Essays in household finance

Pension funding, housing and consumption over the life cycle

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This dissertation comprises three essays that explore the importance of pension funding and housing within the financial portfolios of Dutch households, and their effect on consumption decisions. The first essay considers the design of pension systems that provide both adequate income during retirement and liquidity during the accumulation phase of benefits. The second essay brings together administrative data and expenditure survey waves from the Dutch national statistical office to compare various imputation methods and to empirically investigate the determinants of household spending. The third essay studies the macroeconomic consequences of the different ways in which pension funds can close funding gaps.

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Essays in Household Finance: Pension Funding, Housing and Consumption over the Life Cycle

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Pension Funding, Housing and Consumption over the Life Cycle

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Wassily Kandinsky’s *Circles in a Circle* ties together various themes that have defined the writing of this dissertation. I stumbled upon it in the Philadelphia Museum of Art when I was a visiting PhD candidate at the University of Pennsylvania in 2020. In my imagination, it represents the aggregate economy and the ways I try to make sense of it in my research. The macroeconomy is depicted as a large, black circle in which smaller circles and stripes reside. The circles and stripes signify the various agents that operate in pursuit of their own goals: households, firms, governments. Their overlapping indicates the interaction between them.

How to make sense of this complex system? The two beams that cross the black circle at different angles represent my approach. The theoretical models and empirical methods that I employ in this dissertation shed light on specific facets of the interactions between the agents in the economy. The beams capture some parts well, but abstract from others, and are therefore never fully able to uncover the true workings of the system. They only shine light through a subset of the aggregate economy.

That my research will never be able to capture all complexities is a realisation that has stayed with me throughout the past years. It is only now, as I write these acknowledgements after having mentally distanced myself from this dissertation for some time, that I have some perspective on this insight. Again, I turn to the work of Wassily Kandinsky, who studied law and economics before becoming an artist. It is thus not surprising that my reflections on the science of economics can be interpreted through his paintings and writings. In *Concerning the Spiritual in Art*, he invokes the visual metaphor of the spiritual triangle:

"The whole triangle is moving slowly, almost invisibly forwards and upwards. Where the apex was today, the second segment is tomorrow; what today can be understood only by the apex and to the rest of the triangle as an incomprehensible gibberish, forms tomorrow the true thought and feeling of the second segment. At the apex of the top segment stands often one person, and only one. His joyful vision cloaks a vast sorrow. Even those who are nearest to him in sympathy do not understand him."
While the metaphor harbours an optimistic view on artistic and scientific progress, those who bring about that progress are suffering in uncertainty. Everything starts from a dot, and this dissertation represents my loneliness at the infinitesimal top of the triangle. Before that, during my bachelor’s and master’s studies, I resided comfortably in the second segment of the triangle. I thrived by reading, digesting and critiquing the work of others. Doing research of my own felt like a natural extension that would come easy to me. But when I actually stood at the top of the triangle, I could not keep myself from continuously doubting the methods, the data, the writing, the code, the approach and, most of all, myself. Fortunately, I can now present a more heartening interpretation of the metaphor.

Firstly, I was not alone at the top of the triangle. If it was not for the unwavering patience and commitment from my advisors, Roel and Ward, this dissertation would have never materialised (or originated, since together we secured the NWO Research Talent Grant). They allowed me to wander through various methods and topics, provided pragmatic suggestions to get me out of dead ends and ensured that I never strayed too far from the path, yet still trusted me to find my own way. I am forever indebted for their support.

Secondly, everyone stands on the top of a triangle of their own. As I stood on top of mine, I admired how my talented friends (Maria, Sam, Magda, Robin, Timo, Benji, David, Huaiping, Radu, Marc), office mates (Ron, Damiaan, Rui, Nicoleta, Stan, Ioana, Daniel, Merve, Eva, Stefan, Konstantin, Daniel, Jasha) and senior faculty (Massimo, Christian, Albert Jan, Marcelo, Dirk, Elisabeth, Sweder, Björn) stood on top of theirs.

I thank Professor Dirk Krueger for hosting me at the University of Pennsylvania. Being surrounded by brilliant people and exploring gritty Philadelphia was a formative experience. I thank Anand and Sonali for taking care of me when I was most vulnerable. Your hearts are filled with a special kindness. I thank Franc and Wilma for being so understanding and accommodative. Lastly, I thank the committee members for reading and judging my work.

At times, this dissertation has been a selfish strain on those dearest to me. As much as this is an acknowledgement, it is also an apology. To Laura, Astrid, Bas, Annemarie, Ron, Ellen, Larissa. So often my mind was occupied, thoughts elsewhere, not cherishing the present moment. Despite these imperfections, I felt unconditionally loved and supported. You share this achievement.

Utrecht, 2022
Voor Bas
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Introduction

This dissertation studies the importance of pension funding and housing within the financial portfolios of Dutch households, and their effect on consumption decisions. Its topic is inspired by the macroeconomic literature that followed in the wake of the 2008 financial crisis. As Kaplan & Violante (2018) argue, a collapse in house prices propagated through the balance sheets of households and depressed aggregate consumer demand. Three interrelated aspects shaped the understanding of this event: 1) the specific characteristics of different asset classes, 2) the heterogeneous composition of household financial portfolios, and 3) the role of aggregate demand. Housing is the asset class that naturally has received the most attention since. Households take out mortgages to acquire real estate and, once purchased, trading it or borrowing against it is subject to adjustment costs. This gives rise to a group of households that Kaplan et al. (2018) refer to as the ‘wealthy hand-to-mouth’. Judging from their balance sheet compositions, these households appear affluent and able to cope with unexpected changes in their income or wealth. However, because large portions of savings are allocated to illiquid asset classes (such as housing) and because borrowing against them might be impossible or prohibitively costly, households considerably cut back on spending in case of, for example, loss of income. A common shock such as a widespread drop in house prices will force the hands of many ‘wealthy hand-to-mouth’ households and the subsequent decline in aggregate demand will have far-reaching macroeconomic consequences.

Similar to housing, pension funding is a quantitatively important asset class with unique characteristics and effects on household spending decisions. Participation in pension plans tends to be either mandated or subsidised via employer matching and tax deferral to ensure that households save enough for retirement. In the Netherlands, pension funds collectively manage assets worth about 1.750 billion euros, which is almost twice the gross domestic product of the country. Accrued pension fund entitlements comprise about half of the total financial wealth of Dutch households with housing taking up roughly forty percent. Pension wealth is even more illiquid than housing wealth because contributions to pension plans are typically irreversible until retirement and borrowing against accumu-
lated benefits is outlawed. This hampers the ability of households to smooth out adverse shocks. The unique characteristics of pension wealth and its effects on consumer demand are thus deserving of consideration. The three chapters that comprise this dissertation explore these themes and, in doing so, touch on current pension policy discussions pertaining to the choice freedom of households and the allocation of pension entitlements.

The first chapter studies the design of pension systems that provide both adequate income during retirement and liquidity during the accumulation phase of benefits. We construct a life-cycle portfolio model where households allocate their wealth to three asset classes: liquid private savings, illiquid durable goods and illiquid pension plans. Our flexible pension fund framework nests various contribution mandates, participation subsidies in the form of employer matching and tax deferral, voluntary participation and (conditional) early withdrawal of accrued benefits. Contributions are collected by a pension fund that invests them on behalf of participants, who in return accrue an annuity that is paid out during every period in which they are alive while retired. Households balance the accumulation of illiquid pension wealth to hedge longevity risk against maintaining a buffer stock of liquid private savings to offset earnings risk, and this consideration is complicated by their wish to purchase illiquid durable goods as well. We calibrate the model using administrative data on income and wealth, and find that it replicates the observed illiquid financial portfolios of Dutch households. The lack of liquid private savings directly leads to heightened consumption sensitivities, particularly amongst younger households who are mandated to make pension fund contributions even though they would prefer not to.

Current policy debate wonders how the pension system of the Netherlands can be altered to improve household resilience to adverse shocks without sacrificing the sufficient and uniform accrual of pension wealth. We consider three proposed policies. First, we allow households to decide for themselves how much and when to contribute to the pension fund. This is less effectual than anticipated, because foregoing the participation subsidies is costly. Second, we allow households to withdraw pension benefits early after they have been hit by an adverse income shock. This increases the liquidity of pension wealth and diminishes associated drops in consumption. Thirdly, we adapt the linear contribution rule of the Dutch pension fund system to become a function of household age and financial position. This facilitates a sizeable reallocation of wealth across the three asset classes and over the life cycle. Young to middle-aged households have both a larger stock of durable goods and more precautionary savings, but much less accumulated pension wealth. As households approach retirement, they divert increasingly large portions of their labour income to the pension fund, slowly allow their stock of durable goods to depreciate and eat up their liquid wealth. Since the earnings risk that is left to materialise at this stage
of the life cycle is only minor, overall household resilience to adverse shocks is enhanced and the corresponding welfare effect of a richer contribution mandate is significant.

The second chapter brings together administrative data and an expenditure survey from Statistics Netherlands (the Dutch national statistical office) to compare various imputation methods and to empirically investigate the determinants of household spending. The study of household consumption behaviour is troubled by data availability, where single datasets do not jointly contain information on expenditures, income and wealth. For instance, the expenditure survey does not include sufficiently rich income and wealth data, while administrative data based on tax records does not contain information on consumption. We combine both data sources to study how the consumption of Dutch households reacts to changes in income and wealth, and devote particular attention to the effect of low levels of cash-on-hand, of negative housing equity and of mandatory pension fund participation. We approach this question from two angles. First, we supplement an expenditure survey with detailed income and wealth information from unlinkable administrative data through matching based on variables that are present in both datasets. Second, we impute consumption in the administrative data by using the household budget constraint which implies that total consumption equals disposable income minus the returns-corrected change in asset holdings. We exploit that households in the expenditure survey wave of 2015 can be identified exactly in the administrative data to assess the precision of the two imputation methods.

The first imputation approach correctly matches many households between both datasets with relatively small imputation errors and no selection in the type of households that are matched. The second imputation approach uncovers a puzzle in the measurement of household spending. While in the expenditure survey only ten percent of households consume in a hand-to-mouth fashion, the household budget constraint imputation approach suggests that the percentage is about forty percent. Unfortunately, we cannot determine which of the two consumption proxies is (most) at fault. Next, we move beyond measurement issues and estimate regression models of consumption. We allow for heterogeneous responses by interacting the effect of changes in income and wealth with indicators of low liquidity, high leverage and mandatory pension fund participation. While the effects of the former two have been studied extensively in the literature, and reaffirmed by our results, we additionally present evidence for the role of pension fund system design. System features such as mandatory participation, uniform accrual and longevity insurance imply heterogeneous effects of pension benefit accrual on consumption across the age and income distribution.

The third chapter studies the macroeconomic consequences of the different ways in
which pension funds can close funding gaps. As a result of the 2008 financial crisis, many pension funds were left with a funding deficit since the present discounted value of accumulated pension promises of fund participants far exceeded the value of invested contributions. If pension funds were to avoid exhausting their assets, funding deficits needed to be covered through the implementation of suitable restoration policies. We assess the business cycle effects and distributional implications of pension fund restoration policy by extending a canonical New-Keynesian dynamic general equilibrium model with a tractable demographic structure and a flexible pension fund framework. This model is used to investigate how the economy responds to an unexpected capital quality shock when the financial adequacy of pension funds is restored by revaluing previously accumulated pension wealth (Defined Contribution, DC) or by changing the pension fund contribution rate on labour income (Defined Benefit, DB).

We find that when individuals accumulate indexed pension benefits a DC economy behaves similarly to an economy without a pension fund, because the writing down of previously accumulated pension wealth has a similar effect on total lifetime wealth as losing private savings. In a DB economy, there are two counteracting forces at work. On the one hand, the pension fund increases the contribution rate on labour income and distorts labour supply. On the other hand, the pension fund redistributes wealth towards the group of individuals that has a higher marginal propensity to consume out of wealth, which is important in a demand-driven model. We find that the former effect is the strongest and that the DB pension fund exacerbates economic fluctuations. There are also consequences for welfare, because the recovery from capital quality shocks requires the pension fund to distribute welfare losses to different groups of individuals and generations. We find that indexed DB pension funds transmit capital quality shocks asymmetrically: workers are negatively affected by adverse shocks and less positively affected by positive shocks. Thus, the message of Gollier (2008) that maintaining intergenerational risk-sharing through pension funds requires strong government commitment after poor capital market performance (because younger generations will want to abolish it), becomes even more of a concern in a New-Keynesian setting.
Chapter 1

Wealth and Consumption over the Life Cycle with Pension Plans and Durable Goods

1.1 Introduction

This chapter studies the design of pension systems that provide both adequate income during retirement and liquidity during the accumulation phase of benefits by considering the role of pension plans within the wider financial portfolio of households. Together with real estate, pension plans are one of the most important household wealth categories. OECD (2020) reports that, in 2019, the total assets of pension plans amounted to 50.9 trillion US dollars (58% of world GDP) and Causa et al. (2019) report that net housing wealth represents roughly 60% of household financial wealth (excluding pension plans) in OECD countries. While high rates of home-ownership and elaborate pension systems are generally viewed as signs of economic development, the two asset classes are comparatively illiquid. A large literature has studied the importance of housing, adjustments costs and leverage for aggregate dynamics\(^1\), but the unique characteristics of pension wealth have largely been neglected in this context even though they carry comparable potential for macroeconomic amplification. Participation in pension plans is typically mandated or subsidised through employer matching and tax deferral to ensure that households save enough for retirement. However, such policies likely distort the accumulation of durable goods early on in the life cycle. Additionally, Beshears et al. (2015) note that the contributions to pension plans are typically irreversible until retirement and that borrowing

\(^1\)Examples include Iacoviello (2005), Yang (2009), Berger et al. (2017) and Kaplan et al. (2018).
against pension wealth is outlawed. While households might have substantial amounts of housing and pension wealth, the lack of accessible liquid wealth might cause them to respond strongly to adverse shocks such as job loss. There thus appears to be an inherent trade-off to the design of pension systems: encouraging the gradual build-up of pension wealth during working life has to be balanced against maintaining liquidity so that households can smooth out shocks during working life.

The pension system of the Netherlands is an ideal exhibit to study this trade-off, where housing and pension plans together account for 80% to 90% of total household wealth. Most employed households are mandated to contribute a fraction of their labour income to a pension fund and such contributions are subsidised through employer matching and tax deferral. In return, households accumulate an annuity that is paid out during retirement. Since employed households have little to no choice over whether and how much they contribute and since it is impossible for them to reverse contributions during working life, pension wealth is a highly illiquid asset. Similarly, Ebner (2013) shows that Dutch households rarely withdraw home equity to sustain consumption despite the fact that the Netherlands has a developed mortgage market that would facilitate such secured borrowing. In chapter 2 of this dissertation we demonstrate that the illiquid financial portfolios of Dutch households contribute to their heightened consumption sensitivities. Current debate wonders how the pension system of the Netherlands can be altered to improve household resilience to adverse shocks without sacrificing the sufficient and uniform accrual of pension wealth. Considered policy proposals revolve around adding flexibility and choice freedom during both the accumulation and withdrawal phase of pension savings (Ciurila et al., 2021).

To shed light on such questions, we construct a life-cycle portfolio model à la Carroll (1997) where households allocate their wealth to three asset classes: liquid private savings, illiquid durable goods and illiquid pension plans. Purchasing durable goods is subject to non-convex adjustment costs and borrowing constraints, and modelled after Berger & Vavra (2015). To this, we add a flexible pension fund framework that nests various contribution mandates, voluntary participation and (conditional) early withdrawal of accrued benefits. Contributions are collected by a pension fund that invests them on behalf of participants, who in return accrue an annuity that is paid out during every period in which they are alive while retired. Households balance the accumulation of illiquid pension wealth to hedge longevity risk against maintaining a buffer stock of liquid private savings to offset earnings risk, and this consideration is amplified by their wish to purchase illiquid durable goods as well. We calibrate the model using administrative data on income and wealth, and find that it replicates the observed illiquid financial portfolios of Dutch households.
households. The lack of liquid private savings directly leads to heightened consumption sensitivities, particularly amongst younger households who are mandated to make pension fund contributions even though they would prefer not to.

We consider alternative designs of the Dutch pension fund system by departing from the observation that either subsidised voluntary participation or unsubsidised mandated participation is sufficient to ensure adequate saving for retirement. The current Dutch system contains both saving nudges simultaneously: participation is mandated, and encouraged through employer matching (where the employer triples household contributions) and tax deferral (where households economise on their tax bill because the payment of income tax, often even at a lower rate, is postponed until the pay-out phase of pension wealth). One of the two can therefore be relaxed and doing so proves to be welfare enhancing.

Allowing households to decide for themselves how much and when to contribute to the pension fund with the participation subsidies kept in place is less effectual than anticipated. The employer match is so large that most households simply bunch their contributions at the matching limit and only deviate in extreme scenarios. The youngest households forego the participation subsidies and make up the shortfall in pension wealth as they approach retirement. Young households therefore manage to maintain a slightly larger buffer stock of private savings at the cost of being more vulnerable later on. However, because the remaining earnings risk is minor at this later age, there is less need for precautionary savings as well. While households ultimately accumulate a similar pension fund replacement rate upon retirement, the choice freedom is thus accompanied by an improvement in resilience to adverse shocks even though there is little reallocation of wealth across the three asset classes or over the life cycle. A further improvement can be realised by allowing early withdrawal of pension wealth on top of voluntary participation. Permitting the partial reversal of pension fund contributions under certain stipulations effectively increases the liquidity of pension wealth as an asset class and this encourages the youngest households to contribute as well. If households can withdraw previously accumulated pension wealth at a modest penalty during unemployment, they do not have to downsize their stock of durable goods and as a result do not have to incur the non-convex adjustment cost in order to sustain consumption. The drop in non-durable consumption can be halved and the drop in durable consumption can be fully averted during unemployment.

Alternatively, the linear contribution rule of the Dutch pension fund system can be adapted to become a function of household age and its financial position. The participation subsidies can then be abolished and distributed as higher labour income that is taxed at a lower rate. The most favourable ad hoc contribution mandate that we study consists of a relatively low baseline contribution rate, a time trend from when households become
middle-aged, an annuity correction component that enhances pension fund accrual uniformity and early withdrawal at no penalty when young households are unemployed. This facilitates a sizeable reallocation of wealth across the three asset classes and over the life cycle. Young to middle-aged households have both a larger stock of durable goods and more precautionary savings, but much less accumulated pension wealth. As households approach retirement, they divert increasingly large portions of their labour income to the pension fund, slowly allow their stock of durable goods to depreciate and eat up their liquid wealth. Again, since the earnings risk that is left to materialise at this stage of the life cycle is only minor, overall household resilience to adverse shocks is enhanced and the corresponding welfare effect of a richer contribution mandate is significant.

Even though these results are tailored specifically to the pension fund system of the Netherlands, they do speak to the design of pension plans generally with respect to the effects of contribution mandates, participation subsidies and early withdrawal. Pension plans are important vehicles for household saving, but internationally there is a lot of heterogeneity in terms of their design. For example, in the United States the Roth IRA and 401(k) systems feature voluntary participation, while in many OECD countries there is (quasi-)mandatory participation at varying contribution rates (OECD, 2017b). Furthermore, Beshears et al. (2015) note the international diversity in the liquidity provisions that are embedded in pension plans. Studying a plethora of empirically observed pension plans within a model that replicates the illiquid financial portfolios of households thus appears to be an exercise worth undertaking.

Gourinchas & Parker (2002) note that the lack of illiquid pension and housing wealth in their life-cycle model is an important omission that deserves consideration. The existing papers with housing and pension plans embedded in life-cycle models have either focused on the possibility for tax arbitrage between the two asset classes (Marekwica et al., 2013; Ho & Zhou, 2016) or on the interaction with health risk during retirement (Yogo, 2016), while we pay attention to consumption sensitivities during the accumulation phase of retirement savings. With respect to the design of pension plans, Love (2007), Larsen & Munk (2021) and Schlafmann et al. (2021) are most intimately related even though they do not consider durable goods. Love (2007) studies the effects of employer matching and early withdrawal on voluntary contributions to 401(k)’s over the life cycle. Larsen & Munk (2021) calculate the optimal contribution rate of a linear mandate for a population of households with different preferences and degrees of rationality. Schlafmann et al. (2021) find welfare improving contribution mandates for the Swedish pension system that depend on household age and financial position, but they do not allow for early withdrawal. Another literature has considered optimal investment strategies when households have
access to stocks, bonds and pension annuities (Horneff et al., 2009; Koijen et al., 2010; Zhou, 2012; Blake et al., 2014), but we abstract from financial risk and focus on the trade-off of balancing earnings risk against longevity risk in the presence of illiquid financial portfolios and are therefore more in line with work by, for instance, Campanale et al. (2015).

The existence of contribution mandates or subsidies are typically motivated by the argument that households might be incapable of adequately preparing for retirement if they are left to make saving decisions unassisted (Laibson et al., 1998; Lusardi & Mitchell, 2014). This consideration has previously been incorporated into life-cycle models via, for example, hyperbolic discounting (Love & Phelan, 2015) or heterogeneous private costs of stock market participation (Dahlquist et al., 2018). Empirical evidence on whether households follow life-cycle theory when saving for retirement is varied\textsuperscript{2} and policy-makers in charge of shaping pension systems should consider how they jointly accommodate the needs of different types of households in terms of their preferences and degrees of rationality. We restrict attention to households that are not impeded in their financial decision-making and do so for three reasons. First, our results provide a useful benchmark of what enhanced flexibility can achieve if households are unperturbed financial planners. Second, the participation subsidies of the Dutch system are so large that the voluntary contribution decisions of households would have to be extremely hampered to not make use of them. Third, a contribution mandate ensures sufficient savings for retirement regardless of participation subsidies or private obstacles in financial decision-making.

This chapter is structured as follows. We describe the pension system of the Netherlands and present motivating empirical evidence about the illiquid wealth allocations of Dutch households in section 1.2. The life-cycle model is spelled out in section 1.3 and calibrated using administrative data in section 1.4. Section 1.5 shows that the calibrated life-cycle model replicates the financial portfolios of Dutch households and that the mandatory contribution to pension funds causes households to have low levels of cash-on-hand and high consumption sensitivities. Alternative pension fund system designs (such as voluntary participation, early withdrawal and richer contribution mandates) are discussed in section 1.6. These alternatives are shown to improve household liquidity without sacrificing retirement saving adequacy. Welfare results are presented in section 1.7. Section 1.8 concludes with a discussion of our results. Further information about the administrative data, model derivations and numerical implementation, and estimation of income risk are delegated to sections 1.9.1, 1.9.2 and 1.9.3 of the appendix, respectively.

1.2 Pension system of the Netherlands and financial portfolios of Dutch households

We present a brief overview of the Dutch pension system, particularly noting the features that are relevant to this chapter, and relate it to the wealth of households. The pension system consists of three pillars. The first pillar is a pay-as-you-go benefit paid to all retirees, the size of which solely depends on their household composition and the length of time that they have lived in the Netherlands. It is financed through tax revenues, administered by the government and the pensionable age is linked to life expectancy. The aim of the benefit is to provide a minimum pension income close to subsistence, so most retirees have supplementary pension income from the other two pillars. The second pillar consists of occupational, funded pensions. Close to 90% of salaried workers are mandated by collective employment agreements to contribute to a pension fund or are automatically enrolled by their employer to do so (Ponds et al., 2021). The fund collects and invests the contributions, and in return fund participants accrue an annuity that is paid out during each period in which the worker is alive while retired. Furthermore, participation in the pension fund is fiscally attractive: employee contributions are tripled by employers (on average) and tax deductible (up to a limit). The labour income directed to the pension fund in the form of contributions is taxed when households receive the annuity during retirement. Not only is the tax burden on labour income deferred, the average tax rate that households face tends to be lower during retirement as well. Because each pension fund generally has many participants as a result of the contribution mandate and subsidies, adverse selection is not a concern. This allows the pension fund to smooth out idiosyncratic mortality risk and thus provide longevity insurance. Once workers are enrolled in a pension fund, the amount they contribute is not decided by themselves but rule-based instead. Contributions are a constant fraction of the pension base, which is the portion of gross labour income that exceeds a lower bound based on the pay-as-you-go benefit and that is below an upper bound of about three times the average labour income. Early withdrawal of, or borrowing against, pension fund wealth is impossible. The third pillar is of supplementary and voluntary nature, and primarily used by the self-employed. Households can choose to purchase tax-deductible insurance products that are tailored to

---

3 Pension funds can cover all employees within an entire industry, a particular firm or a profession. Participation is mandatory for almost all industry pension funds (which collectively manage about 70% of all accrued pension wealth in the second pillar), while for the other types of funds employers offer enrolment as part of employee remuneration. Self-employed, unemployed and salaried workers who are not offered or who refuse enrolment do not accumulate pension benefits in the second pillar.

4 Pension funds can also smooth financial risk across generations, as discussed by for instance Gollier (2008), but we ignore this aspect.
saving for retirement from financial institutions.\textsuperscript{5}

The Dutch central bank oversees the pension funds in the second pillar and reports that they manage assets valued at about 1.750 billion euros, which is almost twice the gross domestic product of the Netherlands. The second pension pillar is thus an important wealth component for households. To illustrate this, we present an overview of their financial portfolios using administrative data from 2018 by Statistics Netherlands, the Dutch national statistical office.\textsuperscript{6} We restrict our attention to couples that have salary as primary source of income and that own residential property. In 2018, about 93% of wage-earning couples contributed to a pension fund and their home-ownership rate was about 81%. Figure 1.1a depicts average wealth relative to gross labour income by age for the three asset classes that are most important to Dutch households: liquid wealth (sum of bank account balances, stocks and bonds), home equity (value of real estate minus outstanding mortgage debt) and net pension wealth in the second pension pillar.\textsuperscript{7} Figure 1.1b converts the ratios to wealth shares. It is apparent that Dutch households, regardless of their age, primarily invest in illiquid asset classes, leaving them exposed to adverse labour income shocks.\textsuperscript{8}

While the current Dutch pension system is internationally renowned (Mercer, 2021), it is also regarded as overly rigid. Current policy debate therefore revolves around incorporating more flexibility and freedom of choice, which effectively increases the liquidity of pension wealth in the second pillar. For instance, Ciurila et al. (2021) propose a contribution mandate that also depends on the age and financial position of households, and that allows for early withdrawal of pension wealth in case households are in need of liquidity. Some policy suggestions have already been implemented: the revised pension agreement of 2021 allows households to withdraw 10% of accrued pension wealth as a lump-sum upon retirement. We study the effects of such flexibilisation policies using the model outlined in the next section.

\textsuperscript{5}While the size of the third pillar is not known, Statistics Netherlands (the Dutch national statistical office) estimates that it covers about 5% of total pension wealth (Molenaar-Cox & Woestenburg, 2018).

\textsuperscript{6}Details about the dataset are provided in section 1.9.1.

\textsuperscript{7}We observe the size of the gross pension fund annuity that households have accrued in the administrative data. We calculate the net present discounted value using mortality rates published by Statistics Netherlands, the average tax rate that retirees face and an annual real interest rate of 1.5%. The latter corresponds to the ultimate forward rate that pension funds are mandated by the Dutch central bank to use when discounting future pension pay-outs.

\textsuperscript{8}Because we only have information on accrued pension annuities for 2018, it is impossible to interpret figure 1.1a and 1.1b from a life-cycle perspective. The wealth compositions by household age are also influenced by differences between generations, such as experienced house prices, pension system design and income growth.
Figure 1.1: Wealth allocation over the life cycle using administrative data from Statistics Netherlands for 2018 for all home-owning couples that are aged between 25-64 and that have labour income as primary source of income. Solid line: after-tax present discounted value of accrued pension fund annuity. Dashed line: sum of bank account balances, stocks and bonds. Dotted line: value of real estate minus outstanding mortgage debt.
1.3 Model

We build a life-cycle model in the spirit of the buffer-stock literature spawning from Carroll (1997) that captures the observed illiquid financial portfolios of households in the Netherlands. Households invest in three assets: a risk-free asset, a durable good and a pension fund, and face two types of risk: uninsurable income risk and insurable longevity risk. Households are bound by a borrowing constraint and therefore keep a liquid buffer stock to shield against earnings risk. Insuring against longevity risk is possible through participation in the pension fund: contributions accumulate as an annuity that is paid out during each period in which the household is alive during retirement. While contributions to such pension plans are typically irreversible, we allow for early withdrawal of accumulated pension wealth at a penalty. Households prefer to annuitise their liquid wealth only upon retirement, but this is either impossible due to per-period contribution limits or contribution mandates, or discouraged through use-it-or-lose-it policies such as employer matching and tax deferral. With respect to the durable good, we follow the modelling of Berger & Vavra (2015): households derive utility from non-durable and durable consumption goods, but the durable good depreciates and is subject to a non-convex adjustment cost. While the only durable good that we have data on is housing, we interpret it in the model as a broad measure of durable spending that includes both consumer durables and housing. We now elaborate on the separate model elements.

Demographics Time is discrete and one period corresponds to one year. Households enter the labour force at age $t = 1$, work until retirement at age $t = T^{ret}$ and potentially live until age $t = T$ subject to age-dependent conditional survival probabilities. Let $\gamma_t$ denote the probability that the household is alive in period $t$ conditional on being alive in period $t - 1$, with $\gamma_1 = 1$ and $\gamma_{T+1} = 0$.

Preferences Households enter the period with cash-on-hand $M_t$, stock of durable good $N_t$, pension fund annuity $F_t$, permanent income $P_t$ and pension fund early withdrawal eligibility status $I_t$, and choose non-durable consumption $C_t$, durable consumption $D_t$ and pension fund contributions $E_t$. Households maximise expected life-time utility:

$$U(C_1, D_1) + \mathbb{E}_1 \left[ \sum_{t=2}^{T+1} \beta^{t-1} \left( \prod_{i=1}^{t-1} \gamma_i \right) \left( \gamma_t U(C_t, D_t) + (1 - \gamma_t) B(Z_t) \right) \right], \quad (1.1)$$
where $\beta$ is the discount factor and $Z_t$ is the wealth that the household bequeaths. The per-period utility and bequest function are, respectively:

$$U(C_t, D_t) = \left( C_t^\alpha D_t^{1-\alpha} \right)^{1-\rho} ,$$

$$B(Z_t) = \frac{\kappa}{1-\rho} (Z_t/\kappa)^{1-\rho} ,$$

where $\rho$ is the coefficient of relative risk aversion, $\alpha$ is the Cobb-Douglas weight on non-durable consumption, and $\kappa$ is the strength of the bequest motive.

**Labour income** Before retirement, households earn labour income $Y_t$ subject to independently and identically log-normally distributed transitory and permanent shocks $\xi_t$ and $\psi_t$, respectively. During retirement, households are no longer subject to income shocks and receive a pay-as-you-go pension benefit.

$$Y_{t+1} = \begin{cases} \xi_{t+1}P_{t+1} & \text{if } t < T_{\text{ret}} - 1 \\ y_{\text{payg}}P_{t+1} & \text{if } t \geq T_{\text{ret}} - 1 \end{cases} ,$$

$$P_{t+1} = \begin{cases} \psi_{t+1}G_{t+1}P_t & \text{if } t < T_{\text{ret}} - 1 \\ P_t & \text{if } t \geq T_{\text{ret}} - 1 \end{cases} ,$$

$$\xi_{t+1} = \begin{cases} y_{\text{ue}} & \text{with prob. } \pi_{\text{ue}} \\ \epsilon_{t+1-\pi_{\text{ue}}y_{\text{ue}}} & \text{with prob. } 1 - \pi_{\text{ue}} \end{cases} \sim \mathcal{N}(-0.5\sigma_\xi^2, \sigma_\xi^2) ,$$

$$\log \epsilon_{t+1} \sim \mathcal{N}(-0.5\sigma_\epsilon^2, \sigma_\epsilon^2) ,$$

$$\log \psi_{t+1} \sim \mathcal{N}(-0.5\sigma_\psi^2, \sigma_\psi^2) ,$$

where $P_t$ is permanent income, $G_t$ represents a deterministic growth path over the life cycle and $y_{\text{payg}}$ is the gross pay-as-you-go replacement rate. Before retirement, households are unemployed with probability $\pi_{\text{ue}}$ and receive $Y_t = y_{\text{ue}}P_t$ in this state, where $y_{\text{ue}}$ denotes the gross replacement rate of the unemployment benefit. The normalisation in (1.6) ensures that $\mathbb{E}[\xi] = 1$.

