C.6). This leads to an estimated employment elasticity of 0.44 (see Table 2). As a robustness exercise, we assume that *all* individuals who began drawing retirement benefits between 2002 and 2008 were employed in 2002 and thus $Pr(P_{it}^{DB} = 1 \cap A_{it} = 0 \cap E_{it} = 1 | z_i < 50) = 5\%$. In that case, $Pr(P_{it} = 1 \cap A_{it} = 0 \cap E_{it} = 0 | z_i < 50) = 49\% - 5\% = 44\%$ and so the employment elasticity is 0.48 (see Panel E of Table 3).

Online Appendix D Number of Observations by Birth Date and Covariance Balance

Our empirical strategy exploits date of birth: individuals born before January 1st, 1949 stayed in the DB system, while younger individuals switched to NDC. Since their birth dates were determined many years before the policy change, individuals close to the discontinuity could not have manipulated their eligibility in response to the policy.

In Panel (a) of Figure D.2 we plot the number of observations by birth month for the 1946-1953 cohorts in the years 2000-2002. Even though manipulation is not possible, there is a clear spike in reported births which occurs on the 1st of January of every year. Nevertheless, the spikes at January 1st were also present before the policy change, as demonstrated in Figure D.1, which shows the frequencies observed in the pre-reform year 1998. In fact, this spike at January 1st most likely reflects that many in these cohorts were born at home and self reported their date of birth, not that there was a higher coincidence of hospital births on the first day of the year. Since the cut-off enrollment at schools was 31st December/1st January, some parents strategically reported their children at the beginning of the calendar year so that their child would be among the oldest in the class when they started school. While this reporting behaviour took place 50 years before the pension reform was announced, the characteristics of these switchers may be correlated with the labor-market outcomes we care about.

To alleviate this concern about the bunching at January 1st, we apply various donut hole RDD estimates throughout the paper. In particular, our baseline specification drops individuals who were born between December 17th and January 5th. We picked these thresholds visually; there is an excess of births between December 17-31, and an absence of births between January 1-5, but very little evidence of excess births or an absence of births outside of this range. For robustness we also apply a broader donut hole where we drop all individuals who were born in January and December (see Table A.2). Panels (d) and (e) of Figure D.2 and Figure D.1 show the number of observations for the baseline and the broader donut hole, respectively. The unusual January and December effects disappear for both definitions of donut and we observe a seasonal pattern in birth rates observed in other countries (see e.g. Buckles and Hungerman (2013)). There is also a time trend which reflects a post-World War 2 baby boom in Poland.

In panels b, d, and f of Figure D.2 and Figure D.1, we investigate whether there is an abnormal mass of observations at our reform discontinuity above the predictable pattern of monthly births and cohort trend. We regress the number of observations at each birth month on the month-of-birth dummies and a linear trend for the cohorts born between 1944 and 1953. We plot the residuals under each donut assumption. The residuals vary across birth months, but there is no unusual jump or drop in the number of observations between the 1948 and 1949 cohorts.

We also study whether covariates substantially differ between cohorts. Table D.1 shows the regression discontinuity estimates based on equation (E.4), where the outcome variables are various covariates. In panel A, we assess whether there is a change in rural/urban share and share of women. These are the only covariates that we observe in our administrative data. In panel B, we show the change in the region characteristics where individuals live. We present two characteristics: regional level log household income and employment rate in 1998. We measure these outcomes in 1998, before the reform took place.

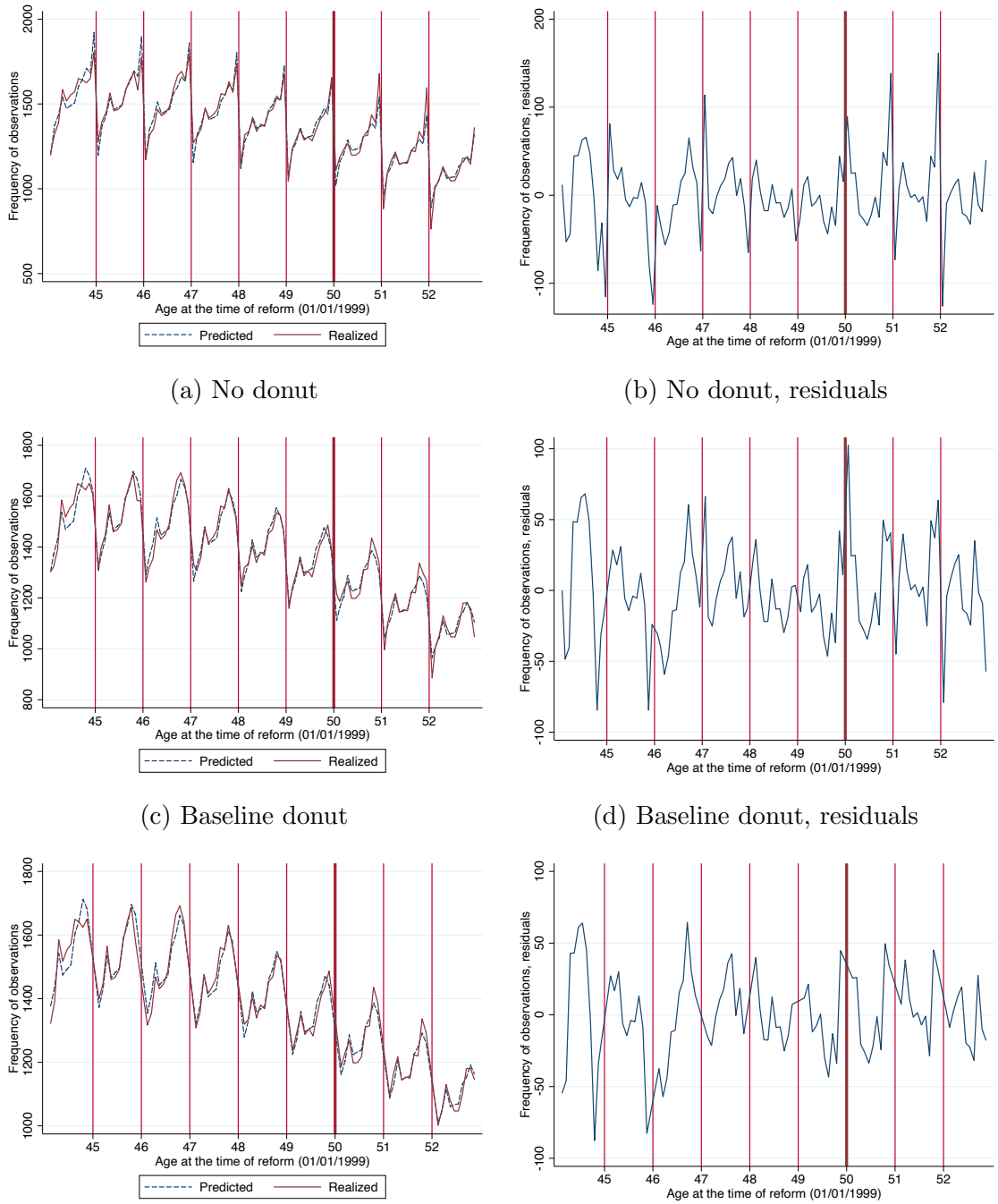
Column (1) shows the difference in covariates for the 1948 cohort and the first treated cohorts (1949). Panel A shows that the rural share in the 1948 December cohort is slightly larger than the rural share for the January 1949 cohort, and the female share is slightly lower. The 1948 December cohort has a lower employment rate in 1998 than the January 1st, 1949 cohort, although there is no differences in log household income. Nevertheless, these differences between the December and January cohorts are very similar to other cohorts, such as the 1949 and 1950 cohorts (see column 2). Reassuringly, when we estimate the discontinuity in covariates between the treated and untreated cohorts relative to two placebo cohorts (similarly to the estimates in the main text, see equation (13)), we find no significant differences in covariates (see column 3). This highlights that our net of placebo estimates pass the covariate balance tests for all outcomes in panels A and B. This can also be seen for individual-level covariates for both types of regions pooled together, and for low and high-growth regions separately.