**Pension fund system** Before retirement, households contribute $E_t$ to a pension fund and in turn their accrued annuity $F_t$ grows by a fraction $\nu_t$ of contributions, corrected for
the adjustment factor $\mu_t$, while contributions during retirement are ruled out:

$$F_{t+1} = \begin{cases} 
F_t + \mu_t \nu t E_t & \text{if } t < T_{\text{ret}} \\
F_t & \text{if } t \geq T_{\text{ret}}.
\end{cases}$$

(1.9)

The pension fund collects the contributions by households and invests them at a risk-free per-period gross return $R_t$, which is the same risk-free rate that the households obtain on their private saving. We thus do not assume that the pension fund earns superior returns compared to households. However, the pension annuity is the only asset available to households which yields a return that is conditioned on living status: households receive the annuity $F_t$ during every period in which they are alive while retired, and 0 otherwise. If sufficiently many households participate in the pension fund, which we assume is achieved either through mandates or subsidised contributions, the pension fund provides insurance against the idiosyncratic longevity risk.

The contributions by households are valued actuarially fairly, meaning that the pension fund has no profit motive or operating cost:

$$\nu_t = \left( \frac{R_{T_{\text{ret}}-t}}{\prod_{j=T_{\text{ret}}+1 \gamma_j}} \right) \left/ \left( \frac{\sum_{i=T_{\text{ret}}}^T \prod_{j=T_{\text{ret}}+1 \gamma_j}}{R_{T_{\text{ret}}}} \right) \right..$$

(1.10)

The first term converts an invested unit of contribution by a household of age $t$ to its accrued value upon retirement, corrected for the probability that the household reaches retirement. The second term denotes the present discounted value in $T_{\text{ret}} - t$ periods of paying out one unit during each period in which the household is alive while retired. In other words, the accrual rate $\nu_t$ balances the revenue of one unit of contribution against its cost so that the pension fund assets are equal to its liabilities by construction.

The amount that households can contribute to the pension fund in each period is restricted:

$$e_t = E_t / P_t,$$

(1.11)

---

9Yearly operating costs of Dutch pension funds are about 0.25% of total assets, which is in line with privately accessible mutual funds (Bikker & Meringa, 2021).

10Note that government mandated participation would allow the pension fund to set different accrual rates from (1.10). In fact, the Dutch pension fund system was characterised by a uniform accrual rate until the revised pension agreement of 2019. A uniform accrual rate implies that contributions by younger households are relatively undervalued and that contributions by older households are relatively overvalued, because the contributions by younger households are invested for a longer time period while the annuity accumulation is the same for all households. With voluntary participation, a uniform accrual rate is untenable as households have a strong incentive to further postpone contributing to the pension fund.
$e_t \in \begin{cases} \begin{array}{ll} [e, \bar{e}] & \text{if } t < T^{\text{ret}}, I_t = 0 \\ [\epsilon^{\text{ue}}, \bar{e}^{\text{ue}}] & \text{if } t < T^{\text{ret}}, I_t = 1 \\ [0, 0] & \text{if } t \geq T^{\text{ret}} \end{array} \end{cases}$

$I_t = \begin{cases} \begin{array}{ll} 1 & \text{if } \xi_t = y^{\text{ue}} \\ 0 & \text{if } \xi_t \neq y^{\text{ue}} \end{array} \end{cases}$

$F_{t+1} \geq 0,$

where $e_t$ is the contribution rate, $\epsilon$ and $\bar{e}$ is its lower and upper bound when the household is employed, and $\epsilon^{\text{ue}}$ and $\bar{e}^{\text{ue}}$ is its lower and upper bound when the household is unemployed. In the absence of an upper bound, households would only contribute to the pension fund in the period before retirement. This would allow them to maintain a liquid buffer stock during working life to cope with earnings risk, while still insuring against longevity risk during retirement.\textsuperscript{11} However, in for instance the American 401(k) system there is a limit on the amount of contributions that households can make in a year. While the contributions in most pension fund systems are irreversible, we allow for negative contribution rates through $\epsilon^{\text{ue}} < 0$ subject to an early withdrawal penalty, the eligibility restriction (1.13) and the non-negativity restriction (1.14). This ensures that households only extract pension fund wealth when they are likely to be close to their borrowing limit.\textsuperscript{12} For ease of exposition, we focus on permitting early withdrawal during unemployment only, but it is possible to model the pension fund contribution bounds more generally as a function of age, income shock realisations and state variables.\textsuperscript{13}

Besides the provision of longevity insurance, contributing to the pension fund is attractive for fiscal reasons. Firstly, employers typically match contributions to pension fund systems by their employees up until a limit. Secondly, contributions tend to be tax deductible. In other words, the labour income that is directed towards the pension fund is only taxed when the pension fund annuity is paid out. Not only does the household incur the tax burden at a much later date, the tax rate that retired households face is usually lower than the tax rate they face during working life. These two fiscal advantages provide an incentive not to defer participation in the pension fund and we call them use-it-or-lose-it policies, because they are only available if they are exploited during the period in which the labour income is earned.\textsuperscript{14}

\textsuperscript{11}Furthermore, there is a chance that the household does not even live until retirement.

\textsuperscript{12}If early withdrawal is permitted in all cases at no penalty, then younger households will exploit the employer match by contributing and afterwards withdrawing pension fund wealth.

\textsuperscript{13}In fact, we incorporate flexible contribution mandates in this way below.

\textsuperscript{14}We note that these use-it-or-lose-it policies are somewhat artificial. Households would prefer to receive
We incorporate the employer matching of contributions and early withdrawal penalty through the adjustment factor $\mu_t$:

$$
\mu_t = \begin{cases} 
\mu^{\text{match}} & \text{if } e_t \in [0, e^{\text{match}}] \\
1 + (\mu^{\text{match}} - 1) \frac{e^{\text{match}}}{e_t} & \text{if } e_t \in (e^{\text{match}}, \bar{e}], \\
\mu^{\text{withdrawal}} & \text{if } e_t < 0
\end{cases}
$$

(1.15)

where $\mu^{\text{match}}$ is the matching rate that is applied until the matching limit $e^{\text{match}}$ and $\mu^{\text{withdrawal}}$ is the early withdrawal penalty.

**Private saving, taxation and durable good** Cash-on-hand $M_t$ is comprised of the return on private saving and net labour or pension income, and evolves according to:

$$
M_{t+1} = \begin{cases} 
RA_t + (1 - \tau_{t+1}) Y_{t+1} & \text{if } t < T^{\text{ret}} - 1 \\
RA_t + (1 - \tau_{t+1}) (Y_{t+1} + F_{t+1}) & \text{if } t \geq T^{\text{ret}} - 1
\end{cases}
$$

(1.16)

where $A_t$ represents private saving and $\tau_t$ is the age-dependent linear income tax rate. The labour income of households is taxed at a higher rate than their pension income to reflect that households typically pay less taxes during retirement than before it:

$$
\tau_t = \begin{cases} 
\tau^w & \text{if } t < T^{\text{ret}} \\
\tau^r & \text{if } t \geq T^{\text{ret}}
\end{cases}
$$

(1.17)

Households enter the period with an existing stock of the durable good $N_t$ and have the option to either keep the stock unchanged $(D_t = N_t)$ or to adjust it $(D_t \neq N_t)$. If the household chooses the latter, it incurs a proportional adjustment cost $\zeta$.\(^{15}\) Its cash-on-hand after selling the beginning-of-period stock of the durable good, $X_t$, is thus:

$$
X_t = M_t + (1 - \zeta) N_t.
$$

(1.18)

The stock of the durable good depreciates at rate $\delta$:

$$
N_{t+1} = (1 - \delta) D_t.
$$

(1.19)

---

\(^{15}\)We do not model other institutional details pertaining to durable goods that might be important, such as mortgage debt. Given that the model features up to five state variables and three choice variables already, we restrict ourselves to a simplified treatment of durable goods that captures their most important feature to us: illiquidity through non-convex adjustment costs.
Private saving $A_t$ is given by:

$$A_t = \begin{cases} 
M_t - C_t - (1 - \tau_t)E_t & \text{if } D_t = N_t, \\
X_t - C_t - (1 - \tau_t)E_t - D_t & \text{if } D_t \neq N_t,
\end{cases}$$

(1.20)

where $(1 - \tau_t)E_t$ reflects the tax deductibility of pension fund contributions. Households can borrow up to a fraction $\lambda$ of their stock of the durable good:

$$A_t \geq -\lambda D_t.$$  

(1.21)

Households bequeath their private saving and liquidated stock of the durable good:

$$Z_{t+1} = RA_t + (1 - \zeta)(1 - \delta)D_t.$$  

(1.22)

**Value function** The household decision problem described above can be written in the form of a Bellman equation, where the household value function $V_t$ is a maximum over the value function when adjusting, $V_t^{\text{adjust}}$, and when keeping $V_t^{\text{keep}}$:

$$V_t(M_t, N_t, F_t, P_t, I_t) = \max \left\{ V_t^{\text{adjust}}(X_t, F_t, P_t, I_t), V_t^{\text{keep}}(M_t, N_t, F_t, P_t, I_t) \right\}$$

s.t. (1.18),

where:

$$V_t^{\text{keep}}(M_t, N_t, F_t, P_t, I_t) = \max_{C_t, E_t} U(C_t, D_t) +$$

$$\beta \mathbb{E}_t \left[ \gamma_{t+1}V_{t+1}(M_{t+1}, N_{t+1}, F_{t+1}, P_{t+1}, I_{t+1}) + (1 - \gamma_{t+1})B(Z_{t+1}) \right],$$

s.t. (1.2-1.12), (1.14-1.17), (1.19), (1.21), (1.22),

$$D_t = N_t,$$

$$A_t = M_t - C_t - (1 - \tau_t)E_t,$$

$$I_{t+1} = \begin{cases} 
1 & \text{if } \xi_{t+1} = y^{\text{ue}}, \\
0 & \text{if } \xi_{t+1} \neq y^{\text{ue}},
\end{cases}$$

and:

$$V_t^{\text{adjust}}(X_t, F_t, P_t, I_t) = \max_{C_t, D_t, E_t} U(C_t, D_t) +$$

$$\beta \mathbb{E}_t \left[ \gamma_{t+1}V_{t+1}(M_{t+1}, N_{t+1}, F_{t+1}, P_{t+1}, I_{t+1}) + (1 - \gamma_{t+1})B(Z_{t+1}) \right],$$

s.t. (1.2-1.12), (1.14-1.17), (1.19), (1.21), (1.22),
\[ A_t = X_t - C_t - (1 - \tau_t)E_t - D_t, \]
\[ I_{t+1} = \begin{cases} 1 & \text{if } \xi_{t+1} = y^{ue} \\ 0 & \text{if } \xi_{t+1} \neq y^{ue} \end{cases}. \]

**Numerical approach**  We solve the model by backward induction: given the bequest at age \( T + 1 \), we can solve for the policy and value functions at age \( T \), which allows us to solve for the policy and value functions at age \( T - 1 \), repeating until age \( t = 1 \). However, a simple grid search is infeasible because the model features up to five state variables (cash-on-hand, stock of the durable good, pension fund annuity, permanent income and pension fund early withdrawal eligibility), three choice variables (non-durable consumption, durable consumption and pension fund contributions) and non-convexity in durable good adjustment. To solve the model with reasonable speed and accuracy, we follow three steps. Firstly, we recognise that the decision problem of the adjusting household can be viewed sequentially: after choosing durable consumption, its decision problem is given by that of the keeping household. In turn, the decision problem of the keeping household can be viewed sequentially by first choosing pension fund contributions and then non-durable consumption. Secondly, we exploit that the household problem can be normalised with respect to permanent income, eliminating it as a state variable. Maintaining normalisability of the household problem requires that no model element scales non-linearly in permanent income. As a result, we cannot incorporate non-linear taxation or pension fund contribution mandates. Thirdly, we employ the Nested Endogenous Grid Method (NEGM) of Druedahl (2020), whose solution procedure applies to a model class that nests the model described above. The idea is to use the Endogenous Grid Method (EGM) of Carroll (2006) coupled with an upper envelope procedure to solve for the optimal non-durable consumption choice using the inverted Euler equation (thus eliminating costly root-finding in one dimension) and to use a numerical solver in the remaining choice dimensions. Further details about the nesting, normalisation, optimality condition for non-durable consumption and numerical implementation are stored in section 1.9.2.

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16Normalised variables are denoted by the lower case version of their upper case counterpart, e.g. \( a = A/P \).

17For instance, in the Dutch pension fund system, contributions are paid over the share of income which exceeds a lower threshold (based on the pay-as-you-go benefit) and which does not exceed an upper limit. Conditional on participation, the marginal contribution rate is constant. Such non-linearity of contributions in income breaches the normalisability of the model and would make solving it numerically infeasible. We mimic the Dutch system below by setting a constant contribution rate instead.
1.4 Calibration

We rely on administrative data from 2011-2018 by Statistics Netherlands, the Dutch national statistical office, to calibrate the model parameters with respect to demographics, labour income, pension system and initial conditions of simulations. We elaborate on the administrative data, sample selection and income variable definitions in section 1.9.1. The real interest rate is calibrated within the model to ensure that pension fund contributions line up with observed accumulated pension fund annuities. The remaining parameters, related to technology and preferences, are drawn from national statistics or other papers in the literature. The calibration strategy is motivated below, while model parameter values are summarised in table 1.1.

Demographics  Households enter the labour force at age 25 (which corresponds to \( t = 1 \)), reach retirement at age 65 and potentially live until age 100. The pensionable age in the Netherlands is linked to the evolution of life expectancy and therefore not static. During the sample period, the pensionable age was between 65 years and 65 years plus 9 months. The age-dependent conditional survival probabilities \( \gamma_t \) are derived from mortality rates published in life tables by Statistics Netherlands in 2018. Since the life table ends at 100 years, we cap the maximum reachable age in the model at this value. The corresponding cumulative survival probabilities are plotted in figure 1.2.

Labour income  To estimate the income profile over the life cycle and income risk parameters, we follow the approach of Carroll & Samwick (1997). We first subtract the predictable elements from labour income by regressing the net income of households on age, year and cohort dummies. Because the model normalisation does not allow us to incorporate the progressive tax structure of the Netherlands, we use net income instead of gross income to estimate the model parameters pertaining to labour income. Using gross income would overestimate the labour income risk that households face and therefore distort the trade-off between insuring against income shocks and accumulating sufficient income during retirement. The regression does not contain additional control variables, so that the age dummies capture income developments over the life cycle that are not present in our model (such as changes in household size or education). We run the regression for the sample of home-owning, wage-earning couples aged between 25 and 64, because the pensionable age was 65 for many households between 2011 and 2018. The coefficients of the age dummies correspond to the income profile over the life cycle and are plotted in figure 1.3. We regress them on a fifth-order polynomial in age and use the fitted values in our life-cycle model for \( G_t \). The residuals of the regression are then decomposed into
| **Demographics** |  |
|-----------------|---|---|
| Retirement age  | $T^{\text{ret}} + 24$ | 65 |
| Terminal age    | $T + 24$ | 100 |
| Age-dependent conditional survival probabilities | $\{\gamma_t\}_{t=1}^{T+1}$ | Figure 1.2 |

| **Labour income** |  |
|-------------------|---|---|
| Deterministic life-cycle growth path | $\{G_t\}_{t=1}^{T^{\text{ret}}-1}$ | Figure 1.3 |
| Standard deviation of permanent shock | $\sigma_\psi$ | 9.1% |
| Standard deviation of transitory shock | $\sigma_\xi$ | 9.8% |
| Unemployment probability | $\pi^{\text{ue}}$ | 5.0% |
| Unemployment benefit | $y^{\text{ue}}$ | 70.0% |
| Tax rate before retirement | $\tau^w$ | 37.5% |
| Tax rate during retirement | $\tau^r$ | 25.0% |

| **Pension system** |  |
|---------------------|---|---|
| Pay-as-you-go benefit | $y^{\text{payg}}$ | 34.5% |
| Contribution limits (employed) | $\ell, \bar{e}$ | 3.3% |
| Contribution limits (unemployed) | $\ell^{\text{ue}}, \bar{e}^{\text{ue}}$ | 0.0% |
| Matching limit | $e^{\text{match}}$ | 3.3% |
| Matching rate | $\mu^{\text{match}}$ | 3.30 |
| Withdrawal penalty | $\mu^{\text{withdrawal}}$ | $\infty$ |

| **Technology** |  |
|----------------|---|---|
| Net real interest rate | $R - 1$ | 2.4% |
| Durable good depreciation rate | $\delta$ | 2.4% |
| Durable good adjustment cost | $\zeta$ | 5.0% |
| Borrowing limit | $\lambda$ | 0 |

| **Household preferences** |  |
|---------------------------|---|---|
| Risk aversion             | $\rho$ | 5.0 |
| Discount factor            | $\beta$ | 0.96 |
| Cobb-Douglas weight on non-durable consumption | $\alpha$ | 0.85 |
| Bequest motive            | $\kappa$ | 4.5 |

**Table 1.1:** Baseline model calibration for the Netherlands. Estimates for labour income, pension system and interest rate parameters are obtained for the sample of stable, home-owning, wage-earning couples from 2011-2018 using administrative data from Statistics Netherlands.
Figure 1.2: Cumulative survival probabilities by age, derived using mortality rates published by Statistics Netherlands in 2018. Since the mortality rate series ends at 100 years, we ensure that no household lives beyond this age.

permanent and transitory parts using the imposed error structure from equations (1.4-1.8). Details are provided in section 1.9.3, while the estimated standard deviations of the permanent and transitory income shocks are presented in table 1.1.

The unemployment rate for working age households was roughly 5.0% during our sample period and unemployment benefits are 70.0% of previously earned labour income. We approximate the linear tax rate that households face by calculating the difference between their gross and net income. The worker tax rate $\tau^w = 37.5\%$ is considerably larger than the retiree tax rate $\tau^r = 25.0\%$, indicating that the tax-deferral benefit of pension fund contributions is sizeable.

Pension system We first determine the height of pension income during retirement and then calculate the relative size of its two elements: pay-as-you-go benefit and pension fund annuity. We use retirement events in our dataset (where households have wage income as primary income source in one year and pension benefits in the next) to pin down the replacement rate, which is total pension income during retirement relative to labour income earned before retirement. Estimates of the gross and net replacement rates vary between 90% and 110%, so we set the parameters of the pension system to achieve an after-tax-and-contribution replacement rate of 100%.\(^{18}\) The share of the pension fund annuity in

\(^{18}\)This implies $(1 - \tau^r)(y^\text{payg} + f) = (1 - \tau^w)(1 - e)$, where $y^\text{payg}$ is the gross pay-as-you-go replacement rate, $f$ the gross pension fund annuity replacement rate and $e$ the mandatory pension fund contribution
Figure 1.3: Solid line: estimated income profile over the life cycle derived from the age dummies in regression (1.25). Dashed line: fitted fifth-order polynomial to the age dummies. The dependent variable of the income regression is the log of real net income normalised to the mean of 25-year-old households. Using administrative data from Statistics Netherlands for 2011-2018, we select all home-owning couples that are aged between 25-64 and that have labour income as primary source of income.

total pension income is 57.2%. Together with the calibrated tax and contribution rates, this implies a gross pay-as-you-go replacement rate $y^{payg}$ of 34.5% and a gross pension fund annuity replacement rate $f$ of 46.1%. The pension fund system of the Netherlands is a restricted version of the general system described in section 1.3. Contribution mandates imply that working households pay about 3.3% of gross income to the pension fund, so that $\bar{e} = e = e^{\text{match}} = 3.3\%$. The sum of pension fund contributions paid by employers is 2.3 times larger than the contributions paid by employees, yielding a matching rate $\mu^{\text{match}} = 3.30$. Unemployed households face no mandatory pension fund participation. Since early withdrawal is impossible, the withdrawal penalty $\mu^{\text{withdrawal}} = \infty$. We internally calibrate the gross real interest rate $R = 1.024$ to ensure that the pension fund contributions over the life cycle accumulate towards the target gross pension fund annuity replacement rate $f$ of 46.1% upon retirement. This is higher than the ultimate forward rate of 1.5% that pension funds are mandated by the Dutch central bank to use when discounting future pension pay-outs.
Technology and preferences  We use national statistics published by Statistics Netherlands to calibrate the durable good depreciation rate and utility weight parameter. The average depreciation rate on housing between 2011-2018 was $\delta = 2.4\%$, while the average spending share on non-durable goods amounted to $\alpha = 0.85$. We follow the existing literature with this model structure of durable goods, specifically Berger & Vavra (2015), Berger et al. (2017) and Harmenberg & Öberg (2021), and set a similar parameter value for the durable good adjustment cost: $\zeta = 5.0\%$. Survey evidence by Ebner (2013) indicates that Dutch households scarcely borrow against their stock of durable goods to finance non-durable consumption. In a given year, about 7\% of home-owning households in the Dutch National Bank Household Survey (DHS) withdraw home equity without moving, but more than 80\% of the equity withdrawn is reinvested into residential property, is used to purchase other durable goods or is used to pay off existing debt. We therefore switch off borrowing against the stock of the durable good: $\lambda = 0$. To wrap up the calibration, we set the risk aversion $\rho = 5$ (which is higher than the aforementioned literature on durable goods but similar to the life-cycle model literature), the discount rate $\beta = 0.96$ and the bequest motive $\kappa = 4.5$.

1.5 Wealth and consumption over the life cycle under the Dutch pension system

We simulate the model to study whether the resulting life-cycle wealth allocations match those observed in figure 1.1 using the administrative data from Statistics Netherlands. Since young households have varying levels of income and existing wealth, we fit parameters of log-normal distributions to the data and use these to draw initial conditions for households entering the labour force in our simulations. Specifically, we look at the sample of home-owning, wage-earning couples aged between 24 and 26 in 2018. We define liquid assets as the sum of bank account balances, stocks and bonds, and define the stock of the durable good as the value of real estate minus outstanding mortgage debt. The accrued pension fund annuity is directly observed in the dataset. We normalise the three aforementioned variables by gross income. The estimated parameters in table 1.2 imply that

---

19 As noted by Berger & Vavra (2015), with $\lambda > 0$ and no adjustment costs on liquid assets, the model would counter-factually imply that households can adjust their durable equity (i.e., refinance) without cost.
20 This introduces a selection effect, because the home-ownership rate of wage-earning couples in this age group is relatively low at 46.5\% compared to the 81.1\% amongst all working-age couples.
21 We can not use the entire sample from 2011-2018, because the accrued pension fund annuities of households are only available for 2018.

24
### Table 1.2: Parameters of the log-normal distributions for initial income and wealth used in simulations. Estimates of the mean in levels and the standard deviation of the log-normal distribution obtained for the sample of home-owning, wage-earning couples aged between 24-26 in 2018 using administrative data from Statistics Netherlands. Implied mean is given by $\log(\text{mean in levels}) - \frac{1}{2} \sigma^2$ and implied median in levels by $\exp(\mu)$.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean in levels</th>
<th>Standard deviation</th>
<th>Implied mean</th>
<th>Implied median in levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross income ($P$)</td>
<td>1.000</td>
<td>0.328</td>
<td>-0.053</td>
<td>0.948</td>
</tr>
<tr>
<td>Liquid assets ($a$)</td>
<td>0.241</td>
<td>1.338</td>
<td>-2.318</td>
<td>0.099</td>
</tr>
<tr>
<td>Durable good ($n$)</td>
<td>0.595</td>
<td>1.237</td>
<td>-1.284</td>
<td>0.277</td>
</tr>
<tr>
<td>Pension fund annuity ($f$)</td>
<td>0.031</td>
<td>1.020</td>
<td>-4.176</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Households enter the model with a non-negligible amount of wealth, which has a distribution that is skewed to the right. We draw 250,000 sets of initial conditions and paths of the permanent and transitory income shocks, and use the numerically approximated policy functions to pin down the decisions of households.

Before discussing the life-cycle wealth allocations, we first describe the adjustment and consumption functions of households. The discrete adjustment decision gives rise to two regions in the state space: one in which the household adjusts its stock of the durable good and one in which it keeps its current stock of the durable good. Figure 1.4a shows an example for a household that enters the labour force with an average initial amount of pension wealth. The household adjusts if it has a relatively large or small stock of the durable good compared to cash-on-hand. For intermediate cases it stays put. In the upper adjustment region the household sells a portion of its stock of the durable good to afford more non-durable consumption, while in the lower adjustment region the household cuts down on non-durable consumption to purchase more of the durable good. Households cross the border between the keeping and adjusting region due to depreciation or income shock realisations. For example, a household that experiences a large and positive permanent income shock could enter the lower adjustment region and scale up its stock of the durable good. In the absence of future shocks, the household then keeps its stock of the durable good until it depreciates to a sufficiently low level where it crosses the lower adjustment border again.

The non-convex adjustment cost implies that households exhibit high marginal propensities to consume in a large region of the state space. This is especially clear from the total consumption function in figure 1.4b where the slope is (close to) unity for low cash-on-hand and stock of the durable good. The mandatory pension fund participation in the Dutch system pushes households closer towards this region. Another consequence of the
Figure 1.4: Adjustment and consumption functions of a household that enters the labour force with an average amount of pension wealth. Model calibrated to the Dutch pension fund system.
non-convex adjustment cost is the jumps in the non-durable and durable consumption functions displayed in figure 1.4c and 1.4d. The intuition is explained by Iskhakov et al. (2017): there is a kink in the policy function at points in the state space where the household crosses the border between adjusting and keeping in some future period. This is why there are many jumps when the household enters the labour force: for each future period there is a critical value of current resources for which the household switches regime. Most kinks are small because they are far away and smoothed out due to uncertainty. Closer to retirement there are fewer kinks (due to the shorter remaining length of life), but they become larger (because they are not smoothed out as much due to the disappearing earnings risk upon retirement).

The wealth allocations over the life cycle that follow from the simulation of the model are depicted in figure 1.5. The model replicates the illiquid financial portfolios of households observed in figure 1.1, but there are some differences as a result of both model and data artefacts. Firstly, in the simulations, most households adjust their stock of the durable good upon entering the labour force and therefore the model wealth allocations are initially too illiquid compared to the data. Secondly, in the data, the upward trend in accumulated pension fund wealth disappears close to retirement. This likely stems from selection into early retirement by households with a large stock of pension fund wealth. In 2018, about one third of those retiring were younger than the pensionable age of 65 and early retirees were relatively affluent. Thirdly, our simulation yields much less variability in the gross pension fund annuity replacement rate upon retirement than we observe in the administrative data. In our model all employed households contribute to the pension fund, but Dutch households that are self-employed or that are not covered by the relevant collective employment agreements do not. Since it is impossible to condition on the entire employment history of households, we observe an inflated standard deviation of the gross pension fund annuity replacement rate of 48%, while it is about 23% in our model simulation. If we trim the top and bottom 5% from the administrative data, we arrive at a comparable standard deviation of almost 28%. Fourthly, in the data, households across generations have different experiences with the housing market. Households aged between 30 and 40 that entered the market before the housing slump that followed the financial crisis of 2008 have less housing equity than younger households that entered during the slump, while older households have benefited from multiple housing booms throughout their lives. These subtleties are unaccounted for by our model and simulations.

To show that the low levels of liquid wealth translate into high consumption sensitivities, we calculate the marginal propensity to consume \( MPC_t \) as the numerical derivative
Figure 1.5: Wealth allocation over the life cycle using model calibrated to the pension system of the Netherlands. Solid line: after-tax present discounted value of accrued pension fund annuity. Dashed line: private savings. Dotted line: stock of the durable good.
of the non-durable consumption function \( C_t^* \) and durable consumption function \( D_t^* \):

\[
MPC_t = \lim_{\Delta \to 0} \frac{C_t^*(M_t + \Delta, N_t, F_t, P_t, I_t) + D_t^*(M_t + \Delta, N_t, F_t, P_t, I_t)}{\Delta} - \frac{C_t^*(M_t, N_t, F_t, P_t, I_t) + D_t^*(M_t, N_t, F_t, P_t, I_t)}{\Delta}.
\]

Figure 1.6 presents an overview of the distribution of private saving over the life cycle and its corresponding marginal propensity to consume. While on average households keep about 15% of their wealth in private savings, a considerable portion of households has very little of it. For example, about 12% of households keep less than 5% of annual gross labour income in the form of liquid wealth, which is close to the 11% that we observe for our sample of Dutch households in 2018. The lack of liquid wealth is especially prevalent at young ages when households prefer to grow their stock of the durable good instead. In the model about 30% of households aged 25-40 have normalised private saving of 10% or less, while in the data this proportion is even higher at 34%. The rigid participation mandate of the pension fund system is a contributing factor to low levels of cash-on-hand and as a result consumption sensitivities are high. In a general equilibrium context, such as in a heterogeneous agent New Keynesian model by Kaplan et al. (2018), the aggregate response to fiscal and monetary policy will greatly depend on whether and how they affect the liquid wealth of such constrained households. The marginal propensity to consume weighted by consumption and averaged over all simulated working age households provides an indication of the aggregate consumption sensitivity over the life cycle. Its value is almost 18%, higher than the weighted MPC’s of most alternative pension fund systems that we consider in the upcoming section.

1.6 Alternative designs of the pension fund system

In this section we discuss three adaptations to the Dutch pension fund system: 1) voluntary participation, 2) early withdrawal, and 3) a richer contribution mandate. Such flexibilisation policies are potentially controversial, because pension plans are typically rigid on the basis of imperfect financial planning by households. This point dates back to at least Laibson et al. (1998), who argue against early withdrawal of pension fund wealth to rule out the temptation for households to ‘raid their own eggs’. The role of illiquid asset classes (such as housing and pension savings) as useful commitment devices for households with temptation preferences has been noted by Kovacs et al. (2021). While we do not dispute this motivation, we observe that either strong use-it-or-lose-it policies or strict contribution mandates are sufficient incentives to ensure retirement savings adequacy despite potential
imperfect financial planning by households. The pension fund system of the Netherlands, which features both a contribution mandate and employer matching as well as tax deferral, can thus relax one of the two nudges. Either the use-it-or-lose-it policies are maintained together with voluntary participation, or a rich contribution mandate is accompanied by abolished employer matching and tax deferral. The current rigid contribution mandate forces households - also those that do not suffer from imperfect financial planning - to have illiquid wealth allocations and therefore high consumption sensitivities. Voluntary participation would allow households to delay participation in the pension fund, while a richer contribution mandate could enforce a similar increasing path of contribution rates over the life cycle. In the upcoming subsections, we discuss the effects of alterations to the pension fund system in the wider context of household financial portfolios. We pay specific attention to the liquidity of their wealth allocations and the associated consumption sensitivities, as well as the adequacy and uniformity of retirement savings.

1.6.1 Voluntary participation with use-it-or-lose-it policies

We change the default calibration from table 1.1 by setting the upper contribution limit $\bar{e} = 10.0\%$ and the lower contribution limit $e = 0.0\%$. All other model features, such as tax deductibility of pension fund contributions and employer matching, are maintained. This parametrisation is akin to the structure of 401(k)’s in the United States, but we do not yet allow for early withdrawal. Empirical evidence from the United States has
Figure 1.7: Pension fund contribution function of a household with an age of 40 and an average amount of pension wealth (left) or durable goods (right). Model calibrated to a modified version of the Dutch pension fund system that features voluntary participation.

raised doubts over whether the use-it-or-lose-it policies are sufficiently strong in 401(k)’s to convince short-sighted households to prepare adequately for retirement. Engelhardt & Kumar (2007) show that the empirical saving response to an increase in the matching rate is quite inelastic, while Amromin et al. (2007) show that some households forego a profitable tax arbitrage opportunity by accelerating mortgage payments (even though mortgage interest payments are tax deductible) instead of increasing employer-sponsored contributions to tax-deferred retirement accounts. However, in the Dutch system the employer matching is five to ten times as large and therefore a much stronger incentive to commit early in the life cycle to the pension fund.\textsuperscript{22}

The pension fund contribution choice of a typical employed household of age 40, displayed in figure 1.7, indicates that there is considerable bunching at $e$, $e^{\text{match}}$ and $\bar{e}$. The sizeable employer matching provides a strong incentive to contribute up to the matching limit and the household will only deviate in extreme scenarios.\textsuperscript{23} The household contributes nothing if it has very little cash-on-hand or durable goods, or if it already has accumulated a large pension fund annuity. The household opts for a maximum contribu-

\textsuperscript{22}Love (2007) states that the employer match on 401(k)’s is between 0.25 and 0.50 per unit of contribution, while it is 2.30 on average in the Netherlands.