Table D.1: Covariance Balance between Treatment and Control

	(1)	(2)	(3)
	Baseline RDD		Net-of-placebo RDD
Cohorts of interest	1948-1949	1949-1950	1948-1949
Panel A: individual-level covariates			
Rural, overall	0.0115***	0.0128***	0.0013
	(0.0014)	(0.0014)	(0.0020)
Rural, low-growth regions	0.0102***	0.0111***	-0.0009
	(0.0017)	(0.0016)	(0.0023)
Rural, high-growth regions	0.0140***	0.0155***	-0.0015
	(0.0024)	(0.0024)	(0.0034)
Female, overall	-0.0078***	-0.0083***	0.0005
	(0.0012)	(0.0011)	(0.0016)
Female, low-growth regions	-0.0069***	-0.0102***	0.0033
	(0.0015)	(0.0015)	(0.0021)
Female, high-growth regions	-0.0091***	-0.0056*	-0.0035
	(0.0018)	(0.0018)	(0.0025)
Panel B: regional-level covariates			
Log household income in 1998	-0.0076	0.0078	-0.0045
($\times$100)	(0.0319)	(0.0384)	(0.0462)
Employment in 1998	0.0009***	0.0017***	-0.0005*
	(0.0002)	(0.0002)	(0.0003)
N	1,438,545	1,499,039	2,937,584

Notes: This table shows covariance balance between the treated and control cohorts. For each covariate we assess whether there is a discontinuity in its value between birth cohorts. Column (1) shows the estimated discontinuity in the covariate between the 1948 and 1949 cohorts, while column 2 shows it for the 1949 and 1950 cohorts. We estimate the (linear trend) RDD specification described in equation (E.4) with the reported covariate as an outcome variable. In column (3) we present net-of-placebo estimates where we compare the estimated discontinuity between the 1948 and 1949 cohorts to the estimated discontinuity between the 1949 and 1950 cohorts. There, we estimate the (linear) RDD specification described in equation (13) with the covariate as an outcome variable. In Panel A, the covariate is whether the individual lives in a rural or urban area. In panel B, we use the characteristics of the region where the individual lives. We estimate the regional-level log household income and the regional-level employment rate in 1998, before the policy change. In each specification, we apply a "donut hole" by dropping individuals born between December 17th and January 5th. Robust standard errors are reported in parentheses. Significance levels are: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Figure D.1: Frequencies by Month of Birth, Pre-reform Population Registry (1998)



(a) No donut

(b) No donut, residuals

(c) Baseline donut

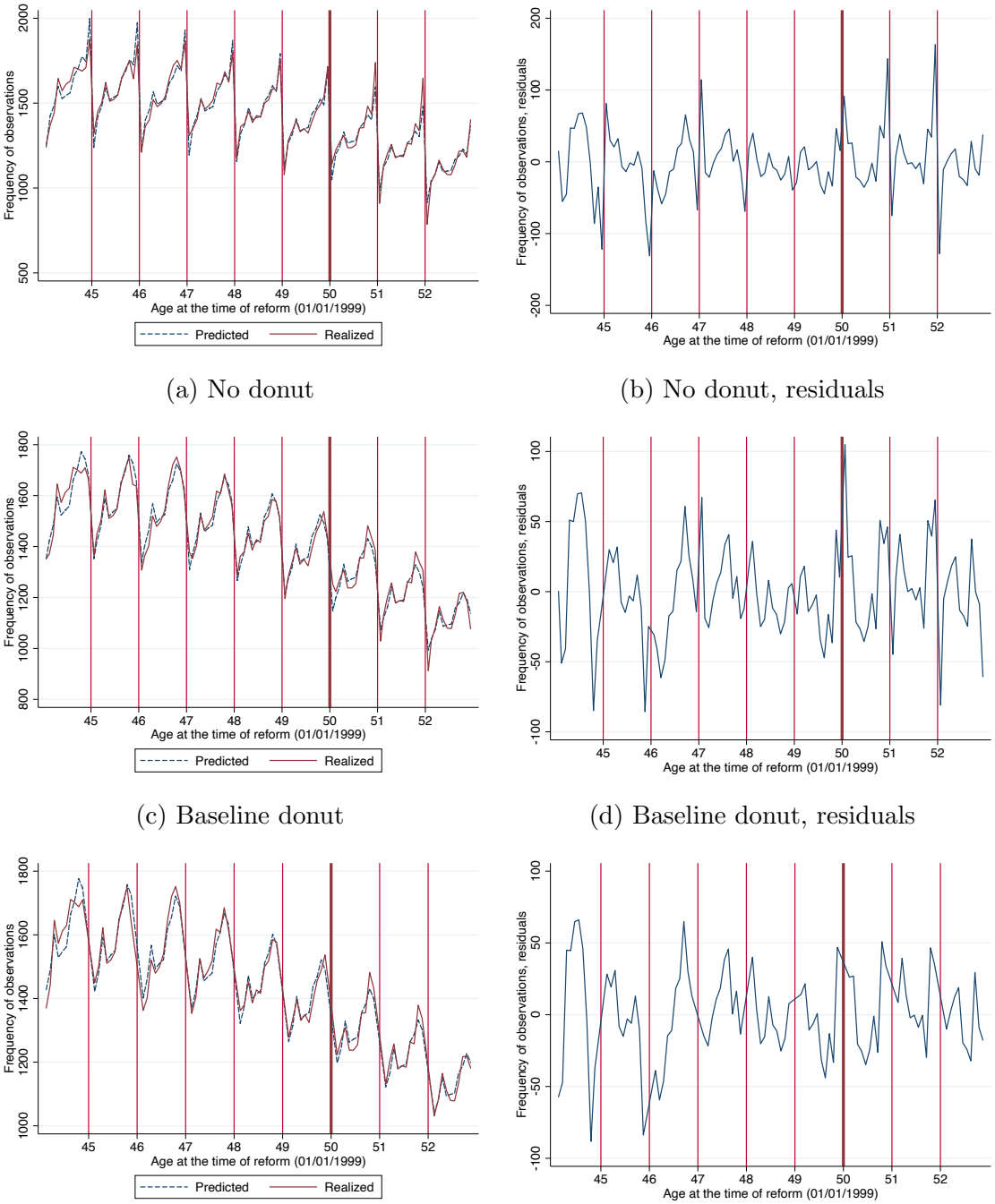
(d) Baseline donut, residuals

(e) Jan-Dec donut

(f) Jan-Dec donut, residuals

Notes: This figure shows the frequencies by month of birth for the cohorts between 1944 and 1953. The frequencies are calculated using the population registry for 1998. We adjust the frequencies with the average number of days in each month. Panels a), c) and e) show the actual number of frequencies (red line) and the predicted one that is based on month of dummies and linear year trend (blue line). Panels (b), (d) and (f) show the difference between the predicted and the actual frequencies – the residuals from the prediction. Panels (a) and (b) show the actual data. Panels (c) and (d) show the frequencies when we drop individuals born between December 17th and January 5th (and adjust with the number of days remained in the month). Panels (e) and (f) show frequencies when we drop everybody born in January or December. Each red vertical line marks the December 31st/January 1st cohort threshold. The thick vertical red line shows the eligibility cut-off of the reform.