\textsuperscript{23}This aligns with Love (2017), who shows that the matching limit can be an important fiscal policy instrument to stimulate consumer spending during downturns because of the bunching it attracts.
tion if the opposite is the case, and will only do so if it expects to contribute maximally in the future as well. Figure 1.8 depicts the corresponding pension fund contribution path over the simulated life cycles. As anticipated, the average contribution rate is below the matching limit at the start of the life cycle and above it at the end. Due to the strong pension fund contribution subsidies, practically all employed households contribute up to the matching limit between age 30 and 50.

While the increasing pension fund contribution path over the life cycle is a modest deviation from the flat contribution path of the Dutch mandate, figure 1.9 highlights that it is accompanied by differences in wealth allocation as well. At the start of working life, households use the funds freed up by contributing less to the pension fund by increasing their holdings of private savings and the durable good. This pattern is reversed once the household approaches retirement, when it allows the stock of the durable good to depreciate and when it eats up private savings to accumulate a pension fund annuity upon retirement that modestly exceeds the annuity achieved by the Dutch mandate. The remaining earnings risk over the life cycle is decreasing in age, and close to retirement there is thus less need for a buffer stock and more interest in insuring against longevity risk.

From figure 1.9 we infer that voluntary participation is preferred to the Dutch mandate. While young households increase their holdings of both durable goods and private savings, the increase in durable goods is relatively small and short-lived compared to the significant and prolonged boost to liquid wealth. It is thus not a concern that, in response to voluntary participation, households substitute away from the most illiquid asset class (pension fund wealth) towards the second most illiquid asset class (durable goods), netting no improvement in household liquidity and consumption sensitivity. Because the buffer stock motive dominates, the financial portfolios of Dutch households become more liquid as a result of voluntary participation. Table 1.3 shows that the fraction of households with very low levels of private savings and marginal propensity to consume close to unity is about 10% smaller compared to the Dutch mandate. An additional benefit of voluntary participation arises at the end of working life. Not only can households control how large their pension fund annuity upon retirement is, they can also adjust their pension fund contribution rate over the life cycle in response to realisations of earnings risk. As a result, the standard deviation of the pension fund annuity replacement rate upon retirement decreases from 23.1% under the Dutch mandate to 20.7% under voluntary participation.

Given the amount of employer matching and tax deferral, the rigid contribution mandate of the current Dutch pension fund system thus achieves an average annuity upon retirement that is similar to what households would choose for themselves and in that sense the mandate could therefore be regarded as ‘optimal’.

32
Figure 1.8: Mean pension fund contribution rate (right axis) and fraction of pension fund contribution choices below, at or above the matching limit (left axis) by household age. Model calibrated to a modified version of the Dutch pension fund system that features voluntary participation.

Figure 1.9: Mean percentage difference by household age in holdings of private savings, stock of the durable good and pension fund annuity between voluntary participation in the Dutch pension fund system and the contribution mandate of section 1.5.
1.6.2 Early withdrawal

Beshears et al. (2015) survey the liquidity provisions in retirement savings systems of six developed economies and classify them into three groups: 1) banned early withdrawal (Germany, Singapore and United Kingdom), 2) permitted early withdrawal after adverse labour income shocks (Canada and Australia), and 3) unconditional early withdrawal (United States). We change the calibration from section 1.6.1 (which is in line with the first group) and allow for conditional reversibility of pension fund contributions (which is in line with the second group). Unemployed households can now withdraw actuarially fairly from their accumulated annuity to offset the loss of income, provided that the annuity remains non-negative: $e_{ue} = -(1 - y_{ue}) = -0.30$, $\mu^{\text{withdrawal}} = 1$.\(^{25}\) If we were to model the unconditional reversibility of the United States, employed households would abuse the sizeable employer match by ramping up contributions at the start of the life cycle and subsequently withdrawing as much as possible, which seems counter-factual. Amromin & Smith (2003) and Argento et al. (2015) show that withdrawing households in the United States do so primarily after home purchases and adverse shocks (such as job loss and divorce). While we could model the early withdrawal eligibility as a more complex function of household characteristics, we focus on the parsimonious case of early withdrawal during unemployment to illustrate the effects of increasing the liquidity of pension fund wealth.\(^{26}\)

Figure 1.10 shows the mean contribution path and its distribution by household age. It is evident that virtually all unemployed households opt for a negative contribution rate, while compared to figure 1.8 more young households contribute positively to the pension fund. Households withdraw pension fund wealth as they are hit by unemployment shocks, so that the average contribution rate between age 27 and 45 is below the matching limit. To make up for previous withdrawal, from age 45 onwards households ramp up contributions to hit their target pension fund annuity replacement rate. This pattern is also reflected in figure 1.11, which shows the differences in holdings of private savings, durable goods and pension fund wealth compared to the system with voluntary participation and banned early withdrawal. The pension fund annuity grows faster, drops off as households withdraw, and catches up again (though it ultimately falls short of what households accrue in the system of section 1.6.1). While the option of early withdrawal entices young households to contribute more, the average annuity replacement rate upon retirement is lower. There is thus some truth in the concern that households, even those with dynamic-

\(^{25}\)We have experimented with setting $e_{ue} < -(1 - y_{ue})$, but this has little effects on the results.

\(^{26}\)Additionally, unemployment status is directly observable by the government or pension fund administrator, while other household characteristics that could be incorporated into the eligibility function might not be.
Figure 1.10: Mean pension fund contribution rate (right axis) and fraction of pension fund contribution choices below (including early withdrawal), at or above the matching limit (left axis) by household age. Model calibrated to a modified version of the Dutch pension fund system that features voluntary participation and early withdrawal at penalty \( \mu^{\text{withdrawal}} = 1.0 \).

Figure 1.11: Mean percentage difference by household age in holdings of private savings, stock of the durable good and pension fund annuity between voluntary participation with early withdrawal and penalty \( \mu^{\text{withdrawal}} = 1.0 \), and without early withdrawal.
ally consistent preferences, will be tempted to ‘raid their own eggs’. However, in line with
the aforementioned empirical evidence, in our model households do so only to smooth out
adverse shocks. Furthermore, the average annuity replacement rate still exceeds what the
contribution mandate of section 1.5 achieves.

The possibility of early withdrawal implies that the financial portfolios of households
are more liquid. Not only is the pension fund wealth a less illiquid asset class, withdraw-
ing households keep a considerable fraction of the reversed contributions in private savings
(although the holdings of the durable good also go up). Figure 1.11 shows that this is
primarily the case for middle-aged households, who keep a larger buffer stock and shift
back the excess private savings towards the pension fund as they approach retirement.
This pattern is partly driven by the motivation to mint the employer match. Without
early withdrawal, the employer matched contributions only become available upon retire-
ment when the pension fund annuity is paid out, but early withdrawal allows households
to access the employer match during working life already. Figure 1.12 shows that this
can be effectively discouraged with a modest early withdrawal penalty of 10% (which is
the penalty in the United States) or 25%. While the penalty dampens the take-up of
early withdrawal amongst borrowing constrained young households, the fraction of older
households that withdraw early (and the amount they withdraw) decreases severely. A
higher penalty therefore brings the differences in asset holdings from figure 1.11 closer to
zero.

Despite the withdrawal penalty, figures 1.12c and 1.12d indicate that the reversibility
of pension fund contributions allows young households that face unemployment to sustain
both non-durable and durable consumption. These two figures depict the instantaneous
difference in what the unemployed household consumes and what it would have consumed
if it had received a random labour income draw instead, and they should therefore not
be interpreted as dynamic impulse responses. The drop in non-durable consumption is
roughly halved and the drop in durable consumption can be fully eradicated, implying that
households do not have to adjust their stock of the durable good downwards in response
to unemployment thanks to the possibility of early withdrawal. The summary statistics

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27 There is an implicit early withdrawal penalty even with $w^{\text{withdrawal}} = 1$, because reversed contributions
are taxed at the comparatively high rate $\tau^w$. Early withdrawal is thus somewhat discouraged because it
forgoes the tax deferral benefit of pension fund contributions.

28 Since unemployment is a purely transitory event, there are no appreciable effects of early withdrawal
beyond the period in which it is allowed.

29 A similar pattern emerges when we compare the consumption drops between the Dutch system of
section 1.5 and the voluntary participation of section 1.6.1 of employed households who receive a relatively
low transitory income shock. In the Dutch mandate households are forced to continue participation,
while with voluntary participation households can scale down contributions. However, the difference
in consumption drops is smaller than in figures 1.12c and 1.12d because of the zero lower bound on
Figure 1.12: Response to unemployment by household age under various pension fund systems (voluntary participation without early withdrawal or early withdrawal at varying penalties). Consumption responses denote the mean percentage difference in consumption of unemployed households compared to if they had a random labour income draw instead.
reported in Table 1.3 show that early withdrawal implies a further improvement in liquidity of the financial portfolios of households and a further improvement in pension fund annuity uniformity compared to the pension fund systems of Sections 1.5 and 1.6.1. The over-withdrawal of pension fund wealth, stemming from the motive to mint the employer match before retirement, can be successfully avoided with a modest early withdrawal penalty.

1.6.3 Contribution mandate without use-it-or-lose-it policies

Another avenue to ensure both sufficient saving for retirement and liquidity at younger ages is to swap subsidised voluntary participation for unsubsidised contribution mandates. A sufficiently rich contribution mandate can replicate the increasing path of pension fund contributions over the life cycle from Figure 1.8, while the abolished participation subsidies can be given as additional income and therefore provide additional liquidity to younger households. We increase the labour income of employed households by the value of the employer match, \( Y_{\text{new}} = \xi_{\text{old}} P_{\text{old}} \left( 1 + e^{\text{match}} (\mu_{\text{match}} - 1) \right) \). Additionally, pension fund contributions are no longer tax deductible and households face an age-independent tax rate that is calibrated to generate the same present discounted value of government tax receipts over the life cycle as under the Dutch mandate.

We take a similar approach as Schlafmann et al. (2021) and specify an ad hoc contribution mandate for \( t < T_{\text{ret}} \):

\[
e_t = \begin{cases} 
\max \left\{ 0, \theta_1 + 1_{t > T_{\text{trend}}} \left( \theta_2 \left( t - T_{\text{trend}} \right) + \theta_3 \left( f_t - \bar{f}_t \right) \right) \right\} & \text{if } I_t = 0 \\
-1_{t \leq T_{\text{ue}}} \min \left\{ \theta_4, f_t / \nu_t \right\} & \text{if } I_t = 1,
\end{cases}
\]

(1.23)

where \( \theta_1 \) is a constant, \( \theta_2 \) is a time trend, \( \theta_3 \) is an annuity correction and \( \theta_4 \) is early withdrawal during unemployment. We allow the time trend, annuity correction and early withdrawal during unemployment to depend on household age via the indicator functions on \( T_{\text{trend}} \) and \( T_{\text{ue}} \). The annuity correction ensures that households ramp up or slow down contributions if their annuity \( f_t \) is below or above the average annuity of households with the same age \( \bar{f}_t \) that would materialise if \( \theta_3 = 0 \). The contribution rate is bounded from below at zero during employment, while during early withdrawal it is bounded by either \( \theta_4 \) or the non-negativity constraint of the pension fund annuity. Since there is no employer matching and since early withdrawal is mandated, we do not impose a penalty on early withdrawal.

We specify an ad hoc contribution mandate instead of replicating the pension fund contributions and the presence of strong use-it-or-lose-it policies that motivate even households with low levels of liquidity to continue participation.
tribution paths that households would choose if there was voluntary participation without use-it-or-lose-it policies, because in the absence of those subsidies the model contains no features that entice households to participate at younger ages.\textsuperscript{30} In case of the latter, households would delay contributing as long as possible and contribute up until the limit as they approach retirement. It seems unlikely that a government would want to implement a mandate that implies such extreme contribution rates over the life cycle. Instead, we model simple, intuitive and plausible mandates via the specification in (1.23).\textsuperscript{31} We want to show that we can come up with a rule that 1) improves on the Dutch mandate, 2) provides more liquidity to young households, 3) ensures adequate and uniform retirement savings through the pension fund, and 4) does not impose unreasonable contribution rates or access to private information by the pension fund.\textsuperscript{32}

In calibrating the contribution mandate, we set all pension fund parameters exogenously and adjust the time trend $\theta_2$ so that the accrued pension fund annuity at retirement is the same as in the case of the Dutch mandate. We choose $\theta_1 = 7.0\%$ and $T^{\text{trend}} = T^{\text{ret}} = 10$, and vary $\theta_3 = \{0, -0.5\}$ and $\theta_4 = \{0, 0.2\}$. The implied paths of pension fund contributions over the life cycle are shown in figure 1.13 together with those of the Dutch mandate and voluntary participation without early withdrawal.\textsuperscript{33} Employed households contribute a flat 7% of gross labour income until age 34, after which the flat contribution rate rises about 0.5 percentage points per year. The annuity correction parameter prescribes that households older than 34 contribute an additional 5 percentage points if their pension annuity replacement rate is 10 percentage points below the average replacement rate of households with the same age. Households younger than 34 can offset up to 20% of the income loss sustained during unemployment by drawing on their accumulated pension annuity, which is similar to the mean early withdrawal rate observed in figure 1.12b. Taken together, with the mandate in (1.23) households contribute comparatively less when young and they make up this deficit as they approach retirement (especially when early withdrawal of accumulated pension benefits is allowed). The area between the richer contribution mandates and the Dutch mandate is larger after age 40 than before it, because the comparatively larger pension fund contributions at the end of working life are invested

\textsuperscript{30}Model elements such as superior pension fund returns, heterogeneous costs of private stock market participation or sophisticated hyperbolic discounting could motivate households to contribute early on in the life cycle.

\textsuperscript{31}This requires us to place an important caveat on the discussed welfare results in section 1.7: a mandate that delays pension fund contributions later into the life cycle is always preferred by households.

\textsuperscript{32}The contribution mandate could be enriched to depend also on the private savings and durable goods of households, but this would require the pension fund to observe such information. The parsimonious mandate in (1.23) only requires the pension fund to observe household age, employment status and pension fund annuity.

\textsuperscript{33}The latter two include the employer match.
Figure 1.13: Mean pension fund contribution rate (including employer match) by household age. We compare the Dutch mandate (section 1.5) and voluntary participation without early withdrawal (section 1.6.1) to a richer contribution mandate given by (1.23) and the parametrisation in the figure legend. The contribution paths of mandates with annuity correction are almost identical to those without an annuity correction component, and therefore omitted in this figure.

Figure 1.14: Mean percentage difference by household age in holdings of private savings, stock of the durable good and pension fund annuity between the Dutch mandate (section 1.5) and the contribution mandate given by (1.23) and \( \theta_1 = 0.07, \theta_2 = 0.0046, \theta_3 = 0 \) and \( \theta_4 = 0 \).
for a shorter time period.

Figure 1.14 shows that a contribution mandate with an added time trend implies large differences in wealth allocation over the life cycle compared to the Dutch mandate (and analogously compared to the system of voluntary participation as well). Without use-it-or-lose-it policies households do not have to worry about foregoing the employer match and tax deferral when contributions to the pension fund are postponed in a richer mandate, and they can therefore opt for a different financial portfolio throughout their life cycle. Until age $t = T^{\text{trend}}$, households increase their stock of the durable good by about 10% and slowly let it depreciate when the time trend of the contribution mandate kicks in. Because the bulk of the pension wealth accumulation is delayed, households are able to maintain a larger buffer stock to shield against income risk. Similarly to figure 1.9, the household has considerably less private savings in the periods before retirement, but there is also less need for precautionary savings due to the scarce amount of income risk that is left to be incurred.

Table 1.3 summarises key summary statistics with respect to household liquidity, consumption sensitivity and retirement savings adequacy for the four considered contribution mandates. Compared to the alternative pension fund specifications of sections 1.6.1 and 1.6.2, the contribution mandate without annuity correction or early withdrawal brings a similar improvement in household liquidity and consumption sensitivity while ensuring similar accrual of the pension fund annuity. Allowing younger households to withdraw 20% of their permanent income during unemployment constitutes a minor improvement in most summary statistics. The standard deviation of the annuity is slightly lower, because households contribute relatively more when there is little labour income uncertainty left to materialise over the life cycle. However, an even larger reduction in pension fund annuity dispersion is achieved through the inclusion of an annuity correction component. This comes at a cost in terms of resilience to adverse income shocks, because households with a relatively low annuity compared to their peers are mandated to contribute more to the pension fund. Adding early withdrawal on top of the annuity correction maintains the increased retirement savings uniformity while offsetting the adverse effects on household liquidity and consumption sensitivity.

34The differences are similar if either the annuity correction or early withdrawal (or both) are switched on.
Table 1.3: Summary statistics for various pension fund system designs. We consider the Dutch mandate (section 1.5), voluntary participation without early withdrawal (section 1.6.1), voluntary participation with early withdrawal at various penalties (section 1.6.2), and richer contribution mandates with various parametrisations and $\theta_1 = 0.07$, $T^{\text{trend}} = T^{\text{ue}} = 10$ (section 1.6.3). Third column: fraction of working age households with normalised private savings below 5%. Fourth column: fraction of households aged 25-40 with normalised private savings below 10%. Fifth column: fraction of working age households with marginal propensity to consume exceeding 95%. Sixth column: average marginal propensity to consume weighted by consumption. Seventh column: mean annuity gross replacement rate upon retirement. Eighth column: standard deviation of annuity gross replacement rate upon retirement. Ninth column: consumption equivalent variation (CEV) between the different pension fund system designs and a baseline economy without pension fund system (section 1.7).
1.7 Welfare

To get an idea of how much households value access to different pension fund system designs, we compute the Consumption Equivalent Variation (CEV) similarly to Oswald (2019). We compare the value of life under a baseline economy without a pension fund system to an alternative economy that features a pension fund system by asking the question how much consumption compensation \( \iota \) the household would have to receive in the baseline economy to be indifferent between it and the alternative economy. The Cobb-Douglas utility and bequest function with \( \iota \) included as the consumption compensation are

\[
U(C_t, D_t, \iota) = \left( \frac{(1+\iota)C_t^{\alpha}D_t^{1-\alpha}}{1-\rho} \right)^{1-\rho} \quad \text{and} \quad B(Z_t, \iota) = \frac{k}{1-\rho} \left( (1+\iota)Z_t/k \right)^{1-\rho}.
\]

The value of life of household \( j \) with consumption compensation \( \iota \) under economy type is given by:

\[
V_j(\iota, \text{type}) = U(C^{*}_{t,j}(\iota, \text{type}), D^{*}_{t,j}(\iota, \text{type}), \iota) + \sum_{t=2}^{T+1} \beta^{t-1} \left( \prod_{k=1}^{t-1} \gamma_k \right) \left( \gamma_t U(C^{*}_{t,j}(\iota, \text{type}), D^{*}_{t,j}(\iota, \text{type}), \iota) + (1-\gamma_t)B(Z^{*}_{t,j}(\iota, \text{type}), \iota) \right),
\]

where \( C^{*}_{t,j}(\iota, \text{type}), D^{*}_{t,j}(\iota, \text{type}) \) and \( Z^{*}_{t,j}(\iota, \text{type}) \) are the optimal choices for non-durable consumption, durable consumption and bequest given the consumption compensation and pension fund system design. Let \( V(\iota, \text{baseline}) = \frac{1}{N} \sum_{j=1}^{N} V_j(\iota, \text{baseline}) \) be the average value of life under the baseline economy with consumption compensation \( \iota \) over the \( N \) simulated household life-cycle paths, and define \( V(0, \text{alternative}) = \frac{1}{N} \sum_{j=1}^{N} V_j(0, \text{alternative}) \) as the average value of life under the alternative economy without consumption compensation. The CEV is the value of \( \iota \) for which \( V(0, \text{alternative}) = V(\iota, \text{baseline}) \).

The welfare results are obtained in relation to a baseline economy that features no pension fund system, but that has an otherwise unchanged calibration as described in table 1.1. We do not compensate households in the baseline economy with a higher income for the absence of employer matching, but do give the present discounted value of the pre-existing pension fund annuity as additional private savings upon entering the labour force. The resulting CEV’s are reported in the final column of table 1.3. While the compensation compensations are calculated in relation to the baseline economy, we prefer to compare those of the alternative pension fund system designs to the one of the Dutch mandate. We also compare the CEV’s to that of a mandate where the use-it-or-lose-it policies are abolished, labour income is compensated and contributions are postponed until the period before retirement while still achieving the target pension fund annuity replacement rate of 46.1%. The associated CEV of 12.4% could be regarded as the upper bound on the welfare effects of changes to the Dutch pension fund system.

Table 1.3 shows that a system of voluntary participation with conditional early with-
drawal at a modest penalty not only enhances household resilience to adverse shocks, but also that it is preferred by households to the Dutch mandate. The difference in CEV’s, however, is comparatively small. This should not come as a surprise, because the differences in pension fund contribution and wealth allocation over the life cycle from figures 1.10 and 1.11 were relatively small due to the participation subsidies. The use-it-or-lose-it policies are such strong nudges to not deviate from the contribution path implied by the Dutch mandate that voluntary participation has little effect. On the contrary, the welfare gain from a richer contribution mandate and abolished use-it-or-lose-it policies is much more sizeable and associated with substantial reallocation of wealth over the life cycle. The addition of an annuity correction component can increase uniformity in the pension fund annuity replacement rate, while allowing early withdrawal during unemployment enhances household resilience to adverse shocks. The largest welfare gain follows from a rich contribution mandate that features both of these elements jointly.

1.8 Conclusion

This chapter departs from the observation that households allocate substantial portions of their wealth to illiquid asset classes such as pension plans and durable goods, and approaches this fact from a modern macroeconomic perspective which stresses the relation between household balance sheets and (aggregate) consumption. We focus on the case of the Netherlands, where housing and pension plans jointly constitute between 80% and 90% of household wealth. As in other countries with elaborate pension systems, participation in pension plans is mandated through contribution rules and subsidised through employer matching and tax deferral of contributions. Once contributions are made, they are irreversible until retirement. This ensures that households prepare adequately for retirement, but the lack of choice freedom during the accumulation phase of pension benefits impedes on the ability of younger households to accumulate durable goods and to smooth out adverse shocks. We show that choice freedom with sufficiently strong incentives to contribute early still ensures sufficient saving for retirement with the added benefit that younger households can scale down contributions as they see fit. Alternatively, rigid contribution mandates that impose a constant contribution rate over the life cycle can be enriched so that the mandated contribution rate responds to the realisation of labour income shocks and so that the contribution path is increasing over the life cycle. Additional liquidity of pension wealth can be provided by allowing conditional reversibility of contributions at modest early withdrawal penalties. Such modifications to existing pension plans can yield sizeable welfare gains.
It should not come as a surprise that adding flexibility to the design of pension systems increases household welfare in a model where households have dynamically consistent preferences and where they face no financial market imperfections. The existing rigid pension plan mandates are typically motivated on the basis of temptation-driven preferences (Dekel et al., 2009), hyperbolic discounting (Laibson, 1997) or heterogeneous costs of private stock market participation (Dahlquist et al., 2018). While the incorporation of such model elements are beyond the scope of this chapter, we argue that our results present a useful benchmark of what flexibility can achieve if households are unperturbed in their financial planning. Since empirical evidence on whether households follow life-cycle theory when preparing for retirement is mixed, policy-makers in charge of shaping pension systems should consider how they jointly fulfil the needs of different types of households. To that end, rich contribution mandates or voluntary participation with sufficiently strong subsidised contributions can accommodate the desire for commitment and ensure adequate saving for retirement, while also providing younger households with the liquidity to accumulate durable goods and to shield against labour income risk.

1.9 Appendix

1.9.1 Administrative data

The income and wealth of the entire population of Dutch households is derived from tax returns and supplemented with household characteristics (such as household composition, age and home-ownership status) from municipality administration data by Statistics Netherlands, the Dutch national statistical office. We have detailed information on the earned income, paid taxes, received benefits and social security contributions of households, as well as their assets (such as bank account balances, stocks and bonds, real estate and accumulated pension fund annuity) and liabilities (such as mortgage debt). While income information is available at both the individual and household level, wealth information is only shared at the household level. As such, our unit of observation is the household. The aforementioned variables are consistently measured and available to us from 2011-2018, with the exception of the accumulated pension fund annuity which is only available in 2018.

Each household is assigned a household head based on the socio-economic status of its members. We construct a panel dataset by following the household heads from 2011

\[35\text{Data access was facilitated by the Microdata Access Discount (MAD) from the Open Data Infrastructure for Social Science and Economic Innovations (ODISSEI) in the Netherlands.}\]

\[36\text{Generally, the individual with the highest income is identified as the household head.}\]
through 2018 and record the income and wealth information of the households of which it is a member. Some households are dropped from our sample. Firstly, we select only households whose primary source of income is wage income or pension benefits (52.2% and 30.6% of the entire population, respectively), because mandatory pension fund participation is particularly prevalent for wage earning households (93.1%) compared to other primary sources of income (such as self-employment or social security). Secondly, we keep only home-owning households (60.9% of the entire population), because this is the sole information on household ownership of durable goods that is available to us. Thirdly, we focus only on stable couples (with or without children) to mitigate differences over the life cycle as a result of changing household composition. This leaves a sample of about three million households.

To map the income data from tax records to the income variables in our model, we have to be precise about their definitions. We define gross income, equivalent to $y$ in the model, as the sum of labour income and employer contributions to social security, excluding employer pension fund contributions. Net income, equivalent to $(1 - \tau^w)y$ in the model, is defined as gross income plus net receipts from income-related insurances (such as unemployment and disability) and social insurances that are income-dependent (such as disability, handicap and alimony) minus income taxes plus employee pension fund contributions. For retirees, we use the gross income definition for workers and add receipts from pay-as-you-go benefits and pension fund annuities. The definition of net income is the same for retirees as for workers.

1.9.2 Model details and numerical implementation

Nesting and normalisation The decision problem of the household is double-nested and can be viewed sequentially: it consists of an inner non-durable consumption problem, a middle pension fund contribution problem and an outer durable good consumption problem. For the adjusting household, the choice of non-durable consumption and pension fund contributions are given by the solution to the keeper problem subject to the updated state variables as a result of the durable choice. For the keeping household, the choice of non-durable consumption is given by the solution to the inner problem subject to the pension fund contribution choice.

As is common with buffer-stuck models of this kind, no model element scales non-linearly with permanent income $P_t$. This stems from the combined assumption of (1) household preferences with constant relative risk aversion that are homothetic over the two types of consumption and bequests, (2) fully persistent income shocks, (3) constant unemployment and pay-as-you-go replacement rates, (4) bounds on the pension fund con-
tribution rate instead of the level of contributions, and (5) proportional income taxes, adjustment costs, durable good depreciation and borrowing constraint. The entire model can therefore be normalised with respect to $P_t$, eliminating it as a state variable.

Define the following auxiliary variables: 

$$w_t = \frac{W_t}{P_t^{1-\rho}} \text{ for } W_t = V_t^\text{keep}, V_t^\text{adjust}, U, B$$

and $l_t = \frac{L_t}{P_t}$ for any other variable $L_t$. Let $\hat{\psi}_{t+1} = \frac{P_{t+1}}{P_t} = \psi_{t+1} G_t, t < T^{ret} - 1$ and $\hat{\psi}_{t+1} = 1, t \geq T^{ret} - 1$. We can then write the decision problem of the household in nested and normalised form:

$$v_t(m_t, n_t, f_t, i_t) = \max \left\{ v_t^\text{adjust}(x_t, f_t, i_t), v_t^\text{keep}(m_t, n_t, f_t, i_t) \right\}$$

s.t.

$$x_t = m_t + (1 - \zeta)n_t.$$ 

The nested decision problem of the adjusting household:

$$v_t^\text{adjust}(x_t, f_t, i_t) = \max_{d_t} v_t^\text{keep}(m_t, d_t, f_t, i_t),$$

s.t.

$$m_t = x_t - d_t, $$

$$d_t \in [0, x_t].$$

The nested decision problem of the keeping household:

$$v_t^\text{keep}(m_t, d_t, f_t, i_t) = \max_{e_t} v_t^\text{inner}(o_t, d_t, h_t, i_t),$$

s.t.

$$h_t = \begin{cases} f_t + \mu_t \nu_t e_t & \text{if } t < T^{ret} \\ f_t & \text{if } t \geq T^{ret} \end{cases},$$

$$e_t \in \begin{cases} [\underline{e}, \bar{e}] & \text{if } t < T^{ret}, i_t = 0 \\ [\underline{e}^\text{ue}, \bar{e}^\text{ue}] & \text{if } t < T^{ret}, i_t = 1 \\ [0, 0] & \text{if } t \geq T^{ret} \end{cases},$$

$$h_t \geq 0,$$

$$o_t = m_t - (1 - \tau_t)e_t,$$

$$o_t \geq -\lambda d_t,$$

unchanged conditions (1.10), (1.15) and (1.17),
where $h_t$ and $o_t$ are the post-contribution decision normalised pension fund annuity and cash-on-hand, respectively. The inner decision problem:

$$v_t^{\text{inner}}(o_t, d_t, h_t, i_t) = \max_{c_t} u(c_t, d_t) + \beta \mathbb{E}_t \left[ \psi_{t+1}^{1-\rho} \left( \gamma_{t+1} v_{t+1}(m_{t+1}, n_{t+1}, f_{t+1}, i_{t+1}) + (1 - \gamma_{t+1}) b(z_{t+1}) \right) \right],$$

s.t.

$$a_t = o_t - c_t,$$
$$a_t \geq -\lambda d_t,$$

$$u(c_t, d_t) = \frac{(c_t^\rho d_t^{1-\rho})^{1-\rho}}{1-\rho},$$

$$\hat{\psi}_{t+1} = \begin{cases} \psi_{t+1} G_t & \text{if } t < T^{\text{ret}} - 1, \\ 1 & \text{if } t \geq T^{\text{ret}} - 1 \end{cases},$$

$$y_{t+1} = \begin{cases} \xi_{t+1} & \text{if } t < T^{\text{ret}} - 1, \\ y^{\text{payg}} & \text{if } t \geq T^{\text{ret}} - 1 \end{cases},$$

$$m_{t+1} = \begin{cases} Ra_t/\hat{\psi}_{t+1} + (1 - \tau_{t+1}) y_{t+1} & \text{if } t < T^{\text{ret}} - 1, \\ Ra_t + (1 - \tau_{t+1}) (y_{t+1} + f_{t+1}) & \text{if } t \geq T^{\text{ret}} - 1 \end{cases},$$

$$n_{t+1} = (1 - \delta) d_t/\hat{\psi}_{t+1},$$

$$f_{t+1} = h_t/\hat{\psi}_{t+1},$$

$$i_{t+1} = \begin{cases} 1 & \text{if } \xi_{t+1} = y^{\text{ue}}, \\ 0 & \text{if } \xi_{t+1} \neq y^{\text{ue}}. \end{cases},$$

$$z_{t+1} = (Ra_t + (1 - \zeta)(1 - \delta) d_t) / \hat{\psi}_{t+1},$$

$$b(z_{t+1}) = \frac{\kappa}{1-\rho} \left( z_{t+1}/\kappa \right)^{1-\rho},$$

unchanged conditions (1.6-1.8) and (1.17).

**Solution method** Recall that we solve the model by backward induction. At age $T+1$ the household decision problem is reduced to leaving a bequest, the size of which is solely determined by the state variable $z_{T+1}$. We solve each preceding age by starting from the inner problem, where we take as given the state variables after the durable consumption and pension fund contribution choices have been made. We loop over the state space of $d_t, h_t, i_t$ and at each node determine the optimal non-durable consumption choice via the Nested Endogenous Grid Method (NEGM) by Druedahl (2020). We then move on
to the intermediate problem, where we take as given the state variables after the durable consumption choice has been made. We loop over the state space of \( m_t, d_t, f_t, i_t \) and at each node determine the optimal pension fund contribution choice by using a numerical solver over the interpolated value function from the inner problem. Lastly, we solve the outer problem by looping over the state space of \( x_t, f_t, i_t \) and at each node determine the optimal durable consumption choice by using a numerical solver over the interpolated value function from the intermediate problem.

We follow the guide on solving non-convex consumption-saving models by Druedahl (2020), which not only contains the NEGM but also provides a number of other tools to speed up the solution, such as pre-computing the continuation value and placing the irregular endogenous grid back on a regular grid to facilitate fast multi-dimensional interpolation.\(^{37}\) However, the central contribution of Druedahl (2020) is to recognise that, despite the non-convex adjustment costs, the popular Endogenous Grid Method (EGM) by Carroll (2006) can still be used in the inner problem when coupled with an upper envelope routine. This avoids having to rely on costly root-finding in one choice dimension of the household problem. A variational argument in non-durable consumption shows that this model set-up gives rise to an Euler equation that is necessary for an optimum. It is however no longer sufficient due to the discrete adjustment choice. We thus require an upper envelope routine to discard non-optimal points that satisfy the Euler equation.

The inverted Euler equation of the household that has already made optimal durable consumption and pension fund contribution decisions is given by:

\[
c_t = \left( \frac{\beta \mathbb{E}_t\left[ \frac{\gamma_{t+1} \left( \gamma_{t+1} \alpha c_{t+1}^{\alpha(1-\rho)-1} d_{t+1}^{(1-\alpha)(1-\rho)} + (1 - \gamma_{t+1}) \left( z_{t+1}/\kappa \right)^{-\rho} \right)}{d_t^{(1-\alpha)(1-\rho)}} \right]}{\beta \mathbb{E}_t\left[ \frac{\gamma_{t+1} \left( \gamma_{t+1} \alpha c_{t+1}^{\alpha(1-\rho)-1} d_{t+1}^{(1-\alpha)(1-\rho)} + (1 - \gamma_{t+1}) \left( z_{t+1}/\kappa \right)^{-\rho} \right)}{d_t^{(1-\alpha)(1-\rho)}} \right]} \right)^{\frac{1}{\alpha(1-\rho)-1}}. \tag{1.24}
\]

Define the private saving grid \( G_a = \{a_1, a_2, ..., a_\#\} \) with \( a_1 = -\lambda d_t \). Given the states \( d_t, h_t, i_t \) and a node of \( G_a \), the non-stochastic states at age \( t + 1 \) are determined. The optimal choices of \( c_{t+1} \) and \( d_{t+1} \) then follow from the policy functions at age \( t + 1 \), which are available to us since we solve the model by backward induction. For each \( a_i \in G_a \), we can thus determine optimal non-durable consumption \( c_i \) using the inverted Euler equation (1.24) and subsequently find endogenous state cash-on-hand \( o_i \) using the budget constraint \( o_i = a_i + c_i \). The consumption function is given by the combinations of \( \{0, c_1, c_2, ..., c_\#\} \) and \( \{0, o_1, o_2, ..., o_\#\} \). At \( a_1 \) we find the endogenous state \( o_1 \) where the household is just off

---

\(^{37}\)Our model is nested in the general model class for which the tools in Druedahl (2020) apply. Sufficient conditions for using the NEGM centre around the pre-decision states of the outer problems not interfering with the post- and pre-decision state variables of the inner problems. For instance, the inner problem is unaffected by the pre-decision state \( f_t \) of the intermediate problem, while it may (and does) depend on its post-decision state \( h_t \).
the borrowing constraint, i.e. where it chooses the internally optimal consumption level $c_1$ which leaves no end-of-period assets $o_1$. At any $o_t < o_1$ the household is borrowing constrained and consumes $c_t = o_t$.\footnote{An additional benefit of the EGM is thus that the borrowing constraint is precisely identified.}

The endogenously determined grid points will generally not be rectilinear, which is an issue in multi-dimensional problems such as ours. Interpolation on an irregular grid in higher dimensions requires Delaunay triangulation and visibility walks, which Ludwig & Schön (2018) have shown to be computationally intensive. The NEGM places the non-durable consumption and value of choice at the endogenously derived points $\{0, o_1, o_2, ..., o_{#}\}$ back on an exogenous grid $\mathcal{G}_o$ via linear interpolation. If multiple solutions are found at a node of $\mathcal{G}_o$, only the one with the highest value of choice is selected. This final step thus executes the upper envelope routine and preserves fast multi-dimensional interpolation.

**Implementation**  We discretise the continuous state variables into unequally spaced grids that contain more elements towards their minimum value. During retirement, we can incorporate 200 grid points for each continuous state variable because the decision problem of the household does not contain a pension fund contribution choice. Before retirement, we also have 200 grid points for private saving $a$ and cash-on-hand after adjusting $x$. The remaining continuous state variables (cash-on-hand $m$, stock of the durable good $d$ and pension fund annuity $f$) have a grid with 100 points. We can allow for more grid points in the former two state variables, because the NEGM routine over $a$ is relatively fast and because the outer problem has relatively few state variables. The maxima of the grids are set such that they are not exceeded in the life-cycle simulations. Numerical integration is performed using Gauss-Hermite quadrature with 5 shock nodes for both the permanent and transitory income shocks.

We rely on the Matlab solver \texttt{fminbnd} to find the optimal choice of pension fund contribution and durable consumption in the intermediate and outer problem, respectively. A drawback of this solver is that it only finds local and interior solutions. We therefore explicitly check the bounds of the decision space. Additionally, we have experimented with a multi-start algorithm to confirm that the candidate solutions of the solver are in fact global. Furthermore, for the pension fund contribution choice, we run the solver on the three separate regions of $e$ that have a different adjustment factor $\mu$ and select the optimum from the candidate solutions together with all possible corner solutions.

For the outer problem, we have found that the choice of $d$ is non-decreasing in $x$ (keeping other states fixed). We can thus speed up the solution of durable consumption by...
bounding the admissible choice from below at the optimally chosen durable consumption at the same pension fund annuity but slightly lower cash-on-hand. This approach also works in the intermediate problem, where the choice of \( e \) is non-decreasing in \( m \). Lastly, if the unrestricted pension fund contribution choice is in the decision space of the restricted choice, the restricted choice will be equal to the unrestricted choice (again keeping other states fixed). The same applies for durable consumption in the outer problem: if the household with unrestricted pension fund contribution choice opts for durable consumption that implies pension fund contribution within the decision space of the restricted choice, the restricted household picks the same durable consumption and pension fund contribution. As a result of these shortcuts, the solver sections of the code are sped up by about 50% without affecting the resulting policy functions.

For a given parameter constellation, solving the model takes about two hours on one node (Intel® Xeon® Gold 6130 processor with 2.10 GHz and 96 GB of working memory) of the Lisa cluster computer maintained by SURFsara.\(^{39}\)

1.9.3 Income risk and profile over life cycle

We exploit how the variance of changes in net income over different time periods depends on permanent and transitory shocks using the imposed error structure from equations (1.4)-(1.8). This yields a system of multiple equations that pins down the variance of both types of income shocks. We first subtract the predictable elements from labour income through the regression:

\[
y_{h,t} = a_{age} + b_t + c_{cohort} + \psi_{h,t} + \epsilon_{h,t},
\]

where \( y_{h,t} \) is the log of real net income of household \( h \) in year \( t \), \( a_{age} \) are age dummies, \( b_t \) are year dummies, \( c_{cohort} \) is a cohort fixed effect, \( \psi_{h,t} \) denotes the shock to permanent income and \( \epsilon_{h,t} \) is the transitory income shock. Note that the logged versions of equations (1.4) and (1.5) are, after removing the predictable component of income growth \( g_{h,t} = a_{age} - b_t - c_{cohort} \) from permanent income:

\[
y_{h,t} = p_{h,t} + \epsilon_{h,t},
\]

\[
p_{h,t} = p_{h,t-1} + \psi_{h,t}.
\]

\(^{39}\)https://userinfo.surfsara.nl/systems/lisa/description
Define a $d$-year income difference:

\[ r_{h,d} = y_{h,t+d} - y_{h,t} \]
\[ = p_{h,t+d} + \epsilon_{h,t+d} - p_{h,t} - \epsilon_{h,t} \]
\[ = \psi_{h,t+1} + \psi_{h,t+2} + \ldots + \psi_{h,t+d} + \epsilon_{h,t+d} - \epsilon_{h,t}. \]

Because we assume that the permanent and transitory income shocks are independently and identically log-normally distributed, the variance of $r_d$:

\[ \text{Var}(r_d) = d\sigma^2_{\psi} + 2\sigma^2_{\xi}. \]

We can approximate $\text{Var}(r_d)$ for each household with $v_{h,d} = r^2_{h,d}$, which would be an unbiased estimate if the mean of $r_{h,d}$ is zero. Given two $v_{h,d}$'s of different lengths we can solve for $\sigma^2_{\psi}$ and $\sigma^2_{\xi}$. However, we combine the information from multiple years and households to obtain a more accurate estimate. For a dynamic panel of length $n$ there are $n - 1$ estimates of $v_{h,1}$, $n - 2$ estimates of $v_{h,2}$, ..., 1 estimate of $v_{h,n-1}$. We do not use all possible $v_{h,d}$'s, but instead use income differences for which $n - 2 \geq d \geq 3$. Carroll & Samwick (1997) show that this makes our variance estimates robust to MA(2) serial correlation in the transitory shocks and that this ensures that at least two pairs of years are available to estimate each $v_{h,d}$. Our panel from 2011-2018 implies that $n = 8$. We regress the 14 estimates of $v_{h,d}$ on their respective $d$ and a 2-valued constant, and average out the regression coefficients of all households to arrive at our estimates of $\sigma^2_{\psi}$ and $\sigma^2_{\xi}$. 
Chapter 2

Comparing Imputation Methods using Expenditure Surveys and Unlinkable Administrative Data: an Application to Household Consumption Behaviour in the Netherlands

2.1 Introduction

The consumption behaviour of households has received great attention in the recent macroeconomic literature as a result of the 2008 financial crisis. Since then, advances in macroeconomic theory and numerical methods have popularised the use of heterogeneous agent models which highlight the importance of the economic conditions that pertain to specific households (Kaplan & Violante, 2018). Central in these models is how heterogeneity in the marginal propensity to consume across the income and wealth distribution translates into aggregate demand and macroeconomic fluctuations. Borrowing limits play an important role, as they cause households with high leverage and little liquid wealth to respond sharply to fluctuations in their income or wealth. In chapter 1 of this dissertation we pointed out that mandatory pension fund participation in the Netherlands can also lead to higher consumption sensitivities.

\(^1\)See for instance Kaplan & Violante (2014).
Using administrative data from Statistics Netherlands (the Dutch national statistical office) spanning 2011-2018 we document that a considerable fraction of households jointly face low levels of cash-on-hand, negative housing equity and mandatory pension contribution. This is especially prevalent in the upper quintiles of the income distribution and points towards the existence of ‘wealthy hand-to-mouth’ households à la Kaplan et al. (2014). According to the aforementioned theoretical models, the lack of readily accessible liquid wealth should dampen their ability to smooth out shocks and should make their consumption behaviour particularly sensitive to changes in income and wealth.

Empirically validating these predictions requires a dynamic panel dataset that contains growth rates of consumption, income and wealth. Unfortunately, single data sources that are available at Statistics Netherlands (which are administrative data and expenditure survey waves) do not fulfil this requirement. The expenditure survey does not include information on liquidity, leverage and mandated pension fund participation, while administrative data based on tax records does not contain information on consumption. To overcome these deficiencies, we apply two imputation methods. First, we supplement the expenditure survey with detailed information on liquidity, leverage and mandated pension fund participation from the unlinkable administrative data through matching based on variables that are present in both datasets. Second, we impute consumption in the administrative data by using the household budget constraint which implies that total consumption equals disposable income minus the returns-corrected change in asset holdings. Afterwards, we exploit that households in the expenditure survey wave of 2015 can be identified exactly in the administrative data to assess the precision of the two imputation methods.

Unfortunately, our two datasets still have important shortcomings after the imputation procedures are applied. The dataset consisting of the enriched expenditure survey waves is not a true panel, because different households are surveyed in each wave. We turn the repeated cross sections into a pseudo-panel using the cohort-method pioneered by Deaton (1985) and lose valuable household-specific information in the process. On the bright side, the expenditure survey features precise information on spending and this allows us to disentangle non-durable consumption from durable expenditures. The dataset consisting of the administrative data is a true panel, but its measure of consumption is imperfect. The budget constraint approach imputes total expenditures and therefore conflates spending on durable goods with the flow of consumption services derived from them. There is unfortunately no way for us to correct this. It is precisely because both datasets have relative strengths and weaknesses that we report results with both imputation approaches.

Using the two resulting panel datasets we estimate regression models that are inspired
by Campbell & Cocco (2007). More specifically, we regress consumption growth rates on the growth rates of income and wealth, and evaluate possible heterogeneity in the consumption responses by interacting the effect of changes in income and wealth with indicators of low liquidity, high leverage and mandatory pension fund participation. While the effects of the former two have been studied extensively in the literature, and reaffirmed by our results, we additionally present evidence for the role of pension fund system design. System features such as mandatory participation, uniform accrual and longevity insurance imply heterogeneous effects of pension benefit accrual on consumption across the age and income distribution.

Before we describe the imputation methods and results of this chapter in more detail, a review of recent developments regarding the measurement of consumption is in order as it contextualises the difficulties described above with obtaining a dynamic panel dataset that contains consumption, income and wealth. Carroll et al. (2015) document that the popularity of expenditure surveys for studying household consumption behaviour has deteriorated over time due to issues such as the under-reporting of expenditures (Heathcote et al., 2010) and under-representation of certain groups of households (Bee et al., 2013). Fagereng & Halvorsen (2017) also highlight the problems of inconsistent measurement, changing variable definitions, infrequent waves and the limited use of repeated cross-sectional survey data. In reaction to these limitations, a literature starting with Browning & Leth-Petersen (2003) has instead turned to administrative data based on tax records which covers the entire population of households in a true panel format. Disposable income and changes in asset holdings can be used to impute total expenditures through the household budget constraint. The difficulty of this approach is decomposing the observed changes in the value of owned assets into unobserved capital gains and changes in asset stocks. For some countries, such as Sweden, this decomposition can be reliably executed thanks to a wealth tax that requires households to report their holdings of financial instruments (Koijen et al., 2014; Kolsrud et al., 2019). In our administrative data, there is less opportunity to calculate household-specific returns on financial portfolios. Again, we study household consumption behaviour with all available data sources from Statistics Netherlands because each has its own unique set of drawbacks.

The first imputation approach enriches the expenditure survey with income and wealth data by matching households on common variables (such as municipality, household com-

\footnote{Other similar examples from the literature include Baker et al. (2018) and Eika et al. (2020) who improve the consumption imputation from the household budget constraint through access of the specific financial and real estate asset holdings of households. They show that without this information the measurement error in imputed consumption can be sizeable due to intra-year changes in asset values and composition as a result of trading costs, asset distributions, variable trade timing and volatile asset prices between two annual snapshots.}
position, primary source of income and age) that are identically measured in both the administrative data and the expenditure survey. For each variable of interest, we assign to each household in the expenditure survey the average value of the matched households in the administrative data. This approach differs from the regression prediction popularised by Skinner (1987), who uses the Consumer Expenditure Survey (CEX) to impute a more reliable estimate of household consumption into the Panel Study of Income Dynamics (PSID). With regression prediction, a dependent variable is regressed on independent variables that are common to both datasets and then the regression estimates are used to predict the values of the dependent variable that is missing in the main dataset. Since households present in the expenditure survey are also in the administrative data (as the latter covers the universe of Dutch households) and since the set of overlapping variables contains specific information about the household, we do not estimate an overall regression model but instead try to identify specific households instead. We show that our approach correctly identifies roughly sixty to seventy percent of the households from the expenditure survey in the administrative data, that each household in the expenditure survey is matched to only a handful of households in the administrative data, that imputation errors are relatively small, and that there is no selection effect in the type of households that are matched across the two data sources. This highlights that our method of enriching surveys using other unlinkable data sources has potentially wider applicability.

The second imputation approach of using the household budget constraint with administrative data has previously been applied in Sweden and Denmark. Koijen et al. (2014), Kreiner et al. (2014) and Abildgren et al. (2018) compare the resulting consumption measure to the reported expenditures in expenditure surveys and conclude that the imputation method is promising. For most households in our dataset the budget constraint approach is also roughly in line with the consumption reported in the expenditure survey. However, the imputation error is larger for households with more sophisticated balance sheets, even after correcting for income. Another noteworthy discrepancy between the reported consumption in the expenditure survey and the imputed consumption in the administrative data is the fact that implied saving rates are vastly different. The annual snapshots of asset holdings suggest that about forty percent of the households in the expenditure survey consume virtually all of their disposable income per year, while this is only about ten percent of the households using the reported consumption measure in the expenditure survey. Given the critiques of both data sources that were described above, it is impossible to ascertain which of the two measures of consumption is (most) at fault. It could be that households under-report expenditures in the survey, but the impossibility to calculate

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3This is in accordance with the findings of Baker et al. (2018).
household-specific returns on financial portfolios could also play a role. In any case, this measurement puzzle is likely to affect the findings of studies linking liquidity to household consumption.

With respect to the effect of income and liquidity on consumption we verify some results that were previously established in the literature based on hypothetical scenarios presented to surveyed households. Jappelli & Pistaferri (2014) find that households with lower cash-on-hand are more responsive to changes in income and that there is a flat age profile of the marginal propensity to consume out of income. Fuster et al. (2020) document that the marginal propensity to consume is larger for drops in income and Christelis et al. (2019) find that this is especially true for big drops. These results are also reflected in our empirical analysis and coincide with the predictions of models featuring precautionary savings and borrowing constraints.4

With respect to the effect of housing wealth and leverage our findings are less conclusive. While the regressions based on the expenditure surveys with the first imputation method point to a strong housing wealth effect, the administrative data with the second imputation method indicates a much more modest housing wealth effect that is concentrated amongst working age households. The presence of a housing wealth effect (be it small or large) is in line with the results of Bijlsma & Mocking (2017), Ji et al. (2019) and Zhang (2019) who also look at the consumption behaviour of Dutch households with data from Statistics Netherlands.5 Like Disney et al. (2010) and Christelis et al. (2021), we also find that households with negative housing equity respond more strongly to swings in the value of their house (especially if they have amortising mortgages).6

While the role of liquidity and leverage for household consumption behaviour has been studied extensively in the literature7, we contribute by pointing towards the potential influence of pension systems. In the Netherlands, most wage earners are required to participate in a pension fund scheme where their mandatory contribution payments scale with gross income. If households face borrowing constraints, then the mandatory participation exacerbates liquidity problems. However, saving through a pension fund is also heavily

4Note that these results are obtained for transitory shocks to income, while we do not decompose changes in income into transitory and permanent parts.
5There are some important methodological differences, however. Bijlsma & Mocking (2017) estimate regressions whose functional form is most similar to ours, but their dependent variable is not the change in imputed consumption but the change in savings on bank accounts and the value of the outstanding mortgage. Ji et al. (2019) and Zhang (2019) study the relation between consumption and housing wealth with a functional form in levels like Attanasio et al. (2009), whose difference with Campbell & Cocco (2007) has been studied extensively by Cristini & Sevilla (2014).
6Note that these results are obtained for unexpected shocks to housing wealth, while we do not decompose changes in housing wealth into expected and unexpected parts.
subsidised due to employer-matched contributions and tax-deferral.\textsuperscript{8} As such, an additional unit of gross income gives less liquidity compared to a household that does not face mandatory participation, but it also adds considerably to the present discounted value of total lifetime wealth. Our empirical results show that the two counteracting forces balance on the aggregate.

When we unpack the effect, we observe heterogeneous consumption responses along the age and income distribution. Conditional on facing mandatory pension fund participation, we find that younger households are less responsive to changes in gross income compared to older households. This indicates that the liquidity effect is likely to dominate for younger households. However, this result can also be attributed to the uniform accrual rate of pension benefits, which implies that pension fund participants of different ages accumulate the same pension entitlements per unit of contribution even though the contribution of the older participants is invested for a shorter period of time. This causes the total lifetime wealth effect to be increasing in age. Conditional on facing mandatory pension fund participation, we also find that households in the lower quintiles of the income distribution are less responsive to changes in gross income compared to those in the upper quintiles. This could be explained by the fact that less affluent households are more affected by borrowing constraints. However, this result can also be attributed to pension benefits being paid out to retirees in the form of an annuity. Households with a higher (subjective) life expectancy, which is positively associated with income, expect to receive the annuity for a longer period of time and thus stand to gain more from an additional unit of accrual.

This chapter is structured as follows. Section 2.2 describes the Dutch administrative data and expenditure survey, and briefly outlines their shortcomings and the applied imputation methods. Section 2.3 shows the type of households in the Netherlands that have low cash-on-hand, negative housing equity and mandatory pension fund participation. Section 2.4 describes an overview of the general regression framework. Section 2.5 evaluates the fit of the imputation of income and wealth in the expenditure survey by exploiting the perfect link between the administrative data and the expenditure survey of 2015. Section 2.6 does the same for the imputation of consumption in the administrative data. These two sections also present regression results and robustness checks. Section 2.7 concludes with a summary of the two imputation methods and the accompanying empirical results.

\textsuperscript{8}In our dataset we observe that the employer contributes between 2 and 3 euros per euro of employee contributions.
2.2 Data

2.2.1 Administrative data

Administrative data on the income and wealth of the entire population of Dutch households is collected by Statistics Netherlands using tax returns. The available data is split up in multiple datasets, which we bring together in one dataset comprising of income, wealth and household characteristics. The first dataset contains detailed information on the earned income, paid taxes, received benefits and social security contributions of individuals, while the second contains these variables aggregated at the household level. The third includes the bestowals and bequests of receiving and granting individuals that exceed a taxable threshold. The fourth comprises data on the assets (bank account balances, stocks and bonds, real estate, privately owned firms, and miscellaneous assets) and liabilities (mortgage, student, and other debt) of households. Thanks to unique identifiers for households and individuals we can determine the household membership of each individual. While income information is available at both the individual and household level, wealth information is only available at the household level. As such, our unit of observation is the household. Each household is assigned a household head based on the socioeconomic status of its members. Lastly, household characteristics (age of the household head, household composition, main income source of the household head, home-ownership status) and residential location (municipality code) are available from municipality administration data. The aforementioned variables are consistently measured and available to us from 2011-2018. Due to memory capacity constraints on the virtual network of Statistics Netherlands, we randomly select one million (about 15% of the entire population of) Dutch household heads in the year 2011. To accommodate the failure and creation of households, we follow the selected household heads from 2011 through 2018 and record the income and wealth information of the households of which it is a member.

2.2.2 Expenditure survey

Statistics Netherlands has conducted an expenditure survey since 1978, but its design has undergone significant changes throughout the past decades. As a result, the expenditure surveys from 1978-2004, 2005-2010 and 2012 onwards are incomparable. The most recent design has conducted waves in 2012, 2013 and 2015 with minor changes in methodology. Randomly selected households are invited by mail and telephone to keep track of their

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9 Generally, the individual with the highest income is identified as the household head.
10 Unfortunately, the data on bestowals and bequests are only available until 2016.
11 From 2015 onwards, the expenditure survey will be conducted every five years.
spending behaviour. Participating households record all purchases of goods and services above 20 euros for four weeks in an online diary and during one of the four weeks they also record purchases below 20 euros. Expenditures are aggregated using the ECOICOP (European Classification of Individual Consumption according to Purpose) classification of Eurostat. Households also fill in a questionnaire about frequently recurring expenditures and household characteristics. In 2015, households were additionally asked to report large purchases and holiday spending throughout the year. Statistics Netherlands verifies the internal consistency and completeness of the responses and supplements them with income information from the administrative data mentioned above. Households are rewarded with a voucher of 5 euros upon the start of the survey and receive an additional voucher of 30 euros upon its completion. Furthermore, households are presented with an overview of their responses together with a report on how theirs compare to the other responses of the survey wave. The waves of 2012 and 2013 had a similar sample size of respectively 6,003 and 4,914 participating households, but the wave of 2015 had a significantly larger sample of 14,050 households. While Statistics Netherlands could perfectly link participating households to the administrative data at the time of conducting the expenditure survey, the unique identifiers of participating households are only available to the researcher for the wave of 2015 and not for 2012 and 2013.

2.2.3 Description of the two imputation strategies

Neither the administrative data or expenditure survey allow for the analysis of household consumption behaviour without the application of imputation methods. While the administrative data contains detailed information on household income and wealth, a measure of consumption is absent. Browning & Leth-Petersen (2003) show that the household budget constraint can be invoked to obtain a measure of consumption: $c_{i,t} = y_{i,t} - \Delta w_{i,t}$, where $c_{i,t}$ is total consumption of household $i$ during period $t$, $y_{i,t}$ is household disposable income and $\Delta w_{i,t}$ is the return-corrected change in household net financial wealth between the start of period $t$ and $t+1$. Since our administrative data records the value of the assets and liabilities of households at a specific point in time, changes in values have to be decomposed into capital gains and changes in stocks. Gains and losses, as well as bestowals and bequests, do not reflect consumption, while changes in stocks do. Thus, it

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12Statistics Netherlands applies stratified two-step sampling of addresses present in municipality administration data. In the first step sub-municipalities are randomly sampled, where the sample probabilities are proportional to the number of addresses in each sub-municipality. In the second step one household is contacted from each selected sub-municipality. In 2015, a total of 91,190 households were selected, yielding a response rate of about 16%.

13Out of the 14,408 households surveyed in 2015, 358 could not be linked with the administrative data.
is paramount that this decomposition can be precisely calculated. Note that the resulting measure of consumption does not allow for a separation of spending on durable and non-durable goods. This is problematic because spending on durable goods does not equate the flow of consumption services derived from them. This limitation implies an overestimation of consumption in periods of large spending on durable goods and an underestimation in subsequent periods. Using this imputation method, we obtain a true panel dataset on consumption, income and wealth for a large number of Dutch households.

The expenditure survey contains detailed information on household consumption, but data on income and wealth is scarce. Since the waves of 2012 and 2013 are not linkable to the administrative data, we impute the values of the missing variables of interest by matching households in the expenditure survey to households in the administrative data using variables that are present in both datasets. With overlapping variables such as municipality, household composition, primary source of income, age and income we can identify the households in the administrative data that are similar to each household in the expenditure survey. If multiple ‘administrative data households’ are matched to one ‘expenditure survey household’, we set the value of the variable of interest for the ‘expenditure survey household’ equal to the mean of the values for the matched ‘administrative data households’. Because for each wave a new random sample of Dutch households is drawn, we cannot follow specific households over time. In order to make use of the repeated cross sectional expenditure survey, we thus have to resort to the pseudo-panel cohort methods introduced by Deaton (1985). A cohort is defined as a group of households with fixed membership (such as birth year) that can be tracked over time. Any linear relationship that holds at the level of individual households will also pertain to the cohorts, with cohort means replacing individual observations. As such, the two imputation approaches result in regression models with different units of observation: the consumption imputation is a true panel of households, while the income and wealth imputation is a pseudo-panel of cohorts of households.

Thanks to the fact that the expenditure survey of 2015 is linked to the administrative data, we can assess the precision of both imputation methods. In section 2.5 we will compare different sets of matching variables and cohort definitions in terms of sample selection and accuracy of imputed values for income and wealth. In section 2.6 we will compare the imputed measure of total consumption to the survey measure.
2.3 Constraints faced by the universe of Dutch households

Central in our empirical analysis is the degree to which different types of households are constrained. We pay particular attention to the role of cash-on-hand, mortgage indebtedness and mandatory pension fund participation. To illustrate the financial positions of Dutch households, we construct various balance sheet indicators. A household is denoted to be liquidity constrained if its bank account balances amount to less than its monthly income before tax, leverage constrained if the value of its outstanding mortgage is higher than the value of its house, and pension constrained if it pays mandatory pension fund contributions. While these indicators do not necessarily imply that the households in fact are constrained, they are more likely to be. For ease of communication, we say that a household is constrained if it satisfies any of the three above conditions. Table 2.1 depicts how the universe of Dutch households in 2015 is divided by the different indicators along various household characteristics.\(^{14}\) While lower paid, younger, single and renting households tend to have little cash-on-hand, a considerable fraction of higher paid households is either liquidity, leverage or pension constrained (or a combination of the three). Despite their high incomes, many of these households are in the lowest quintile of the net wealth distribution while being jointly constrained along the three indicators. This points towards the existence of ‘wealthy hand-to-mouth’ households as identified by Kaplan et al. (2014), whose lack of readily accessible liquid wealth could make their consumption behaviour particularly sensitive to changes in income and wealth.

The effects of liquidity and leverage on household consumption have been studied extensively in the literature, but we note that the mandatory pension fund contribution scheme in the Netherlands adds additional complexity to the household decision problem. Most wage earners are required to participate in a pension fund scheme, where contributions scale with income before tax. There are two non-convexities: contributions are paid over the share of income that exceeds a lower threshold of roughly 15,000 euros, which is based on the pay-as-you-go benefits that a pensioner receives, and that is capped at an upper limit of roughly 110,000 euros. Contributing households face a similar contribution rate in the margin of income before tax, while some households (who are not covered by a pension fund scheme or who have low incomes, very high incomes or other income sources such as self-employment) face a mandatory marginal contribution rate of zero. Participation in the pension fund has both an advantage and a disadvantage. On the one hand, every euro of employee contribution to the pension fund is matched by two to three euros

\(^{14}\)We pick 2015 because in this year we can link the expenditure survey to the administrative data.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Subgroup</th>
<th>Population</th>
<th>Unconstrained</th>
<th>Liquidity</th>
<th>Leverage</th>
<th>Pension pressure</th>
<th>Jointly</th>
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<tr>
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<td>18.7%</td>
<td>51.4%</td>
<td>6.2%</td>
</tr>
</tbody>
</table>

**Table 2.1:** Constraints faced by the universe of Dutch households in 2015, stratified by various categorical variables. *Population* denotes the fraction of the *Subgroup* in the universe of households. The latter five columns indicate the proportion of households in the *Subgroup* that, respectively, are not constrained at all, have little cash-on-hand, have negative housing equity, face mandatory pension fund contribution, and are jointly constrained in the three aforementioned categories. Fractions split up by the categorical variables might not exactly line up with the fractions reported at the aggregate level due to varying data availability across the categorical variables.
on behalf of the employer. The contributions are also tax-deductible and therefore imply a lower present discounted value of tax payments over the life cycle.\(^{15}\) The contributions are thus heavily subsidised and have a large effect on total lifetime wealth. On the other hand, the mandatory contribution also implies that households are forced to make an irreversible investment that pays out only upon retirement. The mandatory contributions decrease disposable income, and therefore cash-on-hand, while the resulting investment is highly illiquid. The uniform contribution rate is thus likely to have heterogeneous effects on households. Households facing borrowing constraints (such as younger households saving for a down-payment for a house) are impacted more by the liquidity dampening effect and less by the total wealth effect.\(^ {16}\) For them, it would be optimal to contribute less to the pension fund scheme. Some households would want to withdraw a part of their accrued pension entitlements early in the face of adverse health or employment shocks, but the system design does not accommodate this. We have studied these issues with a buffer stock model in chapter 1 and will return to them when discussing the regression results.