Figure D.2: Frequencies by Month of Birth, Post-reform Population Registry (2000-2002)



(a) No donut

(b) No donut, residuals

(c) Baseline donut

(d) Baseline donut, residuals

(e) Jan-Dec donut

(f) Jan-Dec donut, residuals

Notes: This figure shows the number of observations by month of birth for the cohorts between 1944 and 1953. The frequencies are calculated using the population registry between 2000-2002. We adjust the frequencies with the average number of days in each month. Panels a), c) and e) show the actual number of frequencies (red line) and the predicted one that is based on month of dummies and linear year trend (blue line). Panels (b), (d) and (f) show the difference between the predicted and the actual frequencies – the residuals from the prediction. Panels (a) and (b) show the actual data. Panels (c) and (d) show the frequencies when we drop individuals born between December 17th and January 5th (and adjust with the number of days remaining in the month). Panels (e) and (f) show frequencies when we drop everybody born in January or December. Each red vertical line marks the December 31st/January 1st cohort threshold. The thick vertical red line shows the eligibility cut-off of the reform.

Online Appendix E The Effect of Old Age Unemployment Benefit

E.1 Institutional Details and the Change in Net Return to Work

To study the employment response to contemporaneous work incentives, we study the employment response to a radical change in eligibility for an old age unemployment benefit program (OAUB). This program provided generous benefits to older individuals who were laid off from their jobs. The benefit entitled individuals to 80 percent of a hypothetical pension, with a minimum benefit of 120 percent of the unemployment benefit and a cap at 200 percent of the unemployment benefit. The benefit was stopped if the combined earnings from employment and the allowance were more than 200 percent of the unemployment benefit.[35]

On 30th April 2004 a reform raised the eligibility age from 55 to 60, effective starting 1st August 2004. Individuals could therefore take up the benefit if they reached age 55 by the 1st August 2004, and could demonstrate that they were laid off. This created a cohort-based discontinuity in access to this benefit, with individuals born before 1st August 1949 being potentially eligible for the benefit, and individuals born after not eligible.

The net return to work for individuals who were slightly older than 55 on 1st August 2004 and were thus eligible for the OAUB program can be calculated as:

$$nrw_{it}^{\text{OAUB}} = (1 - \tau(\tau^{pi}, \tau^{ss})) \cdot w_{it} - u_{it}^{\text{OAUB}} + E_t(PV_{it}^{\text{Employed}_t, NDC} - PV_{it}^{\text{Not employed}_t, NDC}). \tag{E.1}$$

where $(1 - \tau(\tau^{pi}, \tau^{ss})) \cdot w_{it}$ is the after-tax wage, u_{it}^{OAUB} is the value of old-age unemployment benefit, and $E_t(PV_{it}^{\text{Employed}_t, NDC} - PV_{it}^{\text{Not employed}_t, NDC})$ is the increase in the present-value of pensions as a result of working under the NDC rules. We apply the NDC rules here as the individuals who were slightly older than 55 at 1st August 2004, but younger than 55 at 31st of December 2004, were 49 years old at the time of the 1999 pension reform and hence were ushered into the NDC system.

At the same time the net return to work for individuals who were younger than 55 at 1st of August and are not eligible for the OAUB is as follows :

$$nrw_{it}^{\text{NOAUB}} = (1 - \tau(\tau^{pi}, \tau^{ss})) \cdot w_{it} - u_{it}^{\text{NOAUB}} + E_t(PV_{it}^{\text{Employed}_t, DC} - PV_{it}^{\text{Not employed}_t, DC}). \tag{E.2}$$

where u_{it}^{NOAUB} is the combination of the standard welfare and unemployment programs that every individual in the society has access to. The change in return from work as a result of increasing the eligibility age of the OAUB program is therefore:

$$nrw_{it}^{\text{OAUB}} - nrw_{it}^{\text{NOAUB}} = -(u_{it}^{\text{OAUB}} - u_{it}^{\text{NOAUB}}). \tag{E.3}$$

Following our notation studying the impact of the pension reform (see Section 4), we denote nrw_t^{OAUB},

[35] The Polish name of the program is "zasiłek przedemerytalny" (or "pre-retirement allowance" in English). This name reflects the tight link of these benefits to the DB pension benefit. In that sense the program has some features of early-retirement program. Nevertheless, the program is more similar to a standard unemployment insurance as an individual is required to be laid-off to be eligible for the program.

u_t^{OAUB} and u_t^{NOAUB} as the sample averages of $nrw_i t^{\text{OAUB}}$, u_{it}^{OAUB} and u_{it}^{NOAUB} at age t, respectively. We then define the employment elasticity as follows:

$$\eta^{Contemp} = \frac{(P_t^{\text{OAUB}} - P_t^{\text{NOAUB}})/P_t^{\text{OAUB}}}{-(u_t^{\text{OAUB}} - u_t^{\text{NOAUB}})/nrw_t^{\text{OAUB}}}. \tag{E.4}$$

where the numerator, $(P_t^{\text{OAUB}} - P_t^{\text{NOAUB}})/P_t^{\text{OAUB}}$, shows the employment impact of the OAUB program among those who were eligible. We will describe in the detail how we calculate this next.

E.2 Empirical Strategy and Results

We apply a regression discontinuity design for estimating the effect of the OAUB program. We estimate the following regression equation:

$$P_{it} = \alpha + \beta^{OAUB}\mathbf{1}\{z_i \geq 55\} + f(z_i) + \varepsilon_{it} \tag{E.5}$$

where P_{it} equals to 1 if individual i is employed at time period t and z_i is the age of the individual on 1st August 2004. Those individuals who were younger than 55 years old at the time of the reform, $\mathbf{1}\{z_i < 55\}$, were not eligible for the OAUB program, while those individuals who were older than 55 were eligible for the OAUB if they met certain non-age eligibility requirements described in greater detail below. As such, the regression coefficient β^{OAUB} captures the effect of having access to the OAUB program. We follow Lee and Lemieux (2010) and estimate two separate regressions of $f(z_i)$ on each side of the cutoff point. We use a linear trend in the birth date.

A key assumption in such a regression discontinuity design is that there is no manipulation of the running variable z_i. Such a manipulation would induce bunching in the data. However, there is no such bunching observed in the frequency distribution around the discontinuity (figure available on request).

In Table E.2 we report the estimated β^{OAUB} from the regression equation (E.5). We report estimates using data from all regions (first row), and separately for high (second row) and low earnings growth regions (third row). Column (1) shows estimates with linear trend, while columns (2) - (6) shows the estimates with local-linear estimation by applying various bandwidth choices. The results are very similar across specifications and all specifications. There is a 3.1-4.2 percentage point drop in employment across the specifications and the estimated change in employment in high and low growth regions are similar to each other.

In Column (7) we also implement a net of placebo exercise following a similar strategy as in the main analysis on the pension reform. In particular, we compare the estimated post 2004 employment differences between individuals who were born just before and after 1st August 1949, to the pre 2004 employment differences. The results are virtually the same, which highlights that there is no change in employment preceding the reform. This is shown in Table E.3 where we directly show the employment differences around the discontinuity in the years preceding the reform.

E.3 Calculation of the Employment Elasticity

Our aim is to calculate the employment elasticity as defined in equation (E.4). Our empirical exercise recovers the percentage point change in employment at the policy discontinuity. To recover the percentage

change in employment caused by losing access to OAUB program, $(P_t^{\text{OAUB}} - P_t^{\text{NOAUB}})/P_t^{\text{OAUB}}$, we need to take into account that not everyone who was older than age 55 was eligible to the program. Denote $Elig_i = 1$ if the individual satisfies the non-age related program requirements, such as having a long enough working history, and involuntary job loss and $Elig_i = 0$ if the individual does not satisfy the requirements.