### 2.4 General regression framework

While the precise empirical framework differs slightly between the two imputation methods, we generally examine the relationship between household consumption, income and housing wealth by estimating the following regression equation:

\[
\Delta c_{i,t} = \alpha_i + \beta_1 \Delta y_{i,t} + \beta_2 \Delta h_{i,t} + \beta_3 Z_{i,t} + \varepsilon_{i,t},
\]

(2.1)

where the subscript \(i\) denotes the cohort in the pseudo-panel analysis of the first imputation method and the household in the true panel analysis of the second imputation method. With the first imputation method, \(\Delta c_{i,t} = \ln(c_{i,t}) - \ln(c_{i,t-1})\) is real non-durable consumption growth, while it denotes real total consumption growth in the second imputation method. \(\Delta y_{i,t} = \ln(y_{i,t}) - \ln(y_{i,t-1})\) is real disposable income or income before tax growth, \(\Delta h_{i,t} = \ln(h_{i,t}) - \ln(h_{i,t-1})\) is real house price growth, and \(Z_{i,t}\) is a vector of control variables (such as the real interest rate, household or cohort characteristics, and year dummies). Disposable income is calculated by adding up the earnings from (self-)employed labour, fiscal transfers and capital for all members of the household and by subtracting the sum of paid taxes on income and wealth, unemployment, disability, old

\(^{15}\)Taxes are levied during the pay-out phase of pension benefits when households tend to face a lower marginal tax rate as well.

\(^{16}\)It is impossible to borrow against accrued pension entitlements in the Netherlands.
age and health insurance premiums, and transfers to other households. House prices in period $t$ are assessed annually on January 1\(^{st}\) of period $t+1$ by municipalities and used in the determination of income, water authority and property taxes. While we could set $h_{i,t}$ to the appraised value in period $t+1$, we elect to set it instead to the appraised value in period $t$ since it acts as an important frame of reference for households.\(^{17}\) Nominal values are deflated using the Dutch consumer price index with 2015 as reference year. The regression specification is modelled after Campbell & Cocco (2007) and estimated as a fixed effects model with standard errors that are corrected for both serial correlation and heteroscedasticity.\(^{18}\)

To evaluate possible heterogeneity in the consumption responses and to assess the practical limits of each imputation method, we interact the aforementioned indicators of liquidity, leverage and pension contribution with the income and house price variables. The indicators are assessed at the start of the period. The liquidity indicator will be interacted with disposable income, the leverage indicator with house price, and the pension contribution indicator with income before tax as the relevant margins. If the coefficient of the mandatory pension participation indicator is smaller than zero, the liquidity dampening effect dominates. If the opposite is the case, the total lifetime wealth enhancing effect is stronger. Additionally, we will experiment with adding indicators of the sign and size of changes, age cohorts and the income distribution. We restrict the sophistication of the empirical analysis so that the two imputation techniques can still be directly compared.

The symmetrical comparison is constrained by the scant number of waves of the Dutch expenditure survey. As a consequence it should be noted that the regression coefficients do not permit the interpretation of marginal propensities to consume as in life-cycle models such as Kaplan & Violante (2014). In these models, the marginal propensity to consume refers to the consumption response to unanticipated changes in income or permanent changes in wealth, whereas in this empirical exercise we do not decompose fluctuations of income or housing wealth into anticipated and unanticipated or permanent and transitory components. For ease of communication, however, we will refer to the estimated coefficients as marginal propensities to consume.

\(^{17}\)Furthermore, taking the house price appraisal of period $t+1$ would imply that an entire year of observations would be thrown away.

\(^{18}\)Because the imputation methods give rise to generated regressors, we also run the regressions with bootstrapped standard errors as in Browning et al. (2013). We find that the resulting standard errors are comparable to the robust standard errors reported here.
2.5 Imputation of income and wealth in expenditure survey

2.5.1 Imputation evaluation

To match ‘expenditure survey households’ (henceforth: ES households) to ‘administrative data households’ (henceforth AD households), we exploit the overlap of various variables in both datasets. These matching variables cover household characteristics, residential situation, income and housing wealth. We match exactly on categorical variables and with bandwidths on continuous variables. The values for these matching variables would ideally overlap between the two datasets, but table 2.2 indicates that this is not always the case. The age cohort variable has the fewest overlap and thus is the biggest limiting factor for the number of households we can correctly match, which could be due to a discrepancy between which household member is the assigned household head in the two datasets. Further differences can arise when the household fills in the expenditure survey differently to what the tax authority observes at the end of the calendar year. Besides the age cohort variable, we judge that there is considerable overlap.

In choosing the set of matching variables we balance the amount of ES households that can be linked to at least one similar AD household against the degree of similarity between the ES household and the matched AD households. As a baseline - which we call matching set Micro - we use the variables and bandwidths of table 2.2, but we also consider the following three matching sets: 1. Nano: same as Micro, but with a bandwidth of +/- 2.5% on income before tax, 2. Meso: same as Micro, but with a bandwidth of +/- 10% on income before tax, 3. Macro: same as Meso, but without using the value of residential location and without paid interest on mortgage. For 2012 and 2013 the variable paid interest on mortgage is not available, but we can use the value of the outstanding mortgage instead. Table 2.3 depicts the matching results for 2012, 2013 and 2015. As the matching set becomes wider, more ES households are coupled with at least one AD household and in roughly two thirds of the cases there is a correct match, but the mean and median number of AD households per ES household also goes up. There is a distinct dissimilarity between the matching results for 2012 and 2013 and the matching results for 2015, which likely stems from differences in survey methodology.

To complete the imputation, we set the value of the variables to be imputed for the ES household equal to the mean of the values for the matched AD households.\footnote{We have experimented with imputing using the median of the values for the matched AD households, with using a weighted average where less similar AD households are given less weight in the calculation of the mean, and with picking one AD household that is closest to the ES household. None of these} Using
<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent overlap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household composition</td>
<td>92.7%</td>
</tr>
<tr>
<td>Home-ownership status</td>
<td>99.1%</td>
</tr>
<tr>
<td>Primary source of income</td>
<td>98.6%</td>
</tr>
<tr>
<td>Age cohort (with bands of 5 years)</td>
<td>80.9%</td>
</tr>
<tr>
<td>Household size</td>
<td>90.5%</td>
</tr>
<tr>
<td>Municipality code</td>
<td>98.3%</td>
</tr>
<tr>
<td>Income before tax +/- 5%</td>
<td>86.1%</td>
</tr>
<tr>
<td>Value of residential location +/- 10%</td>
<td>96.5%</td>
</tr>
<tr>
<td>Paid interest on mortgage +/- 25%</td>
<td>96.3%</td>
</tr>
</tbody>
</table>

Table 2.2: Percentage of overlap for the available matching variables between the expenditure survey and the administrative data in 2015. Continuous variables have +/- x% bandwidths associated with them.

<table>
<thead>
<tr>
<th>Year</th>
<th>Matching set</th>
<th>Fraction of ES households matched</th>
<th>Percentage of correct matches</th>
<th>Mean number of AD households per ES household</th>
<th>Median number of AD households per ES household</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Nano</td>
<td>46.9%</td>
<td>17.5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>62.6%</td>
<td>26.1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>76.9%</td>
<td>41.9</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>92.9%</td>
<td>74.3</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Nano</td>
<td>48.0%</td>
<td>19.7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>63.0%</td>
<td>29.6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>76.0%</td>
<td>47.8</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>93.4%</td>
<td>83.0</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>Nano</td>
<td>75.7%</td>
<td>62.4%</td>
<td>10.8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>79.9%</td>
<td>64.6%</td>
<td>19.4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>83.8%</td>
<td>66.0%</td>
<td>35.2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>96.4%</td>
<td>68.0%</td>
<td>70.8</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 2.3: Matching results for 2012, 2013 and 2015 with the four different matching sets. The second column indicates the fraction of households in the expenditure survey that can be matched to at least one AD household and the third column shows the percentage of cases in which the actual ES household is amongst the matched AD households. Since the expenditure survey is not linkable to the administrative data in 2012 and 2013, we cannot calculate the fraction of correct matches for these years. The survey of 2012 contains 6,003 households, of 2013 contains 4,914 households and of 2015 contains 14,050 households.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Matching set</th>
<th>Median</th>
<th>Mean</th>
<th>p95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposable income</td>
<td>Nano</td>
<td>97</td>
<td>1,589</td>
<td>5,589</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>325</td>
<td>1,618</td>
<td>7,100</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>615</td>
<td>2,039</td>
<td>8,470</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>1,282</td>
<td>3,523</td>
<td>15,104</td>
</tr>
<tr>
<td>Bank account balances</td>
<td>Nano</td>
<td>879</td>
<td>14,497</td>
<td>68,960</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>3,554</td>
<td>17,758</td>
<td>76,833</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>6,296</td>
<td>21,454</td>
<td>89,858</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>18,271</td>
<td>40,756</td>
<td>147,222</td>
</tr>
<tr>
<td>Value of outstanding mortgage</td>
<td>Nano</td>
<td>0</td>
<td>8,831</td>
<td>48,328</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>0</td>
<td>11,608</td>
<td>58,607</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>435</td>
<td>14,649</td>
<td>68,299</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>32,634</td>
<td>56,236</td>
<td>189,759</td>
</tr>
<tr>
<td>Mandatory pension fund contributions</td>
<td>Nano</td>
<td>0</td>
<td>172</td>
<td>987</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>0</td>
<td>216</td>
<td>1,139</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>0</td>
<td>261</td>
<td>1,296</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>145</td>
<td>408</td>
<td>1,706</td>
</tr>
<tr>
<td>Liquidity (bank account balances/income before tax)</td>
<td>Nano</td>
<td>0.03</td>
<td>0.26</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>0.07</td>
<td>0.30</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>0.11</td>
<td>0.35</td>
<td>1.41</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>0.26</td>
<td>0.56</td>
<td>1.84</td>
</tr>
<tr>
<td>Leverage (value of outstanding mortgage/value of house)</td>
<td>Nano</td>
<td>0</td>
<td>0.04</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>0</td>
<td>0.05</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>0</td>
<td>0.07</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>0.15</td>
<td>0.23</td>
<td>0.74</td>
</tr>
<tr>
<td>Pension fund contribution pressure (mandatory pension fund contributions/income before tax)</td>
<td>Nano</td>
<td>0.002%</td>
<td>0.2%</td>
<td>1.1%</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
<td>0.003%</td>
<td>0.3%</td>
<td>1.3%</td>
</tr>
<tr>
<td></td>
<td>Meso</td>
<td>0.004%</td>
<td>0.3%</td>
<td>1.4%</td>
</tr>
<tr>
<td></td>
<td>Macro</td>
<td>0.17%</td>
<td>0.4%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

**Table 2.4**: Distribution of absolute differences between true and imputed values for the non-targeted variables and for various matching sets. The imputed values are obtained by averaging the values for the matched AD households. The absolute differences are calculated by exploiting that the expenditure survey of 2015 is linkable to the administrative data.
the linkability between the expenditure survey of 2015 and the administrative data, table 2.4 depicts the distribution of absolute differences between the true and imputed value for variables that were not a part of the matching set. The large means and small medians indicate that the distributions have fat tails: the largest matching errors occur when an ES household is matched to few AD households and at least one of those AD households is vastly different. This is especially pressing for the bank account balances and the corresponding measure of liquidity. Because income before tax, paid interest on mortgage and house value are part of the narrow matching sets, the errors for disposable income, mandatory pension fund contribution, value of outstanding mortgage and the corresponding measure of leverage are modest.

Another concern is whether the matching approach gives rise to a selection effect in the sample, since it could be that ES households with certain characteristics are more easily matched to AD households. Figures A2.1 and A2.2 present an overview of histograms for the entire sample of the expenditure survey of 2015 and for the remaining sample after matching. We observe neither a selection effect for the matching variables or for variables outside of the matching set.

2.5.2 Regression results

At this stage we have applied the matching set Micro to impute the values of variables of interest that are missing in the expenditure survey of 2012 and 2013. However, since the expenditure survey is a repeated cross section, we cannot use the resulting sample to estimate regression equation (2.1). We apply the pseudo-panel cohort methods pioneered by Deaton (1985) to further reduce the sample from individual households to cohorts of households. A cohort is defined as a group of households with fixed membership (such as birth year) that can be tracked over time. Any linear relationship that holds at the level of individual households will also pertain to the cohorts, with cohort means replacing individual observations. According to Verbeek (2008), the construction of cohorts is met with a trade-off between an accurate approximation of the cohort means (i.e., bias) and the loss of observations (i.e., variation).

The chosen cohort variables typically include birth cohorts and additional household characteristics. It is required that households within cohorts are similar and different between cohorts. To correct for the potential mismeasurement of the cohort means, Deaton (1985) proposes the application of errors-in-variables techniques. However, Verbeek & Nijman (1992) show that the pseudo-panel can be treated as a regular panel if there are approaches yielded significantly better matching results.
Table 2.5: Percentage of households in the administrative data for which the value of various variables is the same from 2012 to 2013, 2013 to 2015 and 2012 to 2015 (based on 6,165,472 households).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Household composition</td>
<td>96.1%</td>
<td>94.5%</td>
<td>92.5%</td>
</tr>
<tr>
<td>Primary source of income</td>
<td>95.2%</td>
<td>92.6%</td>
<td>90.5%</td>
</tr>
<tr>
<td>Home-ownership status</td>
<td>98.2%</td>
<td>96.8%</td>
<td>95.7%</td>
</tr>
<tr>
<td>Liquidity dummy</td>
<td>86.5%</td>
<td>84.1%</td>
<td>83.9%</td>
</tr>
<tr>
<td>Leverage dummy</td>
<td>93.7%</td>
<td>94.0%</td>
<td>92.1%</td>
</tr>
<tr>
<td>Pension contribution dummy</td>
<td>95.3%</td>
<td>92.4%</td>
<td>90.3%</td>
</tr>
</tbody>
</table>

at least 100 households per cohort. In the baseline regressions, the average cohort size will be roughly 150 and we judge that this is sufficient to treat the dataset as a true panel. However, there is heterogeneity in cohort sizes (for instance, there are few households above the age of 65 that have wage as primary source of income) and in accordance with Deaton (1985) we therefore weight observations in the regressions by the square root of the cohort size. To assess the importance of low cash-on-hand, negative housing equity and mandatory pension contribution, we add the indicator variables to the set of cohort variables. We insert these indicator variables one at a time to ensure that we achieve sufficiently large cell sizes. To further ensure that cohorts have a sufficient number of households within it, we use a more lenient definition of low cash-on-hand and negative housing equity. A household has low cash-on-hand if its bank account balances amount to less than 1.5 month of its income before tax and negative housing equity if its leverage ratio exceeds 90%. About 45% of the cohorts then have low cash-on-hand and 33% have "negative" housing equity. Table 2.5 shows that membership of each of the cohort variables is considerably stable for the universe of Dutch households. Regression tables will show not only the amount of observations used, but also the average number of households per cohort.

We start with a regression model that most closely resembles the baseline regression of Campbell & Cocco (2007). Control variables, besides year dummies and cohort fixed effects, include the real interest rate, the change in the average age of the cohort and the change in the average family size of the cohort. The expenditure survey records not only the house price of home-owners, but also of renters. The home-ownership indicator is interacted with the growth rate of the house value to verify that renters respond less to house price fluctuations than home-owners. Regressions (i) and (ii) of table 2.6 show that qualitatively the results are in line with Campbell & Cocco (2007). Household consumption responds strongly to changes in disposable income, while home-owners strongly respond
<table>
<thead>
<tr>
<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta y_{i,t} )</td>
<td>0.376***</td>
<td>0.328***</td>
<td>0.150</td>
<td>0.339**</td>
<td>0.298***</td>
</tr>
<tr>
<td></td>
<td>(0.107)</td>
<td>(0.113)</td>
<td>(0.102)</td>
<td>(0.155)</td>
<td>(0.106)</td>
</tr>
<tr>
<td>( \Delta y_{i,t} \times \text{Liq.} )</td>
<td></td>
<td></td>
<td>0.329**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.135)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta y_{i,t} \times \text{Pen.} )</td>
<td>0.193***</td>
<td></td>
<td>0.265***</td>
<td>0.261**</td>
<td>0.271***</td>
</tr>
<tr>
<td></td>
<td>(0.063)</td>
<td></td>
<td>(0.081)</td>
<td>(0.119)</td>
<td>(0.048)</td>
</tr>
<tr>
<td>( \Delta h_{i,t} \times \text{Lev.} )</td>
<td></td>
<td></td>
<td>0.157</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.181)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta h_{i,t} \times \text{Own} )</td>
<td></td>
<td>0.391**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.158)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta h_{i,t} \times \text{Rent} )</td>
<td></td>
<td>0.125**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.060)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real interest rate</td>
<td>0.175***</td>
<td>0.222***</td>
<td>0.132***</td>
<td>0.193***</td>
<td>0.180***</td>
</tr>
<tr>
<td></td>
<td>(0.040)</td>
<td>(0.052)</td>
<td>(0.042)</td>
<td>(0.042)</td>
<td>(0.036)</td>
</tr>
<tr>
<td>( \Delta \text{Age} )</td>
<td>-0.143**</td>
<td>-0.159**</td>
<td>-0.047</td>
<td>-0.106*</td>
<td>-0.078*</td>
</tr>
<tr>
<td></td>
<td>(0.064)</td>
<td>(0.062)</td>
<td>(0.031)</td>
<td>(0.055)</td>
<td>(0.043)</td>
</tr>
<tr>
<td>( \Delta \text{Age squared} )</td>
<td>0.001***</td>
<td>0.001***</td>
<td>0.000</td>
<td>0.001*</td>
<td>0.001*</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>( \Delta \ln \text{Family size} )</td>
<td>0.206</td>
<td>0.268**</td>
<td>0.185*</td>
<td>0.222**</td>
<td>0.202*</td>
</tr>
<tr>
<td></td>
<td>(0.134)</td>
<td>(0.127)</td>
<td>(0.097)</td>
<td>(0.090)</td>
<td>(0.118)</td>
</tr>
</tbody>
</table>

| \( R^2 \)            | 0.475        | 0.502        | 0.522        | 0.416       | 0.514      |
| \( N \)              | 89           | 89           | 165          | 121         | 149        |
| Mean cohort size      | 153          | 153          | 81           | 104         | 85         |
| Fraction of indicator = 1 | 0.0%       | 0.0%        | 46.9%        | 32.8%       | 52.2%      |

**Table 2.6:** Regression results of the baseline specification. Regressions (i) and (ii) use the baseline cohort set (birth cohort, home-ownership status, household composition and primary source of income). Regressions (iii), (iv) and (v) also use the indicator for liquidity, leverage and mandatory pension contribution, respectively. \( y_{i,t} \) denotes disposable income in regressions (i)-(iv) and income before tax in regression (v). Liq. denotes low cash-on-hand, Lev. negative housing equity and Pen. mandatory pension contribution. The regressions include year dummies and cohort fixed effects (both not reported). The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. Observations are weighted by the square root of cohort size. * \( p < 0.10 \), ** \( p < 0.05 \), *** \( p < 0.01 \).
to changes in the value of their residential location. The average house price of home-
owners in the expenditure survey wave of 2015 is 231,000 euro, average disposable income is 48,486 euro and average non-durable consumption is 33,414 euro. The elasticities for disposable income of roughly 0.30 and for housing wealth of roughly 0.25 imply that a 1,000 euro increase in disposable income results in a 205 euro increase in non-durable consumption and a 10,000 euro increase in housing wealth results in a 360 euro increase in non-durable consumption. The indicator interactions in regressions (iii) and (iv) show that the marginal propensity to consume out of income is higher for households with little cash-on-hand and that the marginal propensity to consume out of housing wealth is higher for households with negative housing equity (though the latter effect is not statistically significant). Regression (v) shows that the effect of mandatory pension fund contribution is both close to zero and statistically insignificant. We thus conclude that on the aggregate level the liquidity dampening and total lifetime wealth enhancing effects of mandatory pension fund contribution balance out against each other.

Some lack of robustness is to be expected in this empirical scenario. The construction of cohorts averages out a lot of the microeconomic heterogeneity that the expenditure survey captures and the estimation of a fixed effects model implies that identification of the coefficients comes solely from variation over time (with a dimension of two) at the cohort level. We consider a number of robustness checks that are specific to this imputation method. Firstly, we use total consumption instead of non-durable consumption as dependent variable. If the regression coefficients are comparable, then the drawback of imputing total consumption (instead of non-durable consumption) in the administrative data will seem less severe. Table A2.1 shows that this is indeed the case for the indicator interactions and housing wealth coefficients, but the coefficients with respect to income are a cause of concern. Secondly, we use the matching procedure also for 2015 instead of exploiting the perfect link with the administrative data. If the results are comparable, then the trust in our imputation method based on household matching is deepened. Table A2.2 shows that this is indeed the case except for the interaction with the leverage indicator. Thirdly, we run the regressions for the four matching sets Nano, Micro, Meso and Macro. While there are some differences for the wider matching sets, table A2.3 indicates that the results are broadly similar. Overall, the results seem to be fairly robust to these alternative specifications, but we note that the estimates for the negative housing equity indicator appear to be less robust.

Lastly, we investigate whether the marginal propensities to consume differ along the sign and size of changes in income and housing wealth. Adding sign and size dummies to the set of cohort variables is impossible, because we first need to construct cohorts to
Table 2.7: Regression results of the baseline specification with interactions for the size and sign of changes in disposable income and housing wealth. Regressions (i), (ii), (v) and (vi) use the baseline cohort set (birth cohort, home-ownership status, household composition and primary source of income). Regressions (iii-iv) also use the indicator for liquidity and regressions (vii-viii) also use the indicator for leverage. Liq. denotes low cash-on-hand and Lev. negative housing equity. For brevity we do not report the coefficients and standard errors of the control variables. The regressions include year dummies and cohort fixed effects (both not reported). The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. Observations are weighted by the square root of cohort size. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
be able to calculate the changes to begin with. We are thus resorted to looking at the sign and size of the changes in income and housing wealth at the aggregated cohort level over time. As a result, some individual households could have experienced a change that is different from the average change that materialised at the cohort level. We consider a change large if the absolute change in income or housing wealth is in the 75th percentile of its distribution or higher. Table 2.7 depicts the results for the baseline regressions with added dummies to indicate the sign and size of changes. At first glance, it appears from regressions (i) and (ii) as if households respond more to negative as well as small changes in disposable income. However, once we control for the heterogeneous response along the low cash-on-hand indicator in regressions (iii) and (iv) both effects disappear. Due to the small sample size that results from the short time dimension of our pseudo-panel any cross-correlation between the different indicators is likely to affect the estimated coefficients. Regressions (v-viii) show that households respond more strongly to negative and large changes in housing wealth and that this is robust to the inclusion of the leverage indicator. We abstain from interacting the change in income before tax with the mandatory pension fund contribution indicator, because section 2.6.2 will show that there is a lot of heterogeneity in the marginal propensity to consume out of income before tax due to the progressive tax system. The interaction with the mandatory pension fund indicator would thus also have to be interacted with indicators of the income and age distribution, but this is - again due to the scant number of expenditure survey waves - impossible. We thus conclude that while we were able to obtain the same baseline results as Campbell & Cocco (2007) and find intuitive results with respect to the three balance sheet indicators, the small time dimension of our pseudo-panel rules out the possibility of further investigation. We move on to the second imputation method where the resulting sample will contain millions of observations and put us in a position to investigate the relevant channels further.

2.6 Imputation of consumption in administrative data

2.6.1 Imputation evaluation

To impute total consumption $c_{i,t}^{imp}$ using the administrative data, we invoke the accounting identity of the household budget constraint:

$$c_{i,t}^{imp} = y_{i,t} - \Delta a_{i,t} + \Delta l_{i,t} - t_{i,t}^g + t_{i,t}^r,$$
where $y_{i,t}$ is the disposable income of household $i$ from period $t$ to $t+1$, $\Delta a_{i,t}$ is the return-corrected change of assets, $\Delta l_{i,t}$ is the return-corrected change of liabilities, $t^0_{i,t}$ the before tax transfer gifts through inter vivos and bequests, and $t^r_{i,t}$ the after tax transfer receipts through inter vivos and bequests. As mentioned above, it is required to decompose changes in the value of wealth categories from one period to the next in terms of quantity and price. For instance, appreciation of stocks and bonds should not count towards consumption, while the purchase of stocks should. The return-corrected change of assets can be written as $\Delta a_{i,t} = a_{i,t+1} - (1+r_{i,t})a_{i,t}$. We only observe $a_{i,t+1}$ and $a_{i,t}$ from the tax returns and have to estimate $r_{i,t}$, which is the household-specific realised return on the asset. It is crucial that this return can be precisely estimated and we now discuss our approach for each asset and liability category.

**Bank account balances** We correct for the price effect by using the national mutation in bank account balances due to financial transactions and due to capital gains. These mutations are a part of the national account data reported by Statistics Netherlands. This mutation allows us to decompose the change in bank account balances from one period to the next under the assumption that each household experienced the same capital gains as what materialised on the national level.

**Stocks and bonds** We correct for the price effect by again using the national mutation in stocks and bonds reported by Statistics Netherlands. Ji et al. (2019) argue that this improves over setting the capital gains equal to the returns on a benchmark portfolio on the stock exchange and setting the change in stocks equal to the residual. Ideally, we would have access to the trading behaviour of individual households like for instance Baker et al. (2018) do, but these are simply not available in the Netherlands.

**Housing wealth** Some papers in the literature elect to only study non-moving households, but we feel that this is restrictive in a sample spanning seven years. We recognise changes in housing wealth only when households move. All other changes in the value of the house are assumed to be capital gains.$^{22}$ Using the moving date, we interpolate

$^{20}$Eika et al. (2020) highlight that with this approach the purchase of durables are counted entirely as consumption in the year of purchase and identify it as an important drawback of this imputation approach. This is confirmed by the regression results of table A2.1 with total consumption as the dependent variable, where the reaction to income changes are different compared to the baseline results with non-durable consumption as the dependent variable.

$^{21}$Advances in this literature have exploited wealth taxes that require the reporting of financial transactions or financial transaction data to calculate household-specific returns.

$^{22}$This implies that investment and upkeep that would improve the value of the house is not identified as consumption.
linearly the monthly aggregate house price index (which is also reported by Statistics Netherlands). If the household owns a house at the start of period $t$, we apply the index evolution forwards to the moving date. If the household owns a house at the end of period $t+1$, we apply the index evolution backwards to the moving date. The difference between the two corrected values is identified as the change in housing stock. (For households switching from renting to owning or vice versa, we only need to apply the index evolution from one side.)

**Other real estate** This category consists of properties that households own but that are not their primary residential location, such as vacation homes. We observe in the data that households with a non-zero value for this asset category own the assets for a short amount of time and that the reported value barely changes. Applying the evolution in the national house price index would imply large amounts of dissaving. We instead identify absolute growth rates below 15% as the result of capital gains and above as changes in stocks.

**Other asset categories** Correcting for capital gains is difficult for an array of miscellaneous asset categories, which range from large sums of cash and art to privately owned firms. We observe in the data that, contrary to the other real estate category, ownership of these asset categories is both short and long, and its associated values both volatile and stable. Luckily, less than 5% of households own these types of assets. In the absence of a better approach, we again identify absolute growth rates below 15% as the result of capital gains and above as changes in stocks.\(^{23}\)

**Liabilities** We can not correct for any of the liability categories (which are mortgage, student and other debt). This is problematic due to the prevalence of interest-only mortgages that are often coupled with pledged savings or investment accounts used for repayment at the maturity of the mortgage. Mastrogiacomo & van der Molen (2015) document based on loan level data from the Dutch central bank (DNB) that 60% of Dutch households in 2013 have interest-only mortgages. In our dataset we only observe the value of the outstanding mortgage, but the contributions to the pledged savings accounts or their accumulated balances are not recorded in the asset categories. As a result we likely overestimate consumption for these households, because we do not measure the contributions.

\(^{23}\)We have experimented with excluding households that own any of the other asset categories altogether and with identifying any changes in the value as the result of changes in stocks. The regression results discussed below were unaffected.
Table 2.8: Distribution of absolute consumption imputation errors (both in levels and relative to disposable income) for various data selections.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Consumption cleaning</th>
<th>Median</th>
<th>Mean</th>
<th>p95</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>c_{i,2015}^{\text{imp}} - c_{i,2015}^{\text{es}}</td>
<td>Fagereng &amp; Halvorsen (2017)</td>
<td>9,174</td>
<td>16,441</td>
</tr>
<tr>
<td>koilien et al. (2014)</td>
<td>8,955</td>
<td>14,324</td>
<td>46,240</td>
<td></td>
</tr>
<tr>
<td>ji et al. (2019)</td>
<td>8,668</td>
<td>13,903</td>
<td>43,904</td>
<td></td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>10,153</td>
<td>26,301</td>
<td>102,559</td>
</tr>
</tbody>
</table>

| $| \frac{c_{i,t}^{\text{imp}} y_{i,t}^{\text{imp}}}{y_{i,t}^{\text{imp}}} - \frac{c_{i,t}^{\text{es}} y_{i,t}^{\text{es}}}{y_{i,t}^{\text{es}}} | Fagereng & Halvorsen (2017) | 0.22 | 0.38 | 1.11 |
| koilien et al. (2014) | 0.21 | 0.34 | 0.95 |
| ji et al. (2019) | 0.21 | 0.28 | 0.84 |
| | None | 0.24 | 0.88 | 2.15 |

to the accounts while the value of the outstanding mortgage remains constant until maturity. Since 2013 the mortgage interest deductibility has been scrapped for newly issued mortgages that do not feature amortisation and their prevalence is therefore decreasing. Mastrogiacomo & van der Molen (2015) show that in 2015 about 70% of households with mortgage debt over the age of 50 had predominantly interest-only mortgages, while this share was only 20% for those below the age of 50.

Having imputed total consumption in the administrative data, we can now compare the resulting measure $c_{i,2015}^{\text{imp}}$ to the reported total consumption $c_{i,2015}^{\text{es}}$ in the expenditure survey of 2015. We first apply the following sample selection. We drop households that have an unknown home-ownership status, that experience a change in partner status, that have a household head younger than 25 or older than 90 years old, that are multiple person households (such as student housing) since wealth ownership attribution is difficult, that have changes in the stock of other real estate, and that have substantial shareholding of single firm. This leaves 13,135 households from the original 14,050 that could be linked to the administrative data. Imputed total consumption $c_{i,2015}^{\text{imp}}$ can be calculated for 12,106 households. It is also common to clean the imputed total consumption by trimming the top and bottom of its distribution, but the specific approach varies across the literature. Fagereng & Halvorsen (2017) shave the top and bottom 1% change in the value of financial savings (i.e., everything we subtract from disposable income) and drop households with negative consumption. This approach would leave us with 11,120 households. Koijen et al. (2014) shave the top and bottom 2.5% of the change in value of financial active savings, drop households with real estate transactions and drop households with negative consumption. This approach would leave 10,913 households. Ji et al. (2019) do not shave specific percentiles off the distribution, but instead omit unreasonable levels of consump-
Independent variable & $c_{i, 2015}^{imp}$ & $\ln c_{i, 2015}^{imp}$ \\ 
$c_{i, 2015}^{es}$ & 0.849*** & \\ 
 & (0.011) & \\ 
$\ln c_{i, 2015}^{es}$ & 0.829*** & \\ 
 & (0.008) & \\ 
Constant & 11,825.6*** & 1.888*** \\ 
 & (488.7) & (0.086) \\ 
$R^2$ & 0.359 & 0.487 \\ 
$N$ & 10,711 & 10,711 

Table 2.9: Regressing imputed total consumption $c_{i, 2015}^{imp}$ on expenditure survey total consumption $c_{i, 2015}^{es}$. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

They drop households whose average consumption throughout the sample period is below the poverty level of 5,760 euros or 120,000 euros above its average disposable income. They also drop households for which imputed total consumption relative to disposable income exceeds 2.5 or is below 0.2. This approach would leave us with 10,789 households. Table 2.8 shows the absolute consumption imputation errors (both in levels and relative to disposable income) for the various approaches in the literature. We note that the imputation error can be relatively large compared to the imputation errors from the first technique that were reported in table 2.4. We follow the sample selection strategy of Ji et al. (2019) since it produces the smallest errors.

Ideally we would provide a scatter plot of the two measures of total consumption to assess the overall fit like Kreiner et al. (2014) do, but data usage stipulations of Statistics Netherlands prohibit the reporting of data pertaining to specific households. As a next best alternative we regress the two measures of total imputation on each other (with the results reported in table 2.9) and plot histograms of their distribution in figures 2.1a and 2.1b. A regression coefficient of 1 would be a best case scenario and our estimates of 0.85 and 0.83 are not far off. The histograms show that the imputation errors are centred to the left with less consumption imputed in the middle range and more imputed at the upper range of consumption. Since the expenditure survey measure is self-reported, it is impossible to assess whether the resulting imputation errors arise due to measurement error in $c_{i, 2015}^{imp}$ or in $c_{i, 2015}^{es}$. Like Kreiner et al. (2014), however, we observe from table 2.10 that the absolute imputation error (both in levels and relative to disposable income) is higher for richer, larger, older, home-owning and wealthy households. This is unsurprising, because the financial portfolios of these households are more involved and this makes the imputation procedure less precise.
Histogram of $\ln(c_{i,2015}^{es})$ and $\ln(c_{i,2015}^{imp})$

(a) Stacked distribution of logged imputed total consumption (red) and logged expenditure survey total consumption (green).

Histogram of $\ln(c_{i,2015}^{es}) - \ln(c_{i,2015}^{imp})$

(b) Distribution of the consumption imputation error, which is not centred around 0 (the red line), but below it.

Figure 2.1: A distribution comparison of imputed total consumption and total consumption in the expenditure survey of 2015. Roughly 30 observations are trimmed from the tails to comply with the privacy stipulations of Statistics Netherlands.
| Variable          | $|\ln c_{i,2015}^{imp} - \ln c_{i,2015}^{es}|$ | $|\frac{c_{i,t}^{imp} - c_{i,t}^{es}}{y_{i,2015}}|$ |
|-------------------|------------------------------------------|--------------------------------------|
| Income before tax | 0.14                                     | 0.02                                 |
| Family size       | 0.05                                     | 0.01                                 |
| Age               | 0.03                                     | 0.05                                 |
| Home-owner        | 0.07                                     | 0.01                                 |
| Home value        | 0.08                                     | 0.04                                 |
| Net wealth        | 0.13                                     | 0.09                                 |

Table 2.10: Correlation of absolute consumption imputation errors with various variables for households in the expenditure survey of 2015, where $c_{i,2015}^{imp}$ is the imputed total consumption and $c_{i,2015}^{es}$ is the total consumption measure from the expenditure survey of household $i$ in 2015.

Recall that the prevalence of interest-only mortgages which are often coupled with, for us unobservable, pledged savings or investment accounts implies that imputed total consumption is likely to be overestimated. We can identify households with interest-only mortgages by observing whether the nominal value of the outstanding mortgage remains constant over time. We verify the widespread use of these mortgages: roughly 55% of home-owners in the expenditure survey of 2015 are identified to have an interest-only mortgage. It is likely that these households have some sort of pledged savings or investment account that causes us to overestimate total consumption and the associated imputation errors should be centred more to the left than for home-owners that amortise their mortgage.\(^{24}\) Figures A2.3a and A2.3b show, however, that the overestimation of total consumption is virtually just as large for households with interest-only mortgages and for households with some degree of amortisation. Figures A2.3d and A2.3e also indicate that the imputation errors are similarly distributed for home-owners older than 50 years (who have predominantly interest-only mortgages) and home-owners younger than 50 years (who have predominantly amortising mortgages).

Based on the changes in net financial wealth of households, our imputation of total consumption implies that many households consume virtually all of their disposable income.

\(^{24}\)We note that the identification is not faultless since the mortgage structure of most households is relatively complex. It is very common to finance ones house by combining different types of mortgages. As a result, a fraction of the mortgage might be interest-only without an associated pledged savings account, while another fraction might also be interest-only but with an associated pledged investment account and another fraction might have amortisation. A constant nominal value of the outstanding mortgage might mean that the mortgage is entirely interest-only, but it does not indicate to what extent there is a matched pledged savings or investment account. We therefore interpret the group of households with interest-only mortgages as being more likely to have more pledged savings or investment accounts compared to the group of households that have at least some degree of amortisation in their mortgage structure.
Figure 2.2: Distribution of expenditure survey consumption to disposable income conditional on imputed consumption to disposable income lying between 0.9 and 1.1 (indicated by the solid red lines). Roughly 100 observations are trimmed from the tails to comply with the privacy stipulations of Statistics Netherlands.

The expenditure survey, however, implies household saving rates that are much higher.\footnote{Note that the overestimation of consumption is unlikely to result from the unobserved pledged savings or investment accounts of interest-only mortgagors.} To illustrate this, in figure 2.2 we present a histogram of the expenditure survey measure of total consumption relative to disposable income conditional on the imputed measure of total consumption relative to disposable income ranging between 0.9 and 1.1. Roughly 4,500 households are hand-to-mouth consumers according to the consumption imputation, while only roughly 1,150 are according to the expenditure survey. About 2,400 households instead report a ratio of total consumption relative to disposable income that is less than 0.9. This is similar to the findings of Aguiar & Bils (2015) who show that the implied saving rates in the Consumer Expenditure Survey of the United States do not match up with actual saving rates according to national account data. At this stage, it is impossible for us to determine the source of the persistent difference in reported consumption between the two data sources.

2.6.2 Regression results

We again estimate the baseline regression model of Campbell & Cocco (2007), but now using the panel dataset of one million Dutch households with data from 2011-2018. Since
we have a true panel, controlling for changes in the age of the household is moot. We also omit the real interest rate variable, as its value is the same for all households in the sample and is therefore captured by the year dummies. The regression results are documented in table 2.11. The coefficients for $\Delta y_{i,t}$ show conclusive evidence that total consumption is positively associated with changes in income and that this change is especially large for liquidity constrained households. This lines up with the reported coefficients of Crawley & Kuchler (2020), who apply the same consumption imputation approach with Danish administrative data. A housing wealth effect on consumption, which we found in section 2.5.2, is not reflected in the coefficient estimate for $\Delta h_{i,t}$. However, during later robustness checks in table 2.12 we will find that there is a housing wealth effect for working-age households with an elasticity of 0.05. From table 2.11 it appears instead that households with negative housing equity respond more strongly to house price fluctuations, as found previously by Disney et al. (2010) and Christelis et al. (2021). This holds especially for home-owners with amortising mortgages, as indicated by regression (iv). Our measure of housing equity is distorted due to the unobservability of accompanying pledged savings accounts. Home-owners with an interest-only mortgage thus appear to have very high degrees of mortgage indebtedness, while the assets that they are accumulating are not taken into account. The dummy variable $IO$ indicates whether the household has an interest-only mortgage (and is thus likely to have a pledged savings accounts that we do not observe). These households might have negative housing equity according our dataset, but we know that this misrepresents the truth. We find that households with amortising mortgages and negative housing equity respond particularly strongly to fluctuations in house prices.

The average house price of home-owners in the administrative data of 2015 is 234,000 euro, average disposable income is 40,218 euro and average total consumption is 39,680 euro. The elasticities for disposable income of roughly 0.50 and for housing wealth of roughly 0.06 for working-age and negative housing equity households imply that a 1,000 euro increase in disposable income results in a roughly 500 euro increase in total consumption and a 10,000 euro increase in housing wealth results in a roughly 100 euro increase in total consumption. As before, it appears from regression (v) that on the aggregate level the liquidity dampening and total lifetime wealth enhancing effects of mandatory pension fund participation outweigh each other. These results are robust to the joint inclusion of the three indicators of liquidity, leverage and mandatory pension fund participation. Qualitatively, the results with respect to the marginal propensity to consume out of in-

\[\text{Note that we do not insert the indicator for home-ownership status in the regressions. In the administrative data only the house value of home-owners is recorded, while in the expenditure surveys the value of the residential location of renters is also reported.}\]
<table>
<thead>
<tr>
<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta y_{i,t}$</td>
<td>0.550***</td>
<td>0.482***</td>
<td>0.549***</td>
<td>0.550***</td>
<td>0.465***</td>
<td>0.495***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.004)</td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times \text{Liq.}$</td>
<td>0.180***</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times \text{Pen.}$</td>
<td></td>
<td>-0.002</td>
<td>-0.025***</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>(0.004)</td>
<td>(0.006)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t}$</td>
<td>0.014**</td>
<td>0.016**</td>
<td>-0.005</td>
<td>-0.006</td>
<td>0.003</td>
<td>-0.002</td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.006)</td>
<td>(0.006)</td>
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<tr>
<td>$\Delta h_{i,t} \times \text{Lev.}$</td>
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<td>0.182***</td>
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<tr>
<td></td>
<td>(0.009)</td>
<td>(0.018)</td>
<td></td>
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<tr>
<td>$\Delta h_{i,t} \times \text{Lev.} \times \text{IO}$</td>
<td>-0.152***</td>
<td></td>
<td>-0.150***</td>
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<tr>
<td></td>
<td></td>
<td>(0.020)</td>
<td>(0.020)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$\Delta \text{Ln Family size}$</td>
<td>0.276***</td>
<td>0.266***</td>
<td>0.276***</td>
<td>0.276***</td>
<td>0.325***</td>
<td>0.266***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.062</td>
<td>0.063</td>
<td>0.062</td>
<td>0.062</td>
<td>0.057</td>
<td>0.063</td>
</tr>
<tr>
<td>$N$</td>
<td>3,364,090</td>
<td>3,364,090</td>
<td>3,364,090</td>
<td>3,364,090</td>
<td>3,364,090</td>
<td>3,364,090</td>
</tr>
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</table>

**Table 2.11:** Regression results of the baseline specification using the consumption imputation in the administrative data. The regressions include year dummies (not reported) and cohort fixed effects. $y_{i,t}$ denotes disposable income in regressions (i)-(iv) and (vi) and income before tax in regression (v). *Liq.* denotes low cash-on-hand, *Lev.* negative housing equity, *Pen.* mandatory pension contribution and *IO* interest-only mortgage. The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
come and housing wealth, together with the balance sheet indicators, are in accordance with the findings of the first imputation method in section 2.5.2.

Before moving to more elaborate regression specifications, we consider a number of robustness checks that are specific to this imputation method. Firstly, we move away from the standard regression specification of Campbell & Cocco (2007) and add additional control variables relating to household characteristics (age group, home-ownership status, primary source of income and household composition). Table A2.4 shows that the inclusion of these variables does not significantly change the consumption responses. Secondly, we run the baseline regressions only with the panel of households that were present in the expenditure survey wave of 2015. A difference in the regression outcomes would point toward the survey wave of 2015 not being a representative sample of the entire universe of Dutch households. Table A2.5 indicates that the results are consistent. Thirdly, we consider a more restricted sample of households similar to Browning et al. (2013). Specifically, we only select ‘stable’ couples that do not move, do not separate and are below the retirement age. Table A2.6 highlights that the baseline results are again similar.

We assess whether there is heterogeneity in the consumption responses across the age of households. We divide the population into four age brackets: younger households up to age 35, younger middle-aged households from age 35 to 50, older middle-aged households from age 50 to 65, and retired households over age 65. The results are shown in table 2.12. Similar to Jappelli & Pistaferri (2014) we find that there is a flat age profile of the marginal propensity to consume out of income, even after controlling for low cash-on-hand. We do find substantial heterogeneity in age for the house price sensitivity, even after controlling for negative housing equity. Households below the retirement age exhibit a housing wealth effect, while the coefficients of retired households are difficult to rationalise.

To line up with the literature based on hypothetical scenarios presented to surveyed households, we interact the changes in disposable income with sign and size indicators. We denote a change in disposable income as large if the year-on-year change exceeds two months of disposable income. We do the same with the changes in housing wealth and denote a change in house price as large if it exceeds 10% of the initial house price. Given the found heterogeneity across the age distribution in table 2.12, we interact the change in house price with age brackets. The results are depicted in table 2.13. In line with Fuster et al. (2020) and Christelis et al. (2019) we find that households respond more strongly to drops in income and to large changes in income, even after controlling for low cash-on-hand. These results are in agreement with the predictions of models featuring

---

27 Roughly 12.5% of households experiences a large swing in disposable income or house price in a given year.
<table>
<thead>
<tr>
<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta y_{i,t} \times {\text{age} &lt; 35}$</td>
<td>0.550***</td>
<td>0.452***</td>
<td>0.550***</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.007)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times {35 \leq \text{age} &lt; 50}$</td>
<td>0.541***</td>
<td>0.463***</td>
<td>0.541***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.005)</td>
<td>(0.004)</td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times {50 \leq \text{age} &lt; 65}$</td>
<td>0.553***</td>
<td>0.489***</td>
<td>0.553***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.004)</td>
<td>(0.004)</td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times {\text{age} \geq 65}$</td>
<td>0.554***</td>
<td>0.507***</td>
<td>0.554***</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.006)</td>
<td>(0.006)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times \text{Liq.}$</td>
<td>0.185***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {\text{age} &lt; 35}$</td>
<td>0.046**</td>
<td>0.048***</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.014)</td>
<td>(0.017)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {35 \leq \text{age} &lt; 50}$</td>
<td>0.061***</td>
<td>0.064***</td>
<td>0.049***</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.008)</td>
<td>(0.010)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {50 \leq \text{age} &lt; 65}$</td>
<td>0.048***</td>
<td>0.049***</td>
<td>0.042***</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {\text{age} \geq 65}$</td>
<td>-0.087***</td>
<td>-0.084***</td>
<td>-0.088***</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times \text{Lev.}$</td>
<td></td>
<td></td>
<td>0.139***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.019)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times \text{Lev.} \times \text{IO}$</td>
<td>-0.153***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.020)</td>
</tr>
<tr>
<td>$\Delta \text{Ln Family size}$</td>
<td>0.275***</td>
<td>0.263***</td>
<td>0.275***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
</tbody>
</table>

$R^2$ 0.062 0.063 0.062

$N$ 3,364,090 3,364,090 3,364,090

Table 2.12: Regression results of baseline specification using the consumption imputation in the administrative data with interactions of age brackets. The regressions include year dummies (not reported) and cohort fixed effects. $y_{i,t}$ denotes disposable income, Liq. low cash-on-hand, Lev. negative housing equity and IO interest-only mortgage. The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
<table>
<thead>
<tr>
<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta y_{i,t}$</td>
<td>0.607***</td>
<td>0.555***</td>
<td>0.441***</td>
<td>0.382***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.004)</td>
<td>(0.005)</td>
<td>(0.006)</td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times$ Pos.</td>
<td>-0.118***</td>
<td>-0.167***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td>(0.006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times$ Large</td>
<td>0.121***</td>
<td>0.114***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times$ Liq.</td>
<td>0.200***</td>
<td></td>
<td>0.177***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td></td>
<td>(0.004)</td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {\text{age &lt; 35}}$</td>
<td>0.047**</td>
<td>0.041*</td>
<td>0.130***</td>
<td>0.124***</td>
</tr>
<tr>
<td></td>
<td>(0.015)</td>
<td>(0.018)</td>
<td>(0.017)</td>
<td>(0.019)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {35 \leq \text{age &lt; 50}}$</td>
<td>0.064***</td>
<td>0.060***</td>
<td>0.144***</td>
<td>0.139***</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.012)</td>
<td>(0.011)</td>
<td>(0.013)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {50 \leq \text{age &lt; 65}}$</td>
<td>0.054***</td>
<td>0.053***</td>
<td>0.130***</td>
<td>0.128***</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
<td>(0.011)</td>
<td>(0.012)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times {\text{age} \geq 65}$</td>
<td>-0.090***</td>
<td>-0.086***</td>
<td>-0.000</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
<td>(0.011)</td>
<td>(0.012)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Pos.</td>
<td>0.000</td>
<td>-0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.015)</td>
<td>(0.015)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Large</td>
<td>-0.105***</td>
<td>-0.108***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Lev.</td>
<td>0.133***</td>
<td>0.133***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
<td>(0.019)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Lev. × IO</td>
<td>-0.150***</td>
<td>-0.153***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
<td>(0.020)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta \text{Ln Family size}$</td>
<td>0.268***</td>
<td>0.254***</td>
<td>0.274***</td>
<td>0.265***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
</tbody>
</table>

| $R^2$ | 0.062 | 0.064 | 0.062 | 0.063 |
| $N$   | 3,364,090 | 3,364,090 | 3,364,090 | 3,364,090 |

Table 2.13: Regression results of the baseline specification using the consumption imputation in the administrative data with interactions for size and sign of changes. The regressions include year dummies (not reported) and cohort fixed effects. $y_{i,t}$ denotes disposable income, Pos. positive change, Large large change, Liq. low cash-on-hand, Lev. negative housing equity and IO interest-only mortgage. The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
precautionary savings and borrowing constraints. While we find that households respond symmetrically to the sign of changes in house prices, we observe that households are particularly unresponsive to large swings in the value of their house. It is difficult to rationalise this result, especially since the housing wealth effect of the retired households now disappears.\textsuperscript{28} In any case, the inclusion of the size indicator reveals a stronger housing wealth effect for working-age households (compared to table 2.12) who do not experience large swings in the value of their house. These results are robust to the inclusion of the leverage indicator.\textsuperscript{29}

We conclude this section by investigating the relative size of the liquidity dampening and total lifetime wealth enhancing effects of mandatory pension fund contribution. To keep oversight, we do not interact the house price change with age brackets because the coefficients with respect to income changes were unaffected by its inclusion in the previous regressions. We also exclude households over the retirement age, because they rarely face mandatory pension fund contribution. Since the accrual rates of pension wealth are uniform over the age distribution, which implies that pension fund participants of different ages accumulate the same pension entitlements in the margin even though the contribution of the older participants is invested for a shorter period of time, the total lifetime wealth effect should be larger for older households. For younger households, the same marginal accrual is paid out in a much more distant future so that the liquidity dampening effect is expected to dominate. Regression (i) in table 2.14 indicates that this is indeed the case. We should, however, control for the distribution of income before tax due to the progressivity of the tax system.\textsuperscript{30} An additional unit of income before tax is taxed less heavily for households in the lower quintiles of the income before tax distribution and regression (ii) shows that these households indeed have higher marginal propensities to consume out of income before tax. After controlling for the income distribution we still find in regression (iii) that the total wealth effect is larger for older households.

We go one step further by interacting the age bracket with the income before tax quintiles (constructed for each age bracket and sample year) and the mandatory pension fund contribution indicator. This allows us to assess the importance of heterogeneity in the (subjective) life expectancy of households. Bilal et al. (2019) show that there is a persistent, positive relationship between socio-economic status (as proxied by income) and life expectancy. Mirowsky & Ross (2000) show that the same is true for subjective life expectancy.

---

\textsuperscript{28}The same peculiarity arises when we exclude moving or retired households.

\textsuperscript{29}Cross-interactions of the sign and size indicators does not yield different qualitative results.

\textsuperscript{30}This was not necessary in the regressions where we used disposable income instead of income before tax. We use income before tax instead of disposable income when we look at the effect of mandatory pension fund contribution because income before tax determines the amount of contributions a household has to make, and this is therefore the relevant margin.
<table>
<thead>
<tr>
<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta y_{i,t}$ × {age &lt; 35}</td>
<td>0.539***</td>
<td>0.386***</td>
<td>0.365***</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
<td>(0.008)</td>
<td>(0.013)</td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {35 ≤ age &lt; 50}</td>
<td>0.485***</td>
<td>0.393***</td>
<td>0.327***</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.007)</td>
<td>(0.010)</td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {50 ≤ age &lt; 65}</td>
<td>0.469***</td>
<td>0.427***</td>
<td>0.331***</td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td>(0.007)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {age &lt; 35} × Pen.</td>
<td>-0.130***</td>
<td>-0.018</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.012)</td>
<td>(0.013)</td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {35 ≤ age &lt; 50} × Pen.</td>
<td>-0.043***</td>
<td>0.062***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.009)</td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {50 ≤ age &lt; 65} × Pen.</td>
<td>0.021**</td>
<td>0.124***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.008)</td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {Income =1}</td>
<td>0.161***</td>
<td>0.223***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.009)</td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {Income =2}</td>
<td>0.038***</td>
<td>0.074***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.008)</td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {Income =3}</td>
<td>0.019*</td>
<td>0.032***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.008)</td>
<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t}$ × {Income =4}</td>
<td>0.007</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.009)</td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t}$</td>
<td>0.016*</td>
<td>0.019**</td>
<td>0.019**</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.007)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>$\Delta \ln$ Family size</td>
<td>0.311***</td>
<td>0.309***</td>
<td>0.303***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.004)</td>
<td>(0.004)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.067</td>
<td>0.068</td>
<td>0.068</td>
</tr>
<tr>
<td>$N$</td>
<td>2,322,915</td>
<td>2,322,915</td>
<td>2,322,915</td>
</tr>
</tbody>
</table>

Table 2.14: Regression results using the consumption imputation in the administrative data for the evaluation of the liquidity dampening and total lifetime wealth enhancing effects of mandatory pension fund contribution. Excluding households above the retirement age. The regressions include year dummies (not reported) and cohort fixed effects. $y_{i,t}$ denotes income before tax and Pen. mandatory pension fund contribution. Income=$x$ denotes that the household is in the $x$th quintile of the income before tax distribution for year $t$ (reference group $x = 5$). The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
\[
\begin{array}{ccc}
\{age < 35\} & \{35 \leq age < 50\} & \{50 \leq age < 65\} \\
\Delta y_{i,t} \times \text{Pen.} \times \{\text{Income}_{age} = 1\} & -0.093^{***} & -0.001 & 0.001 \\
\quad \quad \quad \quad (0.018) & (0.013) & (0.016) \\
\Delta y_{i,t} \times \text{Pen.} \times \{\text{Income}_{age} = 2\} & -0.009 & 0.065^{***} & 0.157^{***} \\
\quad \quad \quad \quad (0.017) & (0.013) & (0.012) \\
\Delta y_{i,t} \times \text{Pen.} \times \{\text{Income}_{age} = 3\} & 0.073^{**} & 0.115^{***} & 0.223^{***} \\
\quad \quad \quad \quad (0.023) & (0.019) & (0.017) \\
\Delta y_{i,t} \times \text{Pen.} \times \{\text{Income}_{age} = 4\} & 0.083^{**} & 0.153^{***} & 0.230^{***} \\
\quad \quad \quad \quad (0.029) & (0.025) & (0.024) \\
\Delta y_{i,t} \times \text{Pen.} \times \{\text{Income}_{age} = 5\} & -0.041 & 0.056^* & 0.047 \\
\quad \quad \quad \quad (0.032) & (0.026) & (0.025) \\
\end{array}
\]

**Table 2.15:** Regression results using the consumption imputation in the administrative data for the evaluation of the liquidity dampening and total lifetime wealth enhancing effects of mandatory pension fund contribution. Excluding households above the retirement age. \(y_{i,t}\) denotes income before tax and \(\text{Pen.}\) mandatory pension fund contribution. \(\text{Income}_{age} = x\) denotes that the household is in the \(x^{th}\) quintile of the income before tax distribution for year \(t\) and its age bracket. The regression also includes \(\Delta y_{i,t}\) interacted with age brackets and five quintiles of the income before tax distribution, \(\Delta h_{i,t}\), \(\Delta \text{Ln Family size}\), year dummies and cohort fixed effects (all not reported). The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * \(p < 0.05\), ** \(p < 0.01\), *** \(p < 0.001\)
expectancy. Since the pension entitlements are paid out as an annuity (and thus provide longevity insurance), households with a higher life expectancy benefit more from an additional unit of pension accrual. For these households, the total lifetime wealth enhancing effect is especially large. Table 2.15 indeed shows that households who face mandatory pension fund contribution and who are likely to have a higher (subjective) life expectancy respond more strongly to changes in income before tax compared to households with similar incomes who do not face mandatory contribution, and compared to poorer households with a lower (subjective) life expectancy who do face mandatory contribution. The liquidity dampening effect clearly dominates for the young and relatively poor households for whom low levels of cash-on-hand and borrowing limits are expected to be a constraining force. We also find that the coefficients of $\Delta y_{i,t} \times \text{Pen.} \times \{\text{Income}_{\text{age}} = 5\}$ are close to zero. This is expected due to the ceiling on mandatory pension fund contributions. Households in this income quintile have on average an income before tax of roughly 150,000 euro, while marginal mandatory contributions become zero at an income before tax of 110,000 euro. These households thus do not face marginal mandatory participation and should not react differently compared to households in the upper income quintile that do not pay any mandatory contributions at all.

### 2.7 Conclusion

In this chapter we have evaluated the performance of two imputation techniques and used them to study the consumption behaviour of households in the Netherlands. Enriching expenditure surveys with unlinkable administrative data using matching on overlapping variables proves to be a promising alternative to the broadly applied regression prediction method of Skinner (1987). It is required that the combination of overlapping variables are granular, which is typically the case for expenditure surveys and administrative data. Imputation errors are relatively small and many households can be (correctly) matched without selection effects between the two datasets. Using the pseudo-panel methods of Deaton (1985) we have investigated the heterogeneous consumption response to changes in income and housing wealth. Unfortunately, the scant number of Dutch expenditure survey waves implies that drawing conclusions is difficult: standard errors remain large and more advanced empirical designs are not applicable. Nevertheless, many of the estimated

---

31 A difference in the coefficients across the quintiles of the income before tax distribution could arise due to heterogeneity in the expectation about future income streams. However, this does not imply that households who face mandatory pension participation react differently compared to households that are similarly paid and do not face mandatory pension participation. As such, advance information about the future path of income would not explain the heterogeneous coefficients in table 2.15.
coefficients are in line with the findings of Campbell & Cocco (2007) and with those of the consumption imputation method, where the sample contained millions of observations.

The more commonly applied method of imputing consumption into administrative data using the household budget constraint, introduced by Browning & Leth-Petersen (2003), works well for most households. That this imputation method only allows for an approximation of total consumption instead of non-durable consumption does not seem to be a severe limitation. More worrying is that the imputation errors are larger compared to the first imputation method and that they are larger for households with more sophisticated balance sheets, even after correcting for income. Furthermore, based on the annual snapshots of asset holdings, the consumption imputation implies that many more households are hand-to-mouth consumers compared to the expenditure survey. Unfortunately, we have been unable to uncover the source of this consumption measurement puzzle.

We documented that many households in the Netherlands have low levels of cash-on-hand, negative housing equity and mandatory pension fund participation. While the less well-off are typically thought to be the constrained households, we show that many higher earning Dutch households are likely to be constrained as well. Despite their relatively high incomes, these households primarily reside in the lower quintile of the net wealth distribution. Our empirical analysis showed that households with low levels of liquidity who experience large drops in disposable income cut back consumption the most. We also found a persistent housing wealth effect for working-age households that is stronger for households with negative housing equity.

While we found on an aggregated level that the liquidity dampening and total lifetime wealth enhancing effects of mandatory pension fund contribution are equally as large, we observed considerable heterogeneity in the relative size of the two effects across the population of Dutch households, which indicates that the design of the Dutch pension fund system is perhaps too rigid. Especially younger households that face borrowing constraints would benefit from age-dependent contribution rates or flexibility in the extent to which pension contributions are paid. Furthermore, households facing adverse unemployment or health shocks, or households who face borrowing constraints, would benefit from the option to withdraw some of their accumulated pension entitlements early. We have evaluated the desirability of such policies in chapter 1.
2.8 Appendix

2.8.1 Additional figures

![Distribution comparison of regression variables in the entire expenditure survey of 2015 (in green) and in the resulting sample after the matching procedure (in red). Overall, there are few signs of selection effects, except for the bank account balances and resulting liquidity measure (which is understated in the after-matching sample). In each histogram the bottom percentile and top five percentiles are trimmed to comply with the privacy stipulations of Statistics Netherlands.](image)

**Figure A2.1:** Distribution comparison of regression variables in the entire expenditure survey of 2015 (in green) and in the resulting sample after the matching procedure (in red). Overall, there are few signs of selection effects, except for the bank account balances and resulting liquidity measure (which is understated in the after-matching sample). In each histogram the bottom percentile and top five percentiles are trimmed to comply with the privacy stipulations of Statistics Netherlands.
Figure A2.1: (continued)
Figure A2.2: Distribution comparison of matching variables in the entire expenditure survey of 2015 (in green) and in the resulting sample after the matching procedure (in red). Overall, there are few signs of selection effects, except that there is a relative undersampling of middle-aged, self-employed and home-owning households.
(a) $N = 3,826$, mean = -0.112, median = -0.127.

(b) $N = 3,220$, mean = -0.107, median = -0.118.

(c) $N = 2,531$, mean = -0.012, median = -0.030.

(d) $N = 3,163$, mean = -0.113, median = -0.117.

(e) $N = 5,017$, mean = -0.115, median = -0.130.