The regression in equation (E.5) identifies the following difference in employment:[36]

$$\beta^{OAUB} = Pr(P_{it} = 1|z_i < 55) - Pr(P_{it} = 1|z_i > 55)$$

Whereas the above equation identifies the effect over both eligible and ineligible individuals, our elasticity formula shows the percentage change in employment for the eligible population, formally:

$$\frac{P_t^{\text{OAUB}} - P_t^{\text{NOAUB}}}{P_t^{\text{OAUB}}} = \frac{Pr(P_{it} = 1|Elig_i = 1, z_i < 55) - Pr(P_{it} = 1|Elig = 1, z_i > 55)}{Pr(P_{it} = 1|Elig_i = 1, z_i > 55)}. \tag{E.6}$$

We can apply similar steps as in C.2 to get the percentage change in employment for the eligible population. Non-age related eligibility (from layoff and tenure) is unlikely to vary much with age at the discontinuity so we assume $Pr(Elig_i|z_i < 55) = Pr(Elig_i|z_i > 55) = Pr(Elig_i)$ and so

$$\begin{aligned}
& Pr(P_{it} = 1|z_i < 55) - Pr(P_{it} = 1|z_i > 55) = \\
= \quad & \big(Pr(P_{it} = 1|Elig_i = 1, z_i < 55) - Pr(P_{it} = 1|Elig_i = 1, z_i > 55)\big) \times Pr(Elig_i = 1) - \\
& -\big(Pr(P_{it} = 1|Elig_i = 0, z_i < 55) - Pr(P_{it} = 1|Elig_i = 0, z_i > 55)\big) \times Pr(Elig_i = 0) \\
= \quad & (Pr(P_{it} = 1|Elig_i = 1, z_i < 55) - Pr(P_{it} = 1|Elig_i = 1, z_i > 55) \times Pr(Elig_i = 1)
\end{aligned} \tag{E.7}$$

where in the second equality we have used that there is no employment change around the discontinuity for non-eligible workers $Pr(P_{it} = 1|Elig_i = 0, z_i < 55) - Pr(P_{it}^{\text{NOAUB}} = 1|Elig_i = 0, z_i > 55) = 0$. We also have that

$$Pr(P_{it} = 1|Elig_i = 1, z_i > 55) = \frac{Pr(P_{it} = 1 \cap Elig_i = 1|z_i > 55)}{Pr(Elig_i = 1)} \tag{E.8}$$

and plugging the previous two equations into equation (E.6) implies that

$$\frac{P_t^{\text{OAUB}} - P_t^{\text{NOAUB}}}{P_t^{\text{OAUB}}} = \frac{Pr(P_{it} = 1|z_i < 55) - Pr(P_{it} = 1|z_i > 55)}{Pr(P_{it} = 1 \cap Elig = 1|z_i > 55)} = \frac{\beta^{\text{OAUB}}}{Pr(P_{it} = 1 \cap Elig = 1|z_i > 55)}$$

where the numerator is the percentage point change in employment at the discontinuity while the denominator is the fraction of the population that is working and eligible to the OAUB program. The denominator can be rewritten as

$$Pr(P_{it} = 1 \cap Elig_i = 1|z_i > 55) = Pr(P_{it} = 1|z_i > 55) \times Pr(Elig_i = 1|z_i > 55, P_{it} = 1) \tag{E.9}$$

[36] For simplicity, we abstract away from the issue that in our administrative data we only observe non-agricultural workers. Our empirical exercise recovers only the elasticity for non-agricultural workers, but this is exactly what we need for comparing the employment responses to the contemporaneous change in incentives to the changes coming through the pension reform.

where $Pr(P_{it} = 1|z_i > 55)$ is the employment rate to the right of the discontinuity, and $Pr(Elig_i = 1|z_i > 55, P_{it} = 1)$ is the fraction of individuals who are working and eligible to the pension reform.

We can directly observe $Pr(P_{it} = 1|z_i > 55)$ in our data, which is between 36-39%, depending on the region. Nevertheless, we do not directly observe eligibility in our data, and so we need to infer $Pr(Elig_i = 1|z_i > 55, P_{it} = 1)$ indirectly from the data. The key eligibility criteria were whether the worker has long enough previous employment history and the job separation was involuntary termination. In practice, involuntary job separations are not common in Poland. However, the key is whether someone can "engineer" a severance such that makes the worker eligible for old age unemployment benefit program.[37] This "engineering" is likely to be easier for workers at smaller firms with long tenure. We corroborate this conjecture by exploiting the Labor Force Survey (LFS) data where we observe job tenure and firm size. We estimate the employment response around the reform discontinuity by estimating separately the change in employment using equation (E.5) for four groups of workers: workers with short tenure (at or below 8 years) at large firms (more than 10 workers), workers with long tenure (longer than 8 years) at large firms, workers with short tenure at small firms (10 or less workers), and workers with long tenure at small firms.

We report the key estimates in column (2) in Table 4. In most of the groups there is only a limited change in employment, except for workers in small firms and with tenure of long duration. Since the fraction of individuals employed in small firms with long-tenure is around 41.6% (see column (1) in Table 4), we assume 40% is a lower bound for the fraction of workers who were eligible for the unemployment program. In that case applying our formula leads to an elasticity of 0.88 (or 0.96 in high earnings growth regions and 0.84 in low earnings growth regions).

Nevertheless, it is also possible that some of the workers in the other categories can also "engineer" an involuntary separation. We infer an upper bound of the fraction of eligible population in each subgroup as follows. We assume that all of the individuals in the most responsive category of workers (with long tenure and in small firms) are eligible for OAUB. From column (3) of Table E.4, it can be seen that this category of workers experiences a change in employment of 28.4% as a result of the reform. We then assume that the ratio of the estimated percent change for each of the other groups to the change in the most affected group corresponds to the fraction of workers eligible in each employment group. For instance, since the short-tenure and large-firm group experience a 20% change in employment as a result of the reform, we infer that $20.0/28.4 = 70.4\%$ of individuals in this group are eligible for OAUB. And since workers in the short-tenure and large-firm group constitute 17.4% of the workforce, eligible workers in this group constitute 12.3% of the overall workforce. If we apply this exercise to each group and sum up to the total fraction of workers eligible, we arrive at an overall eligibility rate of 60.4%. This is our preferred eligibility rate, as it is likely that some fraction of all employment categories was eligible for the benefit. The corresponding elasticity for this eligibility rate is 0.58 (or 0.64 in high earnings growth regions and 0.56 in low-earnings growth regions).

[37] Employment laws in Poland make firings potentially costly for the employer, since they require severance payments and if the firing is not justified then they are legally responsible for compensation.

E.4 Exploring employment changes between age 56-59: the interaction between OAUB and the pension reform

Eric questions: (1) any possibility of data after age 59? (2)I changed some of the verb tenses (3) We have verbal discussions that the interaction doesn't matter. Can we quantify things? Put differently, have we used our benefit calculator to calculate the percent change in the net return to work?

As explained in Section E.1, the OUAB benefit could be claimed from age 55 until August 1st, 2004, when that age threshold increased to age 60. People around our main pension reform discontinuity (i.e. those whose birth date is before or after January 1st, 1949) were unaffected by this policy change, as people at both sides of the discontinuity could claim OAUB benefits from age 55 if eligible (e.g. if there was an involuntary separation).

The impact of OAUB receipt has two key impacts on the net return to work. First, OAUB receipt reduced the return to work in both the DB and NDC systems since working would lead to the loss of the benefit. Second, OAUB receipt impacted pension benefit accrual under the DB system but not the NDC system. under the DB rules, those not working but receiving OAUB benefits received credit for their non-contributory years, increasing pension benefits. However, under the NDC rules, those not working but receiving OUAB benefits did not increase future pensions. This created stronger work incentives under the NDC system after age 55: since it is more beneficial to receive the OUAB for someone whose pension calculation is based on the DB rules, we expect an additional employment respones at age 55 in this group (relative to the NDC cohorts). Nevertheless, the incentive changes should be the same at high- and low-growth regions indicating that by comparing the differential employment changes around the discontinuity between the regions, we can difference out the additional incentive changes coming from the OUAB.[38] **Eric question: did we run this through the benefit calculator? Right now the claim that there should be no low/high differences sounds very loose.**

Employment change between age 56-59. Taking into account these caveats we estimate the employment effects of the pension reform for ages 56-59 by applying a similar empirical strategy as for the estimates for ages 50-54. We apply the same RDD strategy described in Section (see equation). However, to make sure that the 2004 changes in the OUAB do not contaminate our estimates, we focus on workers who were born before 1st August 1999**Eric question: do you mean 1949, 1950?**, and so are unaffected by this policy. The main estimates for workers aged 56-59 are summarized in Table E.1, which has the structure as our benchmark estimates of Table 1 for workers aged 50-54.

Panel A shows that across various specifications we see negative employment effects of the NDC pension reform for high-wage growth regions and positive effects for low-wage growth regions. This is slightly different than what we saw in Table 1 for ages 50-54, where a larger negative employment effect was observed for high-wage growth regions. This difference is likely to reflect interaction between the pension system and the OAUB: employment in the DB cohorts lowered in general as there claiming OUAB is more advantageous.

[38]The effect of OUAB on employment is the same in high- and low-growth regions. This is demonstrated, for example, in Figure 4, which shows the employment response to the OUAB for those in the NDC system. We also find no differential take-up rate in OUAB when we exploit the eligibility discontinuity at age 55 for those under the DB cohorts (e.g. born in 1948 and 1947).

Nevertheless, once we focus on the differences between high- and low-growth regions, where the differential effect of OUAB should not play a role, we find that a similar pattern emerges as before. Employment for the NDC cohort is lower than for the DB cohort, which reflects the fact that the net return to work was 4.80% lower for the NDC cohort at these ages. We report the implied elasticity in Panel G of Table 3, which is calculated based on Column 4 of Table E.1 (the donut, linear trend, net of placebo specification). The implied employment elasticity is 0.77 (s.e. 0.32), which is slightly larger than our benchmark elasticity (0.44, s.e. 0.18).[39]

Panel B shows the estimates on the intensive margins. Once we focus on the high and low-growth difference we do not see a clear pattern emerging.

[39]Note that when we estimate the employment effect for the 56-59 age group, we only use individuals who were born before August 1st, 1949. If we apply the same restriction for the 50-54 age group, we get an employment elasticity of 0.39 (s.e. 0.21), which is very close to our benchmark estimate of 0.44 (s.e. 0.18) reported in Table 2.

Table E.1: The Effect of the Pension Reform on Employment And Wages at Ages 56-59

	(1)	(2)	(3)	(4)
Panel A: Change in employment probability				
High-growth	-0.0103***	-0.0039	-0.0057	-0.0037
N = 497,474	(0.0027)	(0.0030)	(0.0080)	0.0050)
Low-growth	0.0043	0.0095***	0.0110**	0.0111***
N = 745,349	(0.0022)	(0.0024)	(0.0065)	0.0040)
Difference (High-Low)	-0.0146***	-0.0134***	-0.0167***	-0.0148***
	(0.0035)	(0.0039)	(0.0103)	(0.0064)
Panel B: Change in log wage				
High-growth	-0.0401	-0.0241	0.0272	-0.0194
N = 174,001	(0.0146)	(0.0161)	(0.0390)	(0.0229)
Low-growth	-0.0049	-0.0098	-0.0442	-0.0046
N = 248,968	(0.0120)	(0.0132)	(0.0323)	(0.0190)
Difference (High-Low)	-0.0352	-0.0143	0.0714	-0.0149
	(0.0190)	(0.0208)	(0.0506)	(0.0297)
Sample	Full	Donut	Donut	Donut
$f(z_i)$	linear trend	linear trend	local linear	linear trend
net-of-placebo	no	no	no	yes

Notes: This table shows the estimated change in employment (panel A) and log wage (measured as earned income of workers) for those in work (panel B) at the reform discontinuity, for years 2005-2007 (ages 56-59). Each cell in the table shows the β coefficients of the RDD specification shown in equation (E.4) (Columns (1)-(3)) or in equation (13) (Column (4)). The rows show the estimated employment and wage change for different regions. The first and second rows show the estimated effect in high and low-growth regions, respectively. High-growth regions are regions with above median earnings growth rate between 2000 and 2013, while low-growth regions have below median growth. The third row shows the difference between the high and low-growth regions. In Column (1) we use the full dataset. In Columns (2)-(4) we apply the donut hole RDD specification where we exclude those born between December 17th and January 5th. In Columns (1), (2) and (4) we estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the cutoff. Column (3) estimates a kernel-weighted local linear regression, where we set the bandwidth at 150 days. Column (4) estimates the change in employment at the reform discontinuity relative to the change at the placebo discontinuity as in equation (13). The placebo discontinuity is estimated between the 1949 and 1950 cohorts, both of which switched to the NDC system. We report robust standard errors in parentheses. For the local-linear regression we calculate robust standard errors following Calonico et al. (2014). Significance levels are: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table E.3: Placebo Estimates on Employment Effect of the Old Age Unemployment Benefit (OAUB) Program

Wage growth region	Placebo (2001-2003)
All regions	0.0001
N = 833,934	(0.0023)
High-growth	0.0018
N = 333,173	(0.0036)
Low-growth	0.0010
N = 499,872	(0.0029)
Sample	full
$f(z_i)$	Linear trend

Notes: This table shows the estimated change in employment at the placebo discontinuity. We use the 1949 cohort in 2001-2003, before the OAUB reform was announced. We estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the placebo cutoff. We report robust standard errors in parentheses. Significance levels are: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table E.2: Effect of Old Age Unemployment Benefit (OAUB) Reform on Employment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. All regions	0.0371***	0.0376***	0.0340***	0.0326***	0.0374***	0.0337***	0.0370***
N = 790,783	(0.0022)	(0.0026)	(0.0032)	(0.0033)	(0.0024)	(0.0053)	(0.0060)
2. High-growth	0.0418***	0.0421***	0.0325***	0.0337***	0.0414***	0.0333***	0.0400***
N = 313,470	(0.0036)	(0.0042)	(0.0051)	(0.0053)	(0.0039)	(0.0084)	(0.0096)
3. Low-growth	0.0339***	0.0347***	0.0351***	0.0316***	0.0346***	0.0353***	0.0349***
N = 474,131	(0.0029)	(0.0033)	(0.0060)	(0.0043)	(0.0031)	(0.0064)	(0.0041)
Sample	full	full	full	full	full	full	full
$f(z_i)$	Linear trend	Local-Linear	Local-Linear	Local-Linear	Local-Linear	Local-Linear	Linear trend
Bandwidth	–	150	50	100	200	Calonico et al.	–
net of placebo	no	no	no	no	no	no	yes

Notes: This table shows the estimated change in employment at the old age unemployment benefit program discontinuity. Each cell in the table shows the β^{OAUB} coefficients of the RDD specification shown in equation (E.5). The rows show the estimated employment change for different regions. The first row shows it for all regions, while the second and third rows show the estimated effect in high and low-growth regions, respectively. High-growth regions are regions with above median earnings growth rate between 2000 and 2013, while low-growth regions have below median growth. In all columns we use the full dataset (no donut hole applied). In columns (1), (7) we estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the cutoff. Columns (2)-(6) apply a kernel-weighted local linear regressions with various bandwidth choices. Column (7) estimates the change in employment at the reform discontinuity relative to the change at the placebo discontinuity by applying an analogous empirical strategy to that described in equation (13). The placebo discontinuity is estimated for the 1949 cohort in 2001-2002, before the OAUB reform was announced. We report standard errors in parentheses. For the local-linear regression we calculate robust standard errors following Calonico et al. (2014). Significance levels are: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table E.4: Effects of Old Age Unemployment Benefit (OAUB) by Employment Type