Figure A2.3: Distribution of the consumption imputation error for home-owners with an interest-only mortgage, home-owners with an amortising mortgage, renters, home-owners younger than 50 years and home-owners older than 50 years.
### 2.8.2 Tables for the robustness checks of the first imputation method

<table>
<thead>
<tr>
<th>Independent variable</th>
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<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
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<tr>
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<td>0.103</td>
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<td>(0.169)</td>
<td>(0.130)</td>
<td>(0.155)</td>
<td>(0.191)</td>
</tr>
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</table>

$R^2$  | 0.246 | 0.332 | 0.309 | 0.222 | 0.139 |

$N$    | 89   | 89   | 165   | 121   | 149   |

Mean cohort size | 153 | 153 | 81 | 104 | 85 |

Fraction of indicator = 1 | 0.0% | 0.0% | 46.9% | 32.8% | 52.2% |

**Table A2.1**: Results of regressions (i-v) from table 2.6, but with total consumption as dependent variable instead of non-durable consumption. Regressions (i) and (ii) use the baseline cohort set (birth cohort, home-ownership status, household composition and primary source of income). Regressions (iii), (iv) and (v) also use the indicator for liquidity, leverage and mandatory pension contribution, respectively. $y_{i,t}$ denotes disposable income in regressions (i)-(iv) and income before tax in regression (v). Liq. denotes low cash-on-hand, Lev. negative housing equity and Pen. mandatory pension contribution. The regressions include year dummies and cohort fixed effects (both not reported). The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. Observations are weighted by the square root of cohort size. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
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<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
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<td>( \Delta y_{i,t} )</td>
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<td>0.348***</td>
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<td>(0.127)</td>
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<tr>
<td>( \Delta h_{i,t} \times \text{Rent} )</td>
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<th>(iii)</th>
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<th>(v)</th>
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<td>0.476</td>
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<td>89</td>
<td>164</td>
<td>121</td>
<td>150</td>
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<td>140</td>
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<td>0.0%</td>
<td>47.1%</td>
<td>32.8%</td>
<td>52.4%</td>
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Table A2.2: Results of regressions (i-v) from table 2.6, but with the household matching also applied to the expenditure survey wave of 2015. Regressions (i) and (ii) use the baseline cohort set (birth cohort, home-ownership status, household composition and primary source of income). Regressions (iii), (iv) and (v) also use the indicator for liquidity, leverage and mandatory pension contribution, respectively. \( y_{i,t} \) denotes disposable income in regressions (i)-(iv) and income before tax in regression (v). \( \text{Liq.} \) denotes low cash-on-hand, \( \text{Lev.} \) negative housing equity and \( \text{Pen.} \) mandatory pension contribution. The regressions include year dummies and cohort fixed effects (both not reported). The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. Observations are weighted by the square root of cohort size. * \( p < 0.10 \), ** \( p < 0.05 \), *** \( p < 0.01 \)
<table>
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<th>Meso</th>
<th>Macro</th>
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<td>0.376***</td>
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<tr>
<td>(\Delta h_{i,t})</td>
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<td>0.193***</td>
<td>0.160**</td>
<td>0.146***</td>
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Table A2.3: Results of regressions (i-v) from table 2.6, but with the four matching sets Nano, Micro, Meso and Macro. Regressions (i) and (ii) use the baseline cohort set (birth cohort, home-ownership status, household composition and primary source of income). Regressions (iii), (iv) and (v) also use the indicator for liquidity, leverage and mandatory pension contribution, respectively. \(y_{i,t}\) denotes disposable income in regressions (i)-(iv) and income before tax in regression (v). \(\text{Liq.}\) denotes low cash-on-hand, \(\text{Lev.}\) negative housing equity and \(\text{Pen.}\) mandatory pension contribution. For brevity we do not report the coefficients and standard errors of the control variables. The regressions include year dummies and cohort fixed effects (both not reported). The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. Observations are weighted by the square root of cohort size. * \(p < 0.10\), ** \(p < 0.05\), *** \(p < 0.01\)
<table>
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<th>Independent variable</th>
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<th>Micro</th>
<th>Meso</th>
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</tr>
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Table A2.3: (continued)
2.8.3 Tables for the robustness checks of the second imputation method

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<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta y_{i,t}$</td>
<td>0.544***</td>
<td>0.475***</td>
<td>0.544***</td>
<td>0.544***</td>
<td>0.457***</td>
<td>0.485***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.004)</td>
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<tr>
<td>$\Delta y_{i,t} \times$ Liq. Constr.</td>
<td>0.181***</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td></td>
<td></td>
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<tr>
<td>$\Delta y_{i,t} \times$ Pen. Constr.</td>
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<td>0.002</td>
<td>-0.019***</td>
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<td>(0.004)</td>
<td>(0.004)</td>
<td></td>
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</tr>
<tr>
<td>$\Delta h_{i,t}$</td>
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<td>0.005</td>
<td>-0.007</td>
<td>-0.008</td>
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<td>(0.006)</td>
<td>(0.006)</td>
<td>(0.007)</td>
<td>(0.007)</td>
<td>(0.006)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Lev. Constr.</td>
<td>0.034***</td>
<td>0.162***</td>
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<td>0.157***</td>
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<tr>
<td></td>
<td>(0.009)</td>
<td>(0.018)</td>
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</tr>
<tr>
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<td>-0.172***</td>
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<td>-0.171***</td>
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<tr>
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<td>(0.019)</td>
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<td></td>
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</tr>
<tr>
<td>$\Delta \ln$ Family size</td>
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<td>0.251***</td>
<td>0.261***</td>
<td>0.261***</td>
<td>0.315***</td>
<td>0.251***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
</tbody>
</table>

$R^2$ 0.065 0.067 0.065 0.065 0.060 0.067

$N$ 3,043,725 3,043,725 3,043,725 3,043,725 3,043,725 3,043,725

Table A2.4: Results of regressions (i-v) from table 2.11, but the regressions include additional control variables relating to household characteristics, year dummies and cohort fixed effects (not reported). $y_{i,t}$ denotes disposable income in regressions (i)-(iv) and (vi) and income before tax in regression (v). Liq. denotes low cash-on-hand, Lev. negative housing equity, Pen. mandatory pension contribution and IO interest-only mortgage. The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
<table>
<thead>
<tr>
<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
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<td>$\Delta y_{i,t}$</td>
<td>0.446***</td>
<td>0.408***</td>
<td>0.446***</td>
<td>0.446***</td>
<td>0.368***</td>
<td>0.427***</td>
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<td>(0.020)</td>
<td>(0.022)</td>
<td>(0.020)</td>
<td>(0.020)</td>
<td>(0.028)</td>
<td>(0.031)</td>
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<td></td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times$ Pen. Constr.</td>
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<td></td>
<td></td>
<td></td>
<td>0.006</td>
<td>-0.031</td>
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<tr>
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<td>(0.033)</td>
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</tr>
<tr>
<td>$\Delta h_{i,t}$</td>
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<td>0.029</td>
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<td>0.008</td>
<td>0.016</td>
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<td>(0.046)</td>
<td>(0.046)</td>
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<tr>
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<td>0.238</td>
<td>0.234</td>
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<tr>
<td></td>
<td>(0.061)</td>
<td>(0.130)</td>
<td>(0.130)</td>
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</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Lev. Constr. × IO</td>
<td>-0.236</td>
<td></td>
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<td>-0.231</td>
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<tr>
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<td>(0.140)</td>
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<td>0.380***</td>
<td>0.384***</td>
<td>0.383***</td>
<td>0.429***</td>
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<td>(0.027)</td>
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</table>

| $R^2$ | 0.044 | 0.044 | 0.044 | 0.044 | 0.040 | 0.044 |
| $N$   | 55,422 | 55,422 | 55,422 | 55,422 | 55,422 | 55,422 |

**Table A2.5:** Results of regressions (i-v) from table 2.11, but the sample is restricted to the households in the expenditure survey wave of 2015. $y_{i,t}$ denotes disposable income in regressions (i)-(iv) and (vi) and income before tax in regression (v). Liq. denotes low cash-on-hand, Lev. negative housing equity, Pen. mandatory pension contribution and IO interest-only mortgage. The regressions include year dummies (not reported) and cohort fixed effects. The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
<table>
<thead>
<tr>
<th>Independent variable</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
</tr>
</thead>
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<td>$\Delta y_{i,t}$</td>
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<td>0.528***</td>
<td>0.528***</td>
<td>0.456***</td>
<td>0.489***</td>
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<td>(0.004)</td>
<td>(0.006)</td>
<td>(0.007)</td>
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</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.006)</td>
</tr>
<tr>
<td>$\Delta y_{i,t} \times$ Pen. Constr.</td>
<td></td>
<td>0.010</td>
<td>-0.011</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.007)</td>
<td>(0.006)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t}$</td>
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<td>0.009</td>
<td>-0.006</td>
<td>-0.007</td>
<td>-0.005</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.008)</td>
<td>(0.010)</td>
<td>(0.010)</td>
<td>(0.008)</td>
<td>(0.010)</td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Lev. Constr.</td>
<td>0.035**</td>
<td>0.189***</td>
<td>0.187***</td>
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<tr>
<td></td>
<td>(0.011)</td>
<td>(0.021)</td>
<td>(0.021)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta h_{i,t} \times$ Lev. Constr.×IO</td>
<td></td>
<td>-0.206***</td>
<td>-0.206***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.022)</td>
<td>(0.022)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta \ln$ Family size</td>
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<td>0.294***</td>
<td>0.297***</td>
<td>0.297***</td>
<td>0.346***</td>
<td>0.294***</td>
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<tr>
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<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.005)</td>
</tr>
</tbody>
</table>

| $R^2$                | 0.062   | 0.063   | 0.062   | 0.062   | 0.057   | 0.063   |
| $N$                  | 1,506,354 | 1,506,354 | 1,506,354 | 1,506,354 | 1,506,354 | 1,506,354 |

**Table A2.6:** Results of regressions (i-v) from table 2.11, but the sample is restricted to ‘stable’ couples that do not move, do not separate and are below the retirement age. $y_{i,t}$ denotes disposable income in regressions (i)-(iv) and (vi) and income before tax in regression (v). Liq. denotes low cash-on-hand, Lev. negative housing equity, Pen. mandatory pension contribution and IO interest-only mortgage. The regressions include year dummies (not reported) and cohort fixed effects. The standard errors shown in parentheses are corrected for heteroscedasticity and first order serial correlation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Chapter 3

Pension Fund Restoration Policy in General Equilibrium

3.1 Introduction

The financial positions of pension funds worsened worldwide during the financial crisis of 2008 and the ensuing sovereign debt crisis of 2009. Not only did these crises depress asset values, subsequently low interest rates inflated the discounted value of pension fund liabilities. Pension funds were left with a funding deficit since the present discounted value of accumulated pension promises of fund participants far exceeded the value of invested contributions. Federal Reserve Flow of Funds data indicate that U.S. retirement fund assets were virtually cut in half between 2007 and 2009 as a result of the 2008 financial crisis (Treasury, 2012) and estimations by Novy-Marx & Rauh (2011) imply that the funding gap of U.S. state-sponsored pension plans in 2008 was as large as 3.23 trillion dollars. The experience in other countries has been similar. Laboul (2010) highlights that the estimated pension fund liabilities of 2100 exchange-listed companies from OECD countries were on average roughly 25% larger than their assets in 2008 and 2009.

If pension funds are to avoid exhausting their assets, funding deficits need to be covered through the implementation of suitable restoration policies. Regulations generally stipulate that pension funds should achieve funding adequacy in order to avoid shifting the costs to future generations. However, there are various ways in which this can be done and in this chapter we consider Defined Contribution (DC) systems which write down the value of pension promises to fund participants in order to bring the liabilities of pension funds closer to assets and Defined Benefit (DB) systems which increase the required contributions paid by current and future workers to bring the assets of pension funds closer to liabilities. The 2013 Pensions at a Glance report of the OECD shows that there is
little consensus amongst pension funds and regulators with regards to the preferred way of restoring the financial adequacy of pension funds: between 2009 and 2013 all OECD countries have reformed their pension systems, but the measures taken differ widely. This heterogeneity undoubtedly relates to the fact that different types of restoration policies have different distributional consequences and different implications for macroeconomic performance, which is especially relevant when the economy is in a state of crisis. Unfortunately, much of the pension economics literature studies pension funds only from a long-term perspective (see for instance Gollier (2008) and Beetsma & Bovenberg (2009)) which inherently abstracts from effects materialising at business cycle frequencies. With more countries shifting away from pay-as-you-go pension systems to funded systems (motivated by population ageing) and the recently experienced sensitivity of pension funds to financial crises, insights about sound pension fund policy at a business cycle frequency are essential.

This chapter aims to fill this gap in the literature and thus aims to provide an assessment of the business cycle effects and distributional consequences of pension fund restoration policies. To do so, we extend a canonical New-Keynesian, closed economy, dynamic general equilibrium model with a tractable demographic structure and a flexible pension fund framework. We build on the overlapping generations framework of Gertler (1999), who introduces life-cycle behaviour in a business cycle model. The production sectors of our model are inspired by Kara & von Thadden (2016) and incorporate investment adjustment costs, imperfect competition in the retail sector and nominal Calvo (1983)-pricing rigidities. As a novelty, we extend the pension fund framework of Romp (2013) and incorporate it into our model. This framework embeds various types of pension funds observed in reality, depending on the specific parametrisation, and allows for the accrual of inflation-indexed or non-indexed pension wealth. The pension fund sets the restoration policy (given by the contribution rate on labour income, the accumulation rate of the annuity and a revaluation instrument) depending on its financial position.

From a modelling perspective, this chapter improves upon the pension fund design literature along various dimensions. Firstly, the nominal rigidities and nominal accrual of pension benefits allow for a comparison of fully indexed and non-indexed pension funds that was not possible in the existing literature which does not consider nominal rigidities. Secondly, the demand-side of the economy is enriched compared to Romp (2013), who does not conduct a welfare analysis because agents have a linear utility structure and are hand-to-mouth consumers with no intertemporal reallocation in response to shocks. Thirdly, this chapter focuses on the short-term phenomenon of restoration policy, while others employ long-term OLG models that abstract from distortions and market imperfections.
materialising at business cycle frequencies. Fourthly, others tend to consider open economy models in which the interest rate is set exogenously, while the interest rate in our model is determined endogenously.

We consider a Gertler & Karadi (2011)-type unexpected capital quality shock which evaporates a fraction of the capital stock and leaves the pension fund with a funding gap that needs to be closed. We find that when individuals accumulate real pension benefits a DC economy behaves similarly to a Laissez-Faire economy, because the writing down of previously accumulated pension wealth has a similar effect on total lifetime wealth as losing private financial wealth. In a DB economy, there are two counteracting forces at work. On the one hand, the pension fund increases the contribution rates on labour income and distorts labour supply. On the other hand, the pension fund redistributes wealth towards the group of individuals that has a higher marginal propensity to consume out of wealth, which is important in a demand-driven model. We find that the former effect is the strongest and that the DB pension fund exacerbates economic fluctuations.

When individuals accumulate nominal pension benefits, the shock leaves the pension fund with a surplus due to ensuing inflation in the medium term as the economy recovers. The DB pension fund then subsidises labour supply, which dampens economic fluctuations.

The recovery from the unexpected capital quality shock requires the pension fund to distribute welfare losses (or gains) to different groups of individuals and generations. We calculate equivalent variations to assess the welfare effects for three groups of individuals. Retirees are vulnerable to a loss of pension wealth, but are insensitive to distortions on the labour market, and therefore prefer the pension system that maximises their pension wealth. The workers who have already accumulated pension wealth in the period the shock materialises dislike labour supply distortions, but also dislike losing their pension wealth because it is the only available asset that yields a return conditional on the life-cycle stage of the individual. The future generations prefer the pension system that brings about the most favourable labour market conditions. We find that there is no unanimous agreement between workers, retirees and future generations about optimal pension fund design.

While DB pension funds (which have been studied in environments without nominal rigidities) are generally considered to be ex ante welfare improving because they bring about intergenerational risk-sharing (see Beetsma & Romp (2016) for an overview) and increase the risk-taking capacity of the economy Gollier (2008), our results show that the induced distortions of such systems are sizeable when nominal rigidities are present. This is in agreement with Beetsma et al. (2013) and Romp (2013) who find that DB pension funds induce significant labour supply distortions, but Bonenkamp & Westerhout (2014) and Draper et al. (2017) argue that the welfare gain from intergenerational risk-sharing
dominates the cost of labour supply distortions. We show that, in the presence of nominal rigidities, inflation-indexed DB pension funds cause workers to be negatively affected by adverse shocks, while workers are less positively affected by positive shocks. As a result, the appeal of inflation-indexed DB pension funds (which are closest in design to the pension funds that have been studied in environments without nominal rigidities) is dampened. Thus, the message of Gollier (2008), which stresses that maintaining intergenerational risk-sharing through pension funds after poor capital market performance requires strong government commitment (because younger generations will want to abolish it), becomes even more of a concern in a New-Keynesian setting.

This chapter is structured as follows. Section 3.2 describes the workings of the pension fund, the decision problems of retirees and workers, the supply side of the economy and the actions of fiscal and monetary authorities. Section 3.3 discusses the calibration of the model, analyses the effects of pension fund restoration policy on the rest of the economy and discusses the welfare implications after an unexpected shock to capital quality. Section 3.4 concludes. Technical details are delegated to the appendices.

3.2 Model

The economy is populated by a pension fund, workers, retirees, capital producers, final, intermediate and retail good producers, and a central bank. Workers face a constant probability of becoming retired and retirees face a constant probability of passing away. We invoke RINCE preferences which restrict workers and retirees to be risk neutral, but which allow them to have any arbitrary intertemporal elasticity of substitution. This class of preferences yields that all workers and retirees that are in the same life-cycle stage consume an identical fraction of their total lifetime wealth, irrespective of their age or the amount of wealth they possess, which facilitates aggregation despite the heterogeneity of workers and retirees at the micro-level. In each period, workers and retirees decide how much to consume, labour to supply and to save. When earning labour income, individuals pay a mandatory contribution to the pension fund and in return accumulate pension wealth in the form of an annuity that is inflation-indexed or non-indexed. The annuity, also referred to as the per-period pension benefit, is paid out by the pension fund each period in which the individual is retired. The size of the annuity is not constant over time, but changes when individuals pay pension contributions and when the pension fund writes down or marks up the value of previously accumulated pension wealth. The pension fund sets the contribution rate on labour income, the accumulation rate of the annuity and the revaluation instrument (which together comprise its restoration policy)
depending on its financial position. The production sectors of the economy are of the New- Keynesian form and subject to investment adjustment costs, imperfect competition in the retail sector and nominal Calvo (1983)-pricing rigidities. The timing of the model is such that an unexpected shock to capital quality (inspired by Gertler & Karadi (2011)) might materialise at the start of the period. The pension fund then announces its restoration policy. Afterwards individuals and firms optimise taking into account the capital quality shock and the policy of the pension fund.

3.2.1 Demographic structure

We consider a unit mass of individuals that is split up in two distinct groups. As in Gertler (1999), individuals have finite lives and flow through two consecutive stages of life: work and retirement. Each individual is born as a worker and conditional on being a worker in the current period, the probability of remaining one in the next period is $\omega$ and the probability of becoming retired in the next period is $1 - \omega$. Upon reaching retirement, the probability of surviving until the next period is $\gamma$ and the probability of death is $1 - \gamma$. In order to facilitate aggregation within each group, we assume that the probabilities of retirement and death are independent of age. Furthermore, we assume that the number of individuals within each cohort is ‘large’. Denote by $N^w$ the stock of workers and by $N^r$ the stock of retirees. We focus on the steady state of the demographics in which the stock of workers and retirees is stable. Since each period a share $1 - \omega$ of workers retires, we assume that $(1 - \omega)N^w$ workers are born each period. In order to keep the stock of retirees constant, we need that $N^r = (1 - \omega)N^w + \gamma N^r$. This holds when we start out with the (old-age) dependency ratio $\psi = \frac{N^r}{N^w} = \frac{1 - \omega}{1 - \gamma}$.

3.2.2 Pension fund

The fund aims to achieve a certain funding rate (the ratio of its assets to liabilities). If its funding rate is below target, the pension fund faces a deficit and has to restore the balance between its assets and its liabilities. We refer to the specific menu of the announced contribution, accumulation and revaluation rate as the restoration policy of the pension fund. The other agents in the model will not be able to influence this decision, because the pension fund announces its policy before other agents make their decisions, participation in the pension scheme is mandatory for the retirees and workers, and the number of individuals within each cohort is ‘large’. We allow for flexibility in pension system design

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1 The assumption of a ‘large’ number of retirees and workers ensures that the contributions of a single agent have negligible effects on the financial position of the pension fund. Mandatory participation
along various dimensions. Depending on the parametrisation, we fix the target funding rate, the type of pension fund accounting framework, the recovery speed when the funding rate deviates from the target funding rate and the instruments used to restore financial adequacy.

### 3.2.2.1 Pension fund accounting

Since the restoration policy of the pension fund is determined at the start of the period, we use beginning-of-period notation for the state variables relevant to the finances of the pension fund (contrary to the end-of-period notation used later in the model for the savings of individuals and the capital stock of the economy).

**Pension fund liabilities** At the start of period $t$, the liabilities of the pension fund are given by the present discounted value of the previously accumulated pension wealth of currently alive workers and retirees:

$$L_t^f = R_t^{r,f} B_t^r + R_t^{w,f} B_t^w,$$

which is the sum of the size of the accumulated annuity of the group of retirees $B_t^r$ and workers $B_t^w$ multiplied by the corresponding annuity factors $R_t^{r,f}$ and $R_t^{w,f}$. $B_t^r$ and $B_t^w$ denote the real number of per-period pension benefits that the group of retirees and workers receive each period in which they are retired. The annuity factors denote the real present discounted value of the expected lifetime payment by the pension fund to a fund participant per unit of accumulated per-period pension benefits. The pension fund liabilities are affected by the capital quality shock through the real interest rate. Note that the revaluation and accrual of pension benefits from period $t$ onwards do not yet belong to the liabilities of the pension fund at the start of the period. This is in accordance with Novy-Marx & Rauh (2011) who recognise the Accumulated Benefit Obligation (ABO) as a proper definition of the liabilities of a pension fund. Even if the pension fund would be completely frozen, the ABO would denote the current value of accrued pension benefits still contractually owed to pension fund participants.

guarantees that the pension fund does not collapse in case of underfunding or overfunding. Beetsma et al. (2013) show that newly born workers would not want to participate in case the pension fund is underfunded as they would have to help restore funding adequacy, while van Bommel & Penalva (2012) show that older agents have an incentive to block newly born workers from participating in case the pension fund is overfunded so as to capture the funding surplus for themselves.
The evolutions of the annuities are given by:

\[(\Pi_t)^{\text{acc}} B^r_t = \gamma \left( \mu_t - 1 B^r_{t-1} + \nu_t L^r_{t-1} \right) + (1 - \omega) \left( \mu_t - 1 B^w_{t-1} + \nu_t L^w_{t-1} \right), \] (3.2)

\[(\Pi_t)^{\text{acc}} B^w_t = \omega \left( \mu_t - 1 B^w_{t-1} + \nu_t L^w_{t-1} \right), \] (3.3)

where \( \Pi_t \) denotes the gross inflation from period \( t-1 \) till \( t \), \( \mu_t \) is the revaluation instrument, \( \nu_t \) the accrual rate on labour income, \( \xi \in (0,1] \) the relative productivity of retirees, \( w_t \) the wage rate, \( L^r_t \) the labour supply of the group of retirees and \( L^w_t \) the labour supply of the group of workers. Due to the assumption that the number of individuals within each cohort is ‘large’ and since each period a fraction \( 1 - \gamma \) of retirees deceases, \( B^r_t \) contains a \( \gamma \) share of the accumulated annuity of the group of retirees at the end of period \( t-1 \). Additionally, since each period a fraction \( 1 - \omega \) of workers retires, \( B^r_t \) contains a \( 1 - \omega \) share of the accumulated annuity of the group of workers at the end of period \( t-1 \). The remaining \( \omega \) share is contained in \( B^w_t \), while newborn workers in period \( t \) start out without any previously accumulated pension wealth. In the real accounting framework, \( \text{acc} = 0 \). In the nominal accounting framework individuals accumulate nominal pension wealth and therefore \( \text{acc} = 1 \) to adjust the real value of the annuities \( B^r_t \) and \( B^w_t \) for the change in the price level.

The pension fund annuity factors are given by:

\[ R^r_{t,f} = 1 + \frac{\gamma}{(\Pi_{t+1})^{\text{acc}} (1 + r_{t+1})} R^r_{t+1,f}, \] (3.4)

\[ R^w_{t,f} = \frac{1}{(\Pi_{t+1})^{\text{acc}} (1 + r_{t+1})} \left( \omega R^w_{t+1,f} + (1 - \omega) R^r_{t+1,f} \right). \] (3.5)

\( R^r_{t,f} \) denotes the real present discounted value of the expected lifetime payment by the pension fund to a retiree per unit of accumulated per-period pension benefits (similarly for \( R^w_{t,f} \)). The pension fund discounts future pension payments at the real interest rate in the real accounting framework. In the nominal accounting framework, the pension fund instead discounts future pension payments at the nominal interest rate, where we use the Fisher relation \( 1 + i_t = \Pi_{t+1}(1 + r_{t+1}) \). We can interpret \( R^r_{t,f} \) and \( R^w_{t,f} \) as ‘no policy’ annuity factors, because the pension fund assumes \( \mu_{t+i} = 1, i = 0,1,2,... \) when determining them. This reflects a ‘normal’ course of action in which the pension fund fully covers extended promises to retirees and workers and is in accordance with the definition of the ABO by Novy-Marx & Rauh (2011).

**Pension fund assets** The assets of the pension fund are comprised of the paid contributions by workers and retirees, which are invested in the capital stock of the economy.
Each period, the pension fund receives the pension contributions $\tau_t w_t L_t$, where $\tau_t$ denotes the contribution rate on labour income and $L_t$ denotes the aggregate labour supply, and pays out $\mu_{t-1} B^r_{t-1}$ to the currently retired. The pension fund starts out in period $t-1$ with $A^f_{t-1}$ worth of assets and receives a return on its investment in the capital stock of $1 + r_t$.

The pension fund assets are affected by the capital quality shock through the real interest rate. This gives the following recursive formulation for the pension fund capital:

$$A^f_t = (1 + r_t) \left( A^f_{t-1} + \tau_{t-1} w_{t-1} L_{t-1} - \mu_{t-1} B^r_{t-1} \right). \quad (3.6)$$

When discussing the pension fund policy in section 3.2.2.2 it will be useful to have a recursive definition of the liabilities of the pension fund. We can achieve this by substituting identities (3.2-3.5) in (3.1):

$$L^f_t = (1 + r_t) \left( \mu_{t-1} L^f_{t-1} + (R^r_{t-1} - 1) \nu_{t-1} \xi w_{t-1} L^r_{t-1} + R^w_{t-1} \nu_{t-1} w_{t-1} L^w_{t-1} - \mu_{t-1} B^r_{t-1} \right), \quad (3.7)$$

which states that the pension fund liabilities at the start of period $t$ are equal to the current value of the revalued liabilities of the previous period $\mu_{t-1} L^f_{t-1}$, plus the real present discounted value of newly issued pension entitlements to retirees $(R^r_{t-1} - 1) \nu_{t-1} \xi w_{t-1} L^r_{t-1}$ and workers $R^w_{t-1} \nu_{t-1} w_{t-1} L^w_{t-1}$, minus the fulfilled pension promises to retirees $\mu_{t-1} B^r_{t-1}$.

### 3.2.2.2 Pension fund restoration policy

Pension fund regulations generally stipulate that pension funds should attain a target funding rate $\bar{f}r$ in the long term, which is the ratio of the steady state value of the assets of the pension fund to its liabilities. Additionally, regulations prescribe that any funding surplus or deficit should be reduced over time to ensure that the pension fund does not run out of assets and that participation constraints are not a concern. To replicate such regulations in our model, we suppose that the policy of the pension fund is set to reduce the funding gap of the next period to a fraction $\upsilon$ of the current funding gap:

$$A^f_{t+1} - \bar{f}r L^f_{t+1} = \upsilon (A^f_t - \bar{f}r L^f_t), \quad (3.8)$$

where the funding gap is to be closed within one period if $\upsilon = 0$ and the funding gap is gradually closed over time if $0 < \upsilon < 1$. To get a better picture of how the contribution rate on labour income ($\tau$), the accumulation rate of pension rights ($\nu$) and the revaluation of previously accumulated pension wealth ($\mu$) relate to the closure of the funding gap, we
roll over (3.6) and (3.7) by one period and substitute them into (3.8) to obtain:

\[
\frac{1 + r_{t+1} - \nu}{1 + r_{t+1}} \left( A_t^f - \bar{f} r L_t^f \right) = \\
\bar{f} r \left( 1 - \frac{\bar{f} r}{f r} \mu_t B_t^r + (\mu_t - 1) L_t^f + \nu_t w_t \left( (R_{t}^{r,f} - 1) \xi_t L_t^r + R_{t}^{w,f} L_t^w \right) \right) - \tau_t w_t L_t^r, \quad (3.9)
\]

where the left-hand side denotes the ‘gap to be filled’ and the right-hand side specifies the ways in which the pension fund can do so. For instance, if \( A_t^f < \bar{f} r L_t^f \) the pension fund can reduce the funding gap by writing down the value of previously accumulated pension rights (\( \mu_t < 1 \)), hiking the contribution rate (increase \( \tau_t \)) or lowering the accumulation of new pension benefits (decrease \( \nu_t \)).\(^2\) Note that when \( 0 < \bar{f} r < 1 \) a pay-as-you-go element is introduced in the funded pension system. Since in the steady state the assets of the pension fund are smaller than its liabilities the pension fund pays out a larger portion of the currently paid contributions directly to retirees. This is reflected in the term \( \frac{1 - \bar{f} r}{f r} \mu_t B_t^r > 0 \) when \( 0 < \bar{f} r < 1 \).

### 3.2.2.3 Various types of pension systems

The pension fund structure nests a range of different existing pension systems. In the simulations below, we will analyse the following three types of pension systems: Laissez-Faire, DC and DB. For each system we will discuss what type of restoration policy the pension fund implements when it faces a funding gap.

- **Laissez-Faire (also known as Individual DC):** In this pension arrangement there effectively is no pension system; agents save for their own retirement. The pension fund does not levy contributions (\( \tau_t = 0, \forall t \)), agents do not build up pension benefits (\( \nu_t = 0, \forall t \)) and \( A_t^f = L_t^f = 0, \forall t \). This Laissez-Faire system can also be referred to as an Individual DC pension system where agents save via a private account. Agents reap a private return on the capital market (contrary to the collective return that would be reaped through the pension fund) and are entirely exposed to any unanticipated changes to the value of their retirement savings. This pension arrangement will serve as a benchmark for the other two types of pension systems.

- **DC (also known as Collective DC):** In this pension arrangement, the contri-\(^2\)Note that in reasonable scenarios \( \frac{1 + r_{t+1} - \nu}{1 + r_{t+1}} > 0 \).
butions to the pension fund and the accrual of pension benefits are predetermined. The fund thus fixes the contribution rate \((\tau_t = \bar{\tau}, \forall t)\) and accrual rate \((\nu_t = \bar{\nu}, \forall t)\) on labour income, where \(\bar{\tau}\) and \(\bar{\nu}\) denotes the steady state values of the contribution and accrual rate, respectively. The revaluation instrument \(\mu\) is used to close the funding gap in accordance with condition (3.9). Since retirees are most reliant on receiving pension benefits, they will be severely affected in case of an adverse shock to capital quality.

- **DB:** In this pension arrangement, the fund fixes the revaluation instrument \(\mu_t = 1, \forall t\) and the accrual rate on labour income \(\nu_t = \bar{\nu}, \forall t\) so that it fully covers extended pension promises to fund participants (either in a real or nominal sense, depending on the accounting framework). The contribution rate \(\tau\) is used to close any funding gap in accordance with condition (3.9). When the pension fund guarantees the value of accumulated pension benefits, the retirees are relatively unaffected by an adverse capital quality shock. On the other hand, workers are made responsible for the closure of the funding gap through an increase in contribution payments, forcing them to contribute more than what they are expected to receive in return. Since the pension fund contributions are levied as a fraction of labour income, the DB pension fund distorts labour supply decisions and therefore has substantial consequences for other macroeconomic variables such as output.

The pension systems described above are extreme cases: either there is effectively no pension fund, or if there is a pension fund, the funding gap is closed using one instrument exclusively. Romp (2013) shows that it is possible to add weighting factors to (3.9) to create a hybrid system that is a convex combination of the two extremes. However, any such convex combination will give impulse responses that lie between the extreme cases of DC and DB. To highlight the macroeconomic effects of various types of pension fund restoration policy we elect to focus on these extreme cases.

### 3.2.3 Decision problems of workers and retirees

Individuals face two types of idiosyncratic risk throughout their life cycle. Firstly, workers might become retired in the next period, which constitutes an income loss due to the assumed lower productivity of retirees. Secondly, retirees face the uncertainty about their time of death. Similar to Blanchard (1985), we introduce annuity markets that shelter retirees from the risk of the timing of death. Upon retirement, individuals hand over their private savings to a perfectly competitive mutual fund that invests the proceeds in the market and promises a return \(\frac{1+r}{\gamma}\) only to those who survive until the next period. Since
the return of the mutual fund dominates the return of the market, all retiring individuals
decide to hand over their private savings. Additionally, the existence of the mutual fund
ensures that there are no accidental bequests that need to be distributed over the surviving
individuals. While it is possible to introduce an insurance market that mitigates the risk
of income loss as a result of retirement, doing so would allow individuals to smooth their
labour income over their life cycle and in turn would kill the life-cycle structure that we aim
to impose. Instead, we specify that individuals are risk neutral with respect to income
risk. Since the income risk in this model follows from the mechanical assumption of a
constant transition probability into retirement, individuals have risk neutral preferences
so as to decrease the impact of income variation in the model.

Let $V^z(a^z_{t-1}, b^z_t)$ be the value function of a particular individual at period $t$, where
$z = \{r, w\}$ indicates whether the individual is a retiree ($r$) or a worker ($w$) in that period,
$a^z_{t-1}$ denotes the number of consumption goods saved and $b^z_t$ denotes the accumulated
pension annuity at the start of period $t$. Preferences of retirees and workers are of the
RINCE (Risk Neutral Constant Elasticity) type and given by:

$$
\left( \left( (c^r_t)^v (1 - l^r_t)^{1-v} \right)^{\rho} + \gamma \beta \left[ V^r(a^r_t, b^r_{t+1}) \right]^{\rho} \right)^{1\over\rho},
$$

$$
\left( \left( (c^w_t)^v (1 - l^w_t)^{1-v} \right)^{\rho} + \beta \left[ \omega V^w(a^w_t, b^w_{t+1}) + (1 - \omega)V^r(a^r_t, b^r_{t+1}) \right]^{\rho} \right)^{1\over\rho},
$$

where $c^z_t$ and $l^z_t$ denote consumption and labour supply, respectively. Each individual has
one unit of time and enjoys $1 - l^z_t$ units of leisure. The curvature parameter $\rho$ implies that
individuals have a desire to smooth consumption over time. As shown by Farmer (1990),
$\sigma = \frac{1}{1-\rho}$ is the familiar intertemporal elasticity of substitution. The RINCE preferences
restrict individuals to be risk neutral with respect to income risk, but allow them to have
any arbitrary intertemporal elasticity of substitution. Since we motivate the presence of
income risk on the mechanical grounds of generating meaningful life-cycle behaviour, it is
favourable that this class of preferences allows for meaningful preferences with respect to
smoothing income over time. Additionally, the specification of RINCE preferences allows
us to aggregate the behaviour of workers and retirees.