	(1) Share of Workforce (%)	(2) RDD estimate	(3) Percent change (%)
Short tenure and large firm	17.42	0.0209	20.00
		(0.0154)	
Long tenure and large firm	32.58	0.0053	2.71
		(0.0238)	
Short tenure and small firm	8.39	0.0059	11.72
		(0.0125)	
Long tenure and small firm	41.61	0.0709***	28.40
		(0.0261)	
Number of observations		2,430	2,430

Notes: Column (1) shows the fraction of workforce in four employment categories: workers with short tenure (at or below 8 years) at large firms (more than 10 workers), workers with long tenure (longer than 8 years) at large firms, workers with short tenure at small firms (10 or less workers), and workers with long tenure at small firms. Column (2) reports the β^{OAUB} coefficients of the RDD specification shown in equation (E.5) estimating separately the employment discontinuity for each of the four categories. Each row corresponds to a separate regression with the outcome being employed in the particular employment category. For instance, in the 1st row, the outcome variable is equal to 1 if an individual is employed at a large firm with short tenure, and 0 otherwise. We use the Labor Force Survey for this analysis and the years for which we have month-of-birth information in the data, namely 2004 (post-1st August) and 2005. We estimate a linear trend in birth date allowing for different slopes and intercepts at either side of the cutoff. Column (3) reports the corresponding percent change in employment in each employment category (dividing column 2 by column 1). Significance levels are: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Online Appendix F Appendix to Lifecycle Model

F.1 Model Pension Systems

Our approach to modeling pension accrual closely follows the approach in the simulations in Section 4. To be consistent with our treatment of the net return to work there, we measure pension accrual as a wage increment, using an approach similar to that of French and Jones (2011). Our approach here differs in one important regard. In our simulations we can allow pension wealth to depend on the entire history of wage and unemployment shocks, whereas in the dynamic model this would be computationally infeasible, and so we must approximate pension accrual given the model's state variables (in particular, age, wage and region).

We consider three scenarios when comparing DB and NDC systems. In the first, we consider DB and NDC systems which would apply to cohorts of individuals who work their entire careers under one of the two systems. We refer to these as 'steady-state' DB and NDC pension systems. In the second we compare a steady state DB system to a composite system where everyone begins in the DB system, but some people transition into the NDC system at age 50, in a way similar to the impacted cohorts in reality. Finally, we consider 'steady state' DB and NDC systems where we construct the two to be revenue-equivalent, allowing us to isolate the effect of work incentives. We now discuss each of these in turn.

F.1.1 Steady state pension systems

DB Pension Our approximated DB system has three components: (1) a universal payment to all individuals in retirement; (2) an increment to contemporaneous wages received in periods in which an individual works; and (3) an increment to contemporaneous income received whether or not an individual works. Taking each in turn, the DB system comprises:

1. A universal payment to all those over the pension age, α_0^{DB}, which represents the universal component of the DB pension (the first term in the last bracket in equation (4)).
2. An increment to contemporaneous earnings in period t received if the agent chooses to work, which is proportional to earnings by a factor ($\alpha_{1,t}^{DB}$) that varies by age and region (we suppress region subscripts here). This is estimated using our simulations in three steps:
   i) We first calculate the change in the present value of DB pensions as a result of choosing to work in a particular year for each simulated agent (in exactly the same manner as we do in Section 4).
   ii) We then take the ratio of the change in the present value to earnings at time t for each simulated agent.
   iii) Finally, we calculate the average of the resulting ratio over all simulated agents for each year t, to yield our measure of $\alpha_{1,t}^{DB}$ for all t.
3. Finally, under the DB system, unemployed individuals accumulated DB benefits by accumulating "contributory years" while on unemployment benefits – a period of 6 months in our model. To account for this, under the DB system, we assume individuals receive a contribution which is proportional (by a factor $\alpha_{2,t}^{DB}$) to their wages (that is, the earnings that they would have received if they had chosen to work).

We calculate this component as the change in the DB pension when being out of work and *not* receiving unemployment benefits, compared with being out of work and receiving unemployment benefits. This is estimated using our simulations as follows:

i) We calculate what the increment to DB wealth would be if the agent worked under the (modeled) scenario where there is 6 months of unemployment benefits received when not working.

ii) We calculate what the increment to DB wealth would be if the agent worked under the (counterfactual) scenario where there would be no unemployment benefit receipt for each individual in our simulations.

iii) We take the difference of the objects calculated in (i) and (ii). We take this to be the increment to DB wealth which results in not working but receiving six months of unemployment insurance.

iv) We express that quantity as a fraction of potential earnings at time t for each simulated agent (potential earnings are the wage – i.e. earnings for workers, and the earnings that those who do not work would receive if they worked).

v) We calculate the average of the resulting ratio over all simulated agents in our simulations for each year t to yield our measure of $\alpha_{2,t}^{DB}$ for all t.

The first of these three components enters the budget sets directly when an individual is retired, as shown in equation (F.14) in the next subsection. The second and third of these components enter through income during working life, which can be characterized as follows:

$$\begin{aligned} y_{it}^{DB} &= (1-\tau(\tau^{pi},\tau^{ss})+\alpha_{1,t}^{DB}+\alpha_{2,t}^{DB})w_{it} \quad \text{if} \quad P_{it}=1 \\ y_{it}^{DB} &= u+\alpha_{2,t}^{DB}w_{it} \quad \text{if} \quad P_{it}=0 \end{aligned} \tag{F.10}$$

where $\tau(.)$ gives tax due, u is an out-of-work welfare payment, and $\alpha_{1,t}^{DB}$ and $\alpha_{2,t}^{DB}$ are pension wealth accrual factors which individuals receive, respectively, if they work and whether they work or not. w_{it} are potential earnings. The calculation of $\alpha_{1,t}^{DB}$ and $\alpha_{2,t}^{DB}$ accounts for the taxation of pension wealth.

NDC Pension We calculate NDC wealth accrual in a similar fashion. There is no universal component to the pension, so the analogy to the DB universal component is $\alpha_0^{NDC}=0$. $\alpha_{1,t}^{NDC}$ is a factor which, when multiplied by earnings, gives an increment to wages if the agent chooses to work. $\alpha_{2,t}^{NDC}$ is a factor which, when multiplied by the wage, gives the increment to income whether or not the agent chooses to work.

The form of income under the NDC system has the same form as that in equation F.10 but with $\alpha_{1,t}^{NDC}$ and $\alpha_{2,t}^{NDC}$ in the place of $\alpha_{1,t}^{DB}$ and $\alpha_{2,t}^{DB}$.

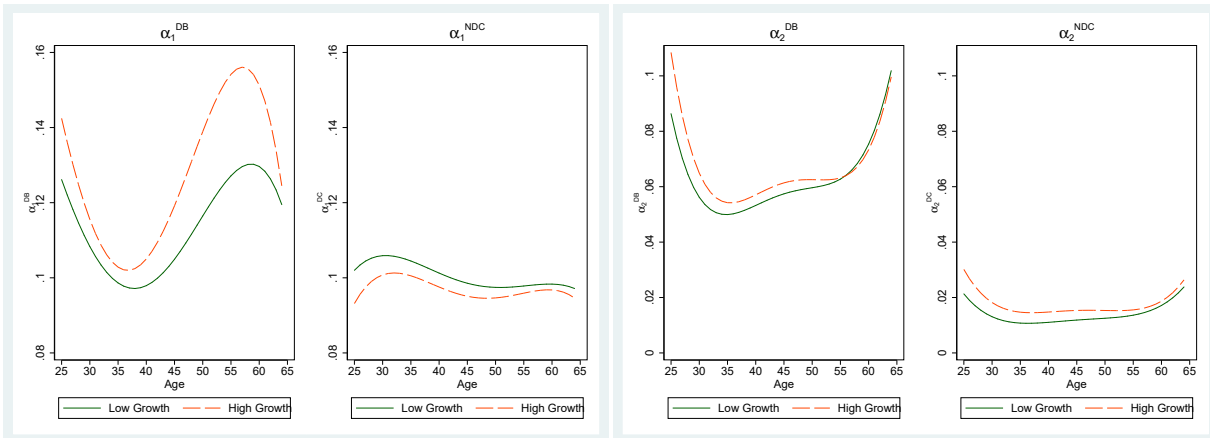
Summary The two steady-state pension systems can therefore be characterized by the following vectors of parameters:

$$\left(\alpha_0^k, \{\alpha_{1,t}^k\}_{t=1}^T, \{\alpha_{2,t}^k\}_{t=1}^T\right), \tag{F.11}$$

where $k \in \{DB, NDC\}$ indexes pension systems. Figure F.1 illustrates the accrual factors $\{\alpha_{1,t}^k\}_{t=1}^T, \{\alpha_{2,t}^k\}_{t=1}^T$ for each of the two pension systems. Note that the return to work arising from the DB system $\{\alpha_{1,t}^{DB}\}_{t=1}^T$ (in the top left panel of the figure) is higher at all ages for those in high-growth regions than for those in low-growth regions. Later in the lifecycle, this predominantly occurs due to more frequent (and larger)

recalculations of AIME for those in high-growth regions. Early in the lifecycle, this predominantly occurs due to the fact that the ultimate pension will be calculated based on an AIME that is large relative to contemporaneous earnings (a fact which is true for both types of individuals, but which is quantitatively more important for those in high-growth regions).

Figure F.1: Pension Accrual Parameters



(a) $\{\alpha_{1,t}^{DB}\}_{t=1}^{T}$ and $\{\alpha_{1,t}^{NDC}\}_{t=1}^{T}$ (b) $\{\alpha_{2,t}^{DB}\}_{t=1}^{T}$ and $\{\alpha_{2,t}^{NDC}\}_{t=1}^{T}$

F.1.2 Pension system for transition cohort

The systems described above characterize the pensions relevant when considering the behaviours of cohorts who lived their entire working lives under the DB and NDC regimes respectively. Our approach to estimating the causal impact of the reform at the cohort discontinuity in Section 6, however, involves comparing the behavior of a cohort who worked their entire career under the DB regime with a transition cohort who worked until age 50 under the DB regime before being switched to the NDC regime. We need to model the behavior of the latter cohort to obtain model predictions of the change in labor supply, which are used in estimation. To do this we model the pension system for that cohort as:

$$\left(\alpha_0^{trans}, \{\alpha_{1,t}^{trans}\}_{t=1}^{T}, \{\alpha_{2,t}^{trans}\}_{t=1}^{T}\right) \tag{F.12}$$

$$\alpha_0^{trans} = \varphi\, \alpha_0^{DB} \tag{F.13}$$

$$\begin{aligned} \alpha_{1,t}^{trans} &= \alpha_{1,t}^{DB} \qquad t < 50 \\ \alpha_{2,t}^{trans} &= \alpha_{2,t}^{DB} \qquad t < 50 \end{aligned}$$

$$\begin{aligned} \alpha_{1,t}^{trans} &= \alpha_{1,t}^{NDC} \qquad t \geq 50 \\ \alpha_{2,t}^{trans} &= \alpha_{2,t}^{NDC} \qquad t \geq 50 \end{aligned}$$

where the transition cohort, unlike those who spend their whole careers under the NDC regime, *do* receive a universal payment ($\alpha_0^{trans} = \varphi\ \alpha_0^{DB}$), which is unrelated to their earnings history and is lower, by a factor φ, than that received by those who stayed in the DB system. This comes through starting capital, the formula for which is outlined in equation (8). Using that formula, we estimate that $\varphi = 0.71$.[40]

In summary, the parameters of the pension accrual increments that are proportional to earnings ($\alpha_{1,t}^{trans}, \alpha_{2,t}^{trans}$) are those of the DB scheme for up to age 50 (before the reform) and those of the NDC scheme from the age of 50 onwards.

F.1.3 Pension systems used in counterfactual exercise

Once the model is estimated, we use it to evaluate the likely effects on lifecycle labor supply of the changes in the net return to work implied by the reform. For this analysis (the results of which are illustrated in Figure 5), in order to isolate the changes in the net return to work from the changes induced by the fact that the payments became less generous overall, we construct two systems – one with NDC work incentives and one with DB work incentives – which are adjusted to yield the same government balance. We hold the two components which *do not* depend on work choices (α_0^k and $\{\alpha_{2,t}^k\}_{t=1}^T$) constant across systems, set at their levels in the DB system ($k = DB$). Pension accrual when working in the modelled NDC system is that of the new system ($\{\alpha_{1,t}^{NDC}\}_{t=1}^T$). Pension accrual when working in the modelled DB system is that prevailing in the old DB system scaled by a factor ϕ ($\{\phi\alpha_{1,t}^{DB}\}_{t=1}^T$). The value of ϕ is chosen such that the discounted value of the government balance (the sum of taxes and social security contributions, less welfare and pension payments) is the same in both cases.

Formally, the two pension systems we compare are a system with accrual in work following the NDC work incentives:

$$\left(\alpha_0^{DB}, \{\alpha_{\mathbf{1,t}}^{\mathbf{NDC}}\}_{t=1}^T, \{\alpha_{2,t}^{DB}\}_{t=1}^T\right),$$

and a modified DB system where the component that the agents get only if they work is scaled by a factor ϕ,

$$\left(\alpha_0^{DB}, \{\phi\alpha_{\mathbf{1,t}}^{\mathbf{DB}}\}_{t=1}^T, \{\alpha_{2,t}^{DB}\}_{t=1}^T\right).$$

We highlight in boldface the component that differs across these two systems. In our counterfactual analysis, ϕ is found to be 0.86 to obtain revenue neutrality.

F.2 Recursive Specification of the model

Equation F.14 gives the recursive specification of the agent's problem. Our vector of state variables is $\mathbf{X}_{it} = \{\text{region}_i, \nu_i, t, a_{it}, \text{offer}_{it}, w_{it}\}$. Two of these variables represent permanent heterogeneity, namely, region of residence $\in$ {low growth, high growth}, and agent's consumption weight (ν_i – their 'type'). The four which vary across the lifecycle are age (t), assets (a_{it}), the presence (or otherwise) of an employment

[40] That is, the transition cohort has a universal component of the pension worth 71% of that of the cohort who remained in the DB pension.

offer (offer_{it}) and wages (w_{it}).

$$V_t(\mathbf{X}_{it}) = \max_{\{c_{it}, P_{it}\}} U(c_{it}, l_{it}; \nu_i) + \beta\Big(s_{t+1}\mathbb{E}_t V_{it+1}(\mathbf{X}_{it+1})\Big) \tag{F.14}$$

$$s.t. \begin{cases} a_{it+1} = (a_{it} + y^k_{it} - c_{it})(1+r) & \text{if } t < R \\ a_{it+1} = (a_{it} + \alpha^k_0 - c_{it})(1+r) & \text{if } t \geq R \\ l_{it} = 1 - hP_{it} \\ a_{it+1} \geq 0 \end{cases}$$

where c and P are the model's choice variables: consumption and participation, $U(.)$ is the utility function, defined over consumption and leisure, given in equation (14), β is the discount factor, s_{t+1} is survival probability to $t+1$, conditional on having survived to t, R is the age at which agents must stop work (65), a is the level of assets held, h is the share of the leisure endowment given up when an agent chooses to work, y^k is income, inclusive of pension wealth accrual under the prevailing pension system k (as defined in equation F.10 for the $k = DB$ case), α^k_0 is the universal component of the prevailing pension system (k) and the expectation operator integrates over future period wage employment offer uncertainty.

F.3 Solution of the Model

The model outlined has no analytical solution and must be solved numerically. We do this using standard methods, which we summarize very briefly here. See the Appendix to Crawford and O'Dea (2020) for a more detailed description of the solution to a similar model.

We first select a discrete subset of the state space ($\mathbf{X}_t$). Of our six state variables, three are naturally discrete (region of residence, age, and employment offer). The other three are continuous variables (assets, wages and consumption weight) that need to be discretized. For assets, we form a grid of 50 points, spaced equally in log terms (so that more points are concentrated at the bottom of the grid where curvature will be greatest). For wages, which are distributed log-normally, we create a grid by dividing the distribution in each period into 20 equi-probable regions, with the grid being formed of the expected value in each of those regions. For preference types, we divide the Normal distribution into 10 equi-probable regions, with the grid being formed of the expected value in each of those regions. These three discretized sets of our continuous state variables, along with our naturally discrete state variables, form our discretized state space.

Solving the model involves solving the objective function at each point in the discretized state space starting in the final period of life T. The solution in this period yields the value function at each point in the discretized state space: $V_T(\mathbf{X}_T)$. Using this, the optimization problem for V_{T-1} and the problems for all earlier periods can be carried out iteratively. Linear interpolation is used to approximate the value function outside of the discrete subset of the state points we evaluate, and integration over wage shocks is carried out using the procedure in Tauchen (1986).

Solution of the model yields decision-rules for each of consumption and labor supply. These give optimal behavior at each point in the state space. Using these decision rules, random draws for earnings which follow the model's earnings process, and an initializing of the asset distribution (all households start with no assets), we can simulate behavior and obtain a simulated data set. Such a simulated data set for the model solved under actual policies can be used for estimation (see Section F.5 below). A simulated data set for a version

solved under counterfactual policies can be used to assess what behavior would be under those policies (as in done in Figure 5).

F.4 Parameterization and Estimation

F.4.1 Parameterization

In our first step we set model features which can be identified external to the model or set with reference to the literature. This includes the interest rate and survival probabilities. We use the same survival probabilities and the same interest rate used previously in the paper. We also set two preference parameters to values commonly used in the literature. One is the coefficient of relative risk aversion on utility, which is set at 4, a typical value for use in a non-separable utility function (e.g., Conesa et al. (2009)), and the other is the discount rate, which we set equal to the interest rate ($\beta = \frac{1}{1+r}$). We normalize the leisure endowment to one and assume that when agents work they forego 30% of their endowment (a standard value in the literature).

The parameters of the deterministic and AR(1) components of the earnings process are those in the simulation (see equation (10)).[41] The Markov process governing unemployment risk is also that in the simulation, discussed in Section 4 and with parameter values given in Table C.2.

F.5 Estimation

We estimate parameters using Indirect Inference. We choose parameters ($\chi = (\mu_\nu, \sigma_\nu^2)$) to minimize the following criterion function:

$$\hat{\chi} = \arg\min_{\chi} \ (\mathbf{m}(\chi) - \hat{\mathbf{m}})'\mathbf{W}(\mathbf{m}(\chi) - \hat{\mathbf{m}}), \tag{F.15}$$

where $\hat{\mathbf{m}}$ is the vector of moments we match, $\mathbf{m}(\chi)$ is a vector of the values of those moments implied by the model at parameter vector χ, and $\mathbf{W}$ is a weighting function for which we use the optimal weighting matrix - the inverse of the empirical variance-covariance matrix of our moment vector, normalized by the number of observations (so an element of $\mathbf{W}$ would be the variance of the estimated employment rate at age 50, for example). Standard errors are calculated using the formula:

$$(\hat{\chi} - \chi_0) \rightsquigarrow N(0, \mathbf{V}), \qquad \mathbf{V} = (1+\tau)(\mathbf{D}'\mathbf{W}^{-1}\mathbf{D})^{-1}$$

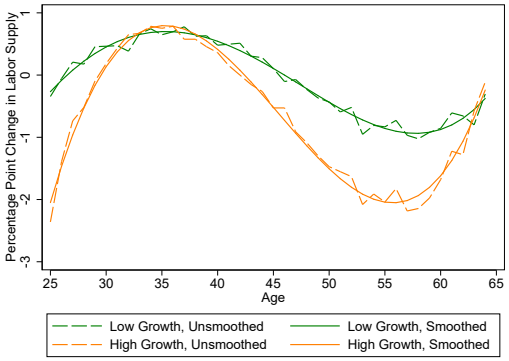
where the formula for V is implied by optimal weighting and $\mathbf{D} = \frac{\partial \mathbf{m}(\chi)}{\partial \chi'}\Big|_{\chi=\chi_0}$ is the gradient matrix of the population moment vector and τ is the number of observations per simulation. In practice $\mathbf{W}$ and $\mathbf{D}$ are replaced by estimated values: see French (2005) for details.

The estimates are given in panel B of Table 5. The estimate of mean consumption weight of approximately 0.485 sits at the mid-point of a range of papers that use utility functions similar to ours applied to data from other countries,[42] and the standard deviation in the consumption weight of 0.145 indicates a

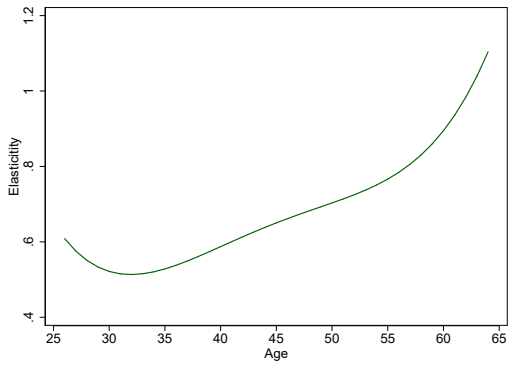
[41] The model does not include the MA(1) component process, which would involve the inclusion of another state variable. However, note from Panel C in Table 3, that our simulations are robust to changes in the earnings process and so this difference between the model and simulation is very unlikely to be consequential.

[42] Conesa et al. (2009) estimate a value 0.377, Nishiyama and Smetters (2007) have between 0.45 and 0.50, O'Dea (2019) estimates a range from 0.42 to 0.52, French and Jones (2011) estimate heterogeneous groups with an average in the population of 0.62.

Figure F.2: Model Outputs



(a) Effect of Switching to an NDC on Labor Supply Over the Lifecycle



(b) Elasticities across the lifecyle

Notes: Panel (a) shows percentage point change in labor supply at each age between the DB and NDC pension schemes. Profiles are smoothed using a polynomial of order 4. To isolate the reform effect on changing the net return to work from the effect operating through a reduction in the overall generosity of the pension system, we scale down the accruals in the DB system (proportionally) to ensure that the two pension systems are revenue- equivalent. Panel (b) shows elasticities which are calculated by perturbing wages by 20% at each age, calculating the percentage change in the proportion in work and dividing it by labor supply at the unperturbed wage profile. Profile is smoothed using a polynomial of order 4.

modest degree of heterogeneity in the population – implying that 95% of the population has a consumption weight of between 0.195 and 0.775.

F.6 Counterfactual

The comparison of labor supply across the lifecycle summarized in Figure 5 compares a system with NDC work incentives with a system with DB work incentives designed to deliver an equivalent government balance to that prevailing under the NDC system. This is described in Section F.1.3.

The results in Figure 5 are smoothed using a fourth-order polynomial in age. To illustrate that there is very little difference between these smoothed profiles and the underlying unsmoothed profiles, Figure F.2(a) shows both together. The modest differences between the two figures are caused by approximation error. Even with fine grids and a large number of simulations, the object that we are analyzing – the difference between two labor supply averages – will be subject to modest approximation error.

F.7 Elasticities

Figure F.2(b) gives our employment elasticities across the lifecycle. At any given age, these are calculated by perturbing wages by 20% at (only) that age, calculating the percentage change in the proportion in work and dividing it by labor supply at the unperturbed wage profile.