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3The state variable $b^z_t$ contains the time subscript $t$ as $b^z_t$ can depend on the inflation $\Pi_t$ in the nominal
accounting framework. Additionally, recall that $a^z_{t-1}$ is written in end-of-period notation, but that $b^z_t$ is
written in beginning-of-period notation.

4We allow retirees to supply labour and to accumulate additional pension benefits when retired, making
the term ‘retiree’ a relatively poor descriptor. Allowing retirees to continue to be active on the labour
market makes the decision problem of retirees conveniently similar to the one of workers. Retirees will
be less productive than workers and we will parametrise the productivity parameter such that the labour
supply of retirees is close to zero.

5The preference class ensures that we do not have to keep track of the period in which agents are
born and in which period agents become retired. We can instead consider the groups of workers and
3.2.3.1 Retiree decision problem

A retiree, who is indexed by \( i \), maximises objective the following objective in period \( t \):

\[
V_{r,i}(a_{t-1}^{r,i}, b_{t}^{r,i}) = \max_{c_{t}^{r,i}, l_{t}^{r,i}, a_{t}^{r,i}, b_{t}^{r,i}} \left( \left( c_{t}^{r,i} \right)^{(1 - l_{t}^{r,i})^{1-v}} + \gamma \beta \left[ V_{r,i}(a_{t}^{r,i}, b_{t+1}^{r,i}) \right]^\rho \right)^{1/\rho},
\]

subject to:

\[
a_{t}^{r,i} = \frac{1 + r_{t}^{i} a_{t-1}^{r,i}}{\gamma} + (1 - \tau_{t}) \xi w_{t} l_{t}^{r,i} + \mu_{t} b_{t}^{r,i} - c_{t}^{r,i},
\]

\[
b_{t+1}^{r,i} = \frac{\mu_{t} b_{t}^{r,i} + \nu_{t} \xi w_{t} l_{t}^{r,i}}{(\Pi_{t+1})^{acc}},
\]

where \( a_{t}^{r,i} \) are the private savings of the retiree at period \( t \), yielding a return of \( \frac{1 + r_{t+1}^{i}}{\gamma} \) in period \( t + 1 \) through the mutual fund, and \( r_{t} \) is the real interest rate on savings from period \( t - 1 \) till period \( t \). The private financial wealth of the retiree is given by \( \frac{1 + r_{t}^{i} a_{t-1}^{r,i}}{\gamma} \) and \( b_{t}^{r,i} \) is the size of the retiree annuity. The effective wage rate of the retiree is given by \( \xi w_{t} \). When working the retiree pays a mandatory contribution to the pension fund equal to a share \( \tau_{t} \) of labour income. In return his annuity \( b_{t+1}^{r,i} \) increases by a share \( \nu_{t} \) of labour income. The retiree receives his previously accumulated annuity \( \mu_{t} b_{t}^{r,i} \) from the pension fund, which is corrected for the revaluation instrument \( \mu_{t} \) and the inflation \( \Pi_{t} \) in the nominal pension fund accounting framework). The retiree, when deciding on his optimal amount of labour to supply and goods to consume, takes as given the financial position of the pension fund and thus the future path of its policy.\(^6\)

Section 3.5.1.1 shows that the decision problem of the retiree gives rise to the following two conditions:

\[
c_{t+1}^{r,i} = \left( \beta(1 + r_{t+1}) \left( \frac{(1 - \tau_{t}^{r}) w_{t}}{(1 - \tau_{t+1}^{r}) w_{t+1}} \right)^{(1-v)\rho} \right) c_{t}^{r,i}, \tag{3.10}
\]

\[
1 - l_{t}^{r,i} = \frac{1 - v}{v} \frac{c_{t+1}^{r,i}}{(1 - \tau_{t}^{r}) \xi w_{t}}, \tag{3.11}
\]

where (3.10) is the retiree Euler equation and (3.11) the optimal labour supply decision. The term \( \tau_{t}^{r} = \tau_{t} - (R_{t}^{r} - 1) \nu_{t} \) is the effective labour income contribution rate that the retiree faces, where \( R_{t}^{r} \) is the retiree annuity factor which denotes the expected real present reitreers as a collective rather than comprised of a range of agents born in different periods. This keeps the state-space of the model small and simplifies aggregation.

\(^6\)This specification of the budget constraint assumes that the retiree was retired already in the previous period. Kara & von Thadden (2016) show that this characterisation is sufficient to derive the aggregate behaviour of retirees and workers.
discounted value to a retiree of receiving a consumption good each period until death, corrected for revaluation (and inflation in the nominal accounting framework). Depending on the pension fund restoration policy the effective contribution rate $\tau^r$ acts as either an effective tax ($\tau^r > 0$) or subsidy ($\tau^r < 0$) on labour income. We define the retiree annuity factor as:

$$R^r_t = 1 + \mu_{t+1} \frac{\gamma}{\Pi_{t+1}^{acc}} (1 + r_{t+1}) R^r_{t+1}.$$  

The retiree annuity factor differs from $R^r_{t,f}$ due to the inclusion of the future path of the revaluation instrument $\mu$ (which was omitted from $R^r_{t,f}$ for supervision purposes). Whereas $R^r_{t,f}$ is to be interpreted as a ‘no policy’ annuity factor used by the pension fund to determine the restoration policy of the current period, the retiree takes into account the future path of the pension fund restoration policy when determining how much labour to supply and how much to consume.

Let $\Delta^r_t$ denote the inverse of the marginal propensity to consume out of wealth (MPCW) of a retiree and let $x^r_{t,i} \equiv c^r_{t,i} + (1 - \tau^r_t)\xi w_t (1 - l^r_{t,i}) = \frac{c^r_{t,i}}{v}$ denote retiree full consumption. Additionally, let retiree full income $d^r_{t,i}$ and retiree human wealth $h^r_{t,i}$ be defined as:

$$d^r_{t,i} = (1 - \tau^r_t)\xi w_t,$$  

$$h^r_{t,i} = d^r_{t,i} + \frac{\gamma}{1 + r_{t+1}} h^r_{t+1}.  \tag{3.13}$$

Section 3.5.1.1 shows that full consumption and the inverse MPCW out of wealth of a retiree satisfy the following two conditions:

$$x^r_{t,i} = \frac{1}{\Delta^r_t} \left( \frac{1 + r_t}{\gamma} a^r_{t-1,i} + h^r_{t,i} + \mu_t b^r_{t,i} R^r_t \right),  \tag{3.14}$$

$$\Delta^r_t = 1 + \gamma^{\sigma} \Delta^r_{t+1} \left(1 + r_{t+1} \right) \left( \frac{(1 - \tau^r_t)w_t}{((1 - \tau^r_{t+1})w_{t+1})} \right)^{1-v} \sigma^{-1}.  \tag{3.15}$$

Retirees spend a fraction $\frac{1}{\Delta^r_t}$ of their total lifetime wealth on consumption goods and leisure. Retiree total lifetime wealth consists of the sum of private financial wealth $\frac{1 + r_t}{\gamma} a^r_{t-1,i}$, human wealth $h^r_{t,i}$ (which contains the expected value of pension wealth to be accumulated in the future) and previously accumulated pension wealth $\mu_t b^r_{t,i} R^r_t$. Since the inverse MPCW of a retiree is the same for all retirees, irrespective of age and total lifetime wealth, aggregation over retirees will be straightforward. Section 3.5.1.1 shows that (3.14) and (3.15) can be used to derive an analytical expression for the indirect retiree value.
function:
\[ V_{t}^{r,i} = (\Delta_{t}^{r})^{{\frac{1}{\sigma}}} v x_{t}^{r,i} \left( \frac{1 - v}{v} \frac{1}{(1 - \tau_{t}^{r})\xi_{t}^{r}} \right)^{1-v}. \]

### 3.2.3.2 Worker decision problem

A worker, who is indexed by \( j \), maximises the following objective in period \( t \):

\[
V^{w,j}(a_{t-1}^{w,j}, b_{t+1}^{w,j}) = \max \left( \left( c_{t}^{w,j} \right)^{\eta} (1 - l_{t}^{w,j})^{1-\eta} \right)^{\rho} + \beta \left[ \omega V^{w,j}(a_{t-1}^{w,j}, b_{t+1}^{w,j}) + (1 - \omega) V^{r,j}(a_{t}^{w,j}, b_{t+1}^{w,j}) \right]^{\rho},
\]

subject to:

\[
a_{t}^{w,j} = (1 + r_{t}) a_{t-1}^{w,j} + (1 - \tau_{t}) w_{t} l_{t}^{w,j} + f_{t}^{w,j} - c_{t}^{w,j},
\]

\[
b_{t+1}^{w,j} = \frac{\mu_{t} b_{t}^{w,j} + \nu_{t} w_{t} l_{t}^{w,j}}{(\Pi_{t+1})^{\alpha_{t}}}.
\]

where \( a_{t}^{w,j} \) are the private savings of the worker at the end period \( t \) and \( b_{t+1}^{w,j} \) is the size of the worker annuity at the start of period \( t + 1 \). The private financial wealth of the worker is given by \((1 + r_{t}) a_{t-1}^{w,j}\) and the worker receives profits \( f_{t}^{w,j} \) from the intermediate and capital good producing firms. Section 3.5.1.2 shows that the decision problem of the worker gives rise to the following two conditions:

\[
\omega c_{t+1}^{w,j} + (1 - \omega) c_{t}^{w,j} \left( \frac{1 - \tau_{t+1}^{w}}{1 - \tau_{t+1}^{r}} \right)^{1-v} \left( \frac{\Delta_{t+1}^{w}}{\Delta_{t+1}^{r}} \right)^{\frac{1}{\sigma}} = \frac{\beta (1 + r_{t+1}) \Omega_{t+1} \left( (1 - \tau_{t+1}^{w}) w_{t} \right) \left( \frac{1 - \tau_{t+1}^{w}}{1 - \tau_{t+1}^{w}} w_{t+1} \right) \left( 1 - \tau_{t+1}^{r} \right)^{(1-v)^{\rho}}}{(1 - \tau_{t+1}^{r} \xi_{t+1})^{\sigma}}, \tag{3.16}
\]

\[
1 - l_{t}^{w,j} = \frac{1 - v}{v} \frac{c_{t}^{w,j}}{(1 - \tau_{t}^{w}) w_{t}}, \tag{3.17}
\]

where we define:

\[
\Omega_{t} = \omega + (1 - \omega) \left( \frac{1 - \tau_{t}^{w}}{1 - \tau_{t}^{r}} \right)^{1-v} \left( \frac{\Delta_{t}^{w}}{\Delta_{t}^{r}} \right)^{\frac{1}{\sigma}}.
\]

The worker Euler equation (3.16) shows that the worker takes into account that he might become retired in period \( t + 1 \). The term \( \Omega_{t} \) reflects that a worker, when switching into retirement, reaches the next (and irreversible) stage in his life cycle. The retirement
stage is characterised by a different effective wage rate (captured by $\xi$), MPCW (captured by $\Delta^w_t$ and $\Delta^r_t$) and effective pension fund contribution rate on labour income (captured by $\tau^r$ and $\tau^w$). The effective worker contribution rate is given by $\tau^w_t = \tau_t - R^w_t \nu_t$ and, similarly to the retiree effective contribution rate, reflects the balance between the costs ($\tau_t$) and the benefits ($R^w_t \nu_t$) of the mandatory pension fund participation to the worker.

We define the worker annuity factor as:

$$R^w_t = \frac{\mu_{t+1}}{(\Omega_{t+1})^{\mu_{t+1}}(1 + r_{t+1}) \left( \frac{\omega}{\Omega_{t+1}} R^w_{t+1} + \left(1 - \frac{\omega}{\Omega_{t+1}}\right) R^r_{t+1} \right)}.$$

The worker annuity factor denotes the expected real present discounted value to a worker of receiving one consumption good each period when retired until death, corrected for revaluation (and inflation in the nominal accounting framework). The definition of $R^w_t$ shows that the term $\Omega_t$ can be interpreted as a subjective reweighting of transition probabilities. The irreversible event of transitioning into retirement entails an income shock for the individual and implies that the worker attaches more importance to receiving income when retired compared to remaining a worker in future periods. This is reflected by the fact that the worker attaches a subjective transition probability of $\frac{\omega}{\Omega_{t+1}}$ (compared to the objective probability $\omega$) to income received when remaining a worker in period $t + 1$ and a subjective transition probability of $1 - \frac{\omega}{\Omega_{t+1}}$ (compared to the objective probability $1 - \omega$) when becoming a retiree in period $t + 1$. The worker annuity factor $R^w_t$ thus does not only differ from $R^{w,f}_t$ due to the inclusion of the future path of the revaluation instrument $\mu$, but also due to the subjective reweighting of transition probabilities of the worker. The pension fund is an ongoing concern, which does not have a life-cycle motive like workers do, and uses the objective transition probabilities for the calculation of the annuity factor $R^{w,f}_t$.

Gertler (1999) shows that the subjective reweighting of transition probabilities causes the Ricardian equivalence to break down in this type of model. The path of government debt influences macroeconomic outcomes and therefore the pension fund is also non-Ricardian. The pension fund also influences macroeconomic outcomes by introducing a new asset in the economy. When workers invest private financial wealth in the capital stock of the economy they obtain the same return regardless of their life-cycle stage in the next period. In the absence of the pension fund, workers thus cannot invest in an asset that yields a return conditional on whether they are a retiree or a worker in the next period. The pension fund introduces such an asset: it only pays out the accumulated pension benefits when the worker is retired and the mandatory investment in the

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7In our calibration it will hold that $\Omega_t > 1, \forall t$. 

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pension fund thus yields a return that is conditioned on the specific life-cycle stage of the individual. Workers cannot replicate this when they invest private financial wealth in the capital stock.

Let $\Delta_w^r$ denote the inverse of the MPCW of a worker and let $x_{t}^{w,j} \equiv c_{t}^{w,j} + (1 - \tau_{t}^w)w_{t}(1 - l_{t}^{w,j}) = \frac{c_{t}^{w,j}}{\Delta_w^r}$ denote worker full consumption. Additionally, let worker full income $d_{t}^{w,j}$ and worker human wealth $h_{t}^{w,j}$ be defined as:

$$d_{t}^{w,j} = (1 - \tau_{t}^w)w_{t} + f_{t}^{w,j},$$

$$h_{t}^{w,j} = d_{t}^{w,j} + \frac{1}{1 + r_{t+1}} \left( \frac{\omega}{\Omega_t+1} h_{t+1}^{w,j} + (1 - \frac{\omega}{\Omega_t+1}) h_{t+1}^{r,j} \right).$$

Section 3.5.1.2 shows that the full consumption function and inverse MPCW of a worker satisfy the following two conditions:

$$x_{t}^{w,j} = \frac{1}{\Delta_w^r} \left( (1 + r_t) a_{t-1}^{w,j} + h_{t+1}^{w,j} + \mu_t b_{t}^{w,j} R_t^w \right),$$

$$\Delta_w^r = 1 + \beta^\sigma \Delta_{t+1}^w \left( (1 + r_{t+1}) \Omega_t+1 \left( \frac{(1 - \tau_{t}^w)w_{t}}{(1 - \tau_{t+1}^w)w_{t+1}} \right)^{1-v} \right)^{\sigma-1}. \quad (3.21)$$

Workers spend a fraction $\frac{1}{\Delta_w^r}$ of their total lifetime wealth on consumption goods and leisure. Worker total lifetime wealth is comprised of the sum of private financial wealth $(1 + r_t) a_{t-1}^{w,j}$, human wealth $h_{t}^{w,j}$ (which contains the expected value of pension wealth to be accumulated in the future) and previously accumulated pension wealth $\mu_t b_{t}^{w,j} R_t^w$. Since the inverse MPCW of a worker is the same for all workers, irrespective of age and total lifetime wealth, aggregation over workers will be straightforward. Section 3.5.1.2 shows that (3.21) and (3.22) can be used to derive an analytical expression for the indirect worker value function:

$$V_{t}^{w,j} = (\Delta_{t+1}^w)^{-\frac{1}{\sigma}} \nu x_{t}^{w,j} \left( \frac{1 - v}{v} \frac{1}{(1 - \tau_{t}^w)w_{t}} \right)^{1-v}. \quad (3.22)$$

### 3.2.3.3 Aggregation over retirees and workers

Aggregate variables are identified by the lack of a superscript $i$ and $j$ and are written in capital letters. We start by aggregating human wealth and private financial wealth and afterwards aggregate the consumption and labour supply functions. Recall that the aggregate annuities of the retirees $B_r^r$ and workers $B_r^w$ are defined recursively by conditions (3.2) and (3.3). Aggregate full income of retirees and workers satisfies:

$$D_r^i = N^r(1 - \tau_r^i)\xi w_t,$$
where \( F_t \) denotes the aggregate profits of the intermediate and capital good producers and is specified by condition (3.56). Note that we do not have to specify how firm profits are distributed over individual workers due to the structure of the derived worker consumption function. Aggregate human wealth of retirees and workers satisfies:

\[
H'_t = D'_t + \frac{\gamma}{1 + r_{t+1}} H'_{t+1},
\]

\[
H''_t = D''_t + \frac{1}{1 + r_{t+1}} \left( \frac{\omega}{\Omega_{t+1}} H''_{t+1} + (1 - \frac{\omega}{\Omega_{t+1}}) \frac{1}{\psi} H''_{t+1} \right).
\]

Aggregate private savings of retirees and workers can be defined recursively:

\[
A'^r_t = (1 + r_t) A'^r_{t-1} + \mu_t B'^r_t + (1 - \tau_t) \xi_t w_t L'^r_t - C'^r_t + \frac{1 - \omega}{\omega} A'^w_t, \tag{3.23}
\]

\[
A'^w_t = \omega \left( (1 + r_t) A'^w_{t-1} + (1 - \tau_t) w_t L'^w_t + F_t - C'^w_t \right). \tag{3.24}
\]

Condition (3.23) shows that the aggregate private savings of the retired in period \( t+1 \) consists of two parts. Firstly, it consists of the sum of income that was not spent by retirees in period \( t \). The lack of a multiplication by \( \gamma \) reflects that all savings by retirees in period \( t \) are transferred to the surviving retirees in period \( t+1 \). On the level of the group of retirees, private financial wealth invested in the capital stock of the economy yields a return of \( 1 + r_t \). Secondly, it consists of the sum of income not spent in period \( t \) by those workers who become retired in period \( t+1 \). The remainder of the sum of income not spent in period \( t \) by workers is given by (3.24), since newly born workers start out without private savings. Having specified retiree and worker private savings, human wealth and pension wealth, we arrive at the aggregate full consumption functions:

\[
X^z_t = \frac{1}{\Delta_t} \left( (1 + r_t) A^z_{t-1} + H^z_t + \mu_t B^z_t R^z_t \right), \quad z \in \{w, r\}. \tag{3.25}
\]

Aggregate consumption of retirees, workers and total population satisfies:

\[
C^z_t = v X^z_t, \quad z \in \{w, r\},
\]

\[
C_t = C'^w_t + C'^w_t.
\]

Aggregate labour supply of retirees, workers and total population satisfies, where \( w^r_t = \)
\[ \xi w_t \text{ and } w_t^w = w_t: \]

\[ L^z_t = N^z - \frac{(1 - \nu) X^z_t}{(1 - \tau^w_t) w^z_t}, \quad z \in \{w, r\}, \]

\[ L_t = L^w_t + \xi L^r_t. \]

Aggregate welfare of retirees and workers satisfies:

\[ V^z_t = (\Delta^z_t)^{\frac{1}{\rho}} v X^z_t \left( \frac{1 - \nu}{v} \frac{1}{(1 - \tau^z_t) w^z_t} \right)^{1-v}, \quad z \in \{w, r\}. \quad (3.26) \]

### 3.2.4 Firms and government

The supply-side of the economy is modelled in a familiar New-Keynesian fashion. Intermediate good producing firms borrow from the households and the pension fund to purchase the capital necessary for production. The revenue generated from the sale of the output to retail firms and of the capital after it has been used is spent on the wages of households and used to pay back the loans from households and the pension fund. Capital producing firms buy the used capital and transform it, together with goods purchased from final good producing firms, into new capital. This new capital is sold to intermediate good producing firms who will use it for production in the next period. While intermediate good producing firms do not face investment adjustment costs at the firm level, the capital producing sector is subject to investment adjustment costs à la Fernández-Villaverde & Rubio-Ramírez (2006) and Christiano et al. (2005). The retail firms repackage the purchased output from intermediate good producing firms in order to produce a unique and differentiated retail product. The output of retail firms is sold to final good producing firms, but at a markup due to the differentiated nature of the retail product. In effect, each retail firm has ‘local’ monopoly power. Retail firms face Calvo (1983)-type pricing frictions. The final good producers convert the output of retail firms into final goods, which are then sold to households and capital producers. This splits up the economy in four production sectors. The capital producing sector isolates the investment adjustment costs. The retail goods sector isolates the Calvo pricing and imperfect competition. The intermediate goods sector isolates the pricing of capital and labour. The final goods sector aggregates. There are no government purchases and the central bank sets its monetary policy according to a Taylor rule. Since the decision making of firms and government is standard in the New-Keynesian literature, we delegate the derivations to section 3.5.2.
3.3 Model analysis

We calibrate the model in section 3.3.1, assess the macroeconomic effects of an unexpected adverse capital quality shock that urges the pension fund to close a funding gap in section 3.3.2 and consider the welfare implications in section 3.3.3.

3.3.1 Baseline calibration

Since the restoration policy of a pension fund is a relatively short-term phenomenon, we calibrate the model at a quarterly frequency. Table 3.1 summarises the chosen values for each model parameter. The demographic parameters are set such that the implied average working period is 45 years and the average retirement period is 15 years. This is consistent with agents entering the labour force at the age of 20, working until 65 and passing away at 80. The old-age dependency ratio $\frac{1-\omega}{1-\gamma}$ is therefore equal to $\frac{1}{3}$. These values are close to empirical estimates for the Euro area in 2008 reported in the statistical annex of the 2009 Ageing Report by the European Commission, who report a life expectancy at birth of 79.5 years and an old-age dependency ratio of 0.27. The intertemporal elasticity of substitution is a crucial parameter in our analysis. In Gertler (1999)-type models the chosen values range from $\frac{1}{4}$ to $\frac{1}{2}$. In the baseline calibration we set it to the intermediate $\frac{1}{3}$ (implying that $\rho = -2$), but we perform sensitivity analyses later. The relative productivity of retirees $\xi$ is set to a smaller value than in other papers in this literature to ensure that retiree labour force participation remains low. We set the discount factor $\beta$ to achieve a yearly real interest rate of roughly 2% in the steady state. As we implement the capital quality shock of Gertler & Karadi (2011), we calibrate the production sectors and central bank in precisely the same fashion. However, we deviate by setting $\bar{\Pi} = 1.0025$ which implies a yearly steady state net inflation rate of 1%. This gives a meaningful difference between the real and nominal pension fund accounting framework in the steady state.

While the OECD (2017a) Pension Markets In Focus report highlights that pension funds have been gaining importance (with pension fund assets growing faster than GDP in most countries from 2006-2016), there is still a wide disparity between countries in terms of the size of the pension fund market. For instance, pension fund assets in Denmark, The Netherlands, Canada and Iceland are larger than 150% of GDP, while pension fund assets in Spain, Portugal, Norway, France, Italy and Germany are smaller than 15% of GDP. In our baseline calibration, we set the pension fund parameters such that the assets of the pension fund are roughly equal to 88% of yearly output, which is in between the average of 50% and weighted average of 125% of OECD countries in 2016 as reported by the Pension Markets In Focus report. We perform sensitivity analyses with respect to the size of the
**Demographics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retirement probability of workers</td>
<td>$1 - \omega$</td>
</tr>
<tr>
<td>Death probability of retirees</td>
<td>$1 - \gamma$</td>
</tr>
</tbody>
</table>

**Households**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intertemporal elasticity of substitution</td>
<td>$\sigma$</td>
</tr>
<tr>
<td>Discount factor</td>
<td>$\beta$</td>
</tr>
<tr>
<td>Consumption preference</td>
<td>$\nu$</td>
</tr>
<tr>
<td>Relative productivity of retirees</td>
<td>$\xi$</td>
</tr>
</tbody>
</table>

**Intermediate good producing firms**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobb-Douglas share of capital</td>
<td>$\alpha$</td>
</tr>
<tr>
<td>Depreciation rate of capital</td>
<td>$\delta$</td>
</tr>
<tr>
<td>AR(1)-coefficient of capital quality shock</td>
<td>$\rho$</td>
</tr>
</tbody>
</table>

**Capital good producing firms**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment adjustment costs parameter</td>
<td>$\kappa$</td>
</tr>
</tbody>
</table>

**Retail good producing firms**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity of demand for intermediate goods</td>
<td>$\epsilon$</td>
</tr>
</tbody>
</table>

**Central bank**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inertial parameter in Taylor rule</td>
<td>$\eta_i$</td>
</tr>
<tr>
<td>Inflation coefficient in Taylor rule</td>
<td>$\gamma_\pi$</td>
</tr>
<tr>
<td>Output coefficient in Taylor rule</td>
<td>$\gamma_y$</td>
</tr>
<tr>
<td>Target inflation rate</td>
<td>$\bar{\Pi}$</td>
</tr>
</tbody>
</table>

**Table 3.1:** Model parameters (excluding those of the pension fund).
pension fund later. Table 3.2 summarises the pension fund parameters and several implied indicators of pension fund size in the steady state. In the steady state we postulate that the pension fund covers its extended promises to retirees by setting the revaluation $\mu = 1$. Fixing the accrual rate $\nu$ then determines the size of the balance sheet of the pension fund and implies a steady state contribution rate $\tau$. We specify that in the steady state the pension fund should achieve a nominal funding rate of 100%. Together with a yearly net inflation rate of 1% in the steady state this implies a real target funding rate of 78.27% in the real accounting framework. The resulting contributions to output ratios of roughly 2% are smaller than the OECD average in 2016 of 2.11% and weighted average of 4.15%, while the benefits to output ratios of roughly 3.5% and 4% lie between the OECD average in 2016 of 1.67% and weighted average of 5.30%. The closure speed $\nu$ is set such that the half-life of the funding gap is equal to 1 year, but we perform sensitivity analyses later.

The emerging pension fund system has relatively high benefits to output ratios compared to the contributions to output ratios for two reasons. First, in our model the only investment opportunity for the pension fund is the capital stock, which yields a return akin to an equity investment. In reality, in 2016 pension funds in OECD countries invested

---

Table 3.2: Pension fund parameters and implied pension fund size in steady state.

<table>
<thead>
<tr>
<th>Set parameters</th>
<th>Real accounting framework</th>
<th>Nominal accounting framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accrual rate $\nu$</td>
<td>0.13%</td>
<td>0.19%</td>
</tr>
<tr>
<td>Steady state funding rate $fr$</td>
<td>78.27%</td>
<td>100%</td>
</tr>
<tr>
<td>Funding gap closure speed $\nu$</td>
<td>0.8409</td>
<td>0.8409</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Implied steady state values</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Contribution rate $\tau$</td>
<td>4.14%</td>
<td>3.56%</td>
</tr>
<tr>
<td>Pension fund assets to yearly output ratio* $\frac{A^f}{Y}$</td>
<td>88%</td>
<td>88%</td>
</tr>
<tr>
<td>Contributions to output ratio $\frac{\tau wL}{Y}$</td>
<td>2.10%</td>
<td>1.81%</td>
</tr>
<tr>
<td>Benefits to output ratio $\frac{B^r}{Y}$</td>
<td>3.96%</td>
<td>3.49%</td>
</tr>
<tr>
<td>Pension fund capital to aggregate capital ratio $\frac{A^f}{K}$</td>
<td>40.78%</td>
<td>40.04%</td>
</tr>
<tr>
<td>Fraction of pension wealth owned by retirees $\frac{R^r L^f}{L^f}$</td>
<td>40.13%</td>
<td>32.26%</td>
</tr>
</tbody>
</table>

* targeted value
<table>
<thead>
<tr>
<th></th>
<th>Real accounting framework</th>
<th>Nominal accounting framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverse MPCW of workers</td>
<td>$\Delta^w$</td>
<td>56.87</td>
</tr>
<tr>
<td>Inverse MPCW of retirees</td>
<td>$\Delta^r$</td>
<td>39.02</td>
</tr>
<tr>
<td>Yearly real interest rate</td>
<td>$(1 + r)^4 - 1$</td>
<td>2.13%</td>
</tr>
<tr>
<td>Subjective reweighting of transition probabilities</td>
<td>$\Omega$</td>
<td>1.01</td>
</tr>
<tr>
<td>Worker annuity factor</td>
<td>$R^w$</td>
<td>35.51</td>
</tr>
<tr>
<td>Worker annuity factor of pension fund</td>
<td>$R^{w,f}$</td>
<td>23.45</td>
</tr>
<tr>
<td>Effective contribution rate of workers</td>
<td>$\tau^w$</td>
<td>$-0.48%$</td>
</tr>
<tr>
<td>Effective contribution rate of retirees</td>
<td>$\tau^r$</td>
<td>$-1.69%$</td>
</tr>
<tr>
<td>Labour force participation rate of workers</td>
<td>$\frac{L^w}{N^w}$</td>
<td>0.51</td>
</tr>
<tr>
<td>Labour force participation rate of retirees</td>
<td>$\frac{L^r}{N^r}$</td>
<td>0.19</td>
</tr>
<tr>
<td>Capital to output ratio</td>
<td>$\frac{K}{Y}$</td>
<td>8.62</td>
</tr>
<tr>
<td>Worker consumption to output ratio</td>
<td>$\frac{C^w}{Y}$</td>
<td>0.72</td>
</tr>
<tr>
<td>Retiree consumption to output ratio</td>
<td>$\frac{C^r}{Y}$</td>
<td>0.08</td>
</tr>
<tr>
<td>Investment to output ratio</td>
<td>$\frac{I}{Y}$</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**Table 3.3:** Steady state values of selected endogenous variables.
roughly 40% of contributions in bonds according to the Pension Markets In Focus report. The same report states that because of this investment portfolio the geometric average annual real returns of pension funds in OECD countries from 2006-2016 was 1.7%, while the steady state annual real interest rates are roughly 2.0%. Second, condition (3.9) shows that underfunded pension funds (where assets are smaller than liabilities) contain a pay-as-you-go component. The more underfunded the pension fund, the more contributions are directly transferred to retirees instead of invested. In the wake of the financial crisis of 2008, many pension funds faced funding deficits, explaining the empirically observed low benefits to output ratios relative to the contributions to output ratios.

Table 3.3 provides an overview of the steady state values of important endogenous variables. The MPCW is considerably higher for retirees than for workers, which is in line with the calibrations of Gertler (1999)-type models and the empirical estimations by Harrison et al. (2002). The subjective reweighting of transition probabilities $\Omega > 1$ drives a substantial wedge between the worker annuity factor $R^w$ and the annuity factor applied by the pension fund $R^{w,f}$. Because saving through the pension fund allows workers to condition their future return on their future life-cycle stage, the effective contribution rate of workers $\tau^w$ is negative or close to zero. Especially the effective contribution rate of retirees $\tau^r$ is negative, which is a feature of uniform policy pension systems in which contribution and accrual rates are equal for all participants irrespective of the participant’s age at the payment time of the contribution. Chen & van Wijnbergen (2020) document that this is the case in many public sector pension plans in OECD countries. In the model, workers face the same contribution and accrual rate as retirees despite the fact that the contributions of the workers are expected to be invested for a longer period of time. As a consequence of the sizeable effective subsidy on labour income, the labour force participation of retirees is higher compared to the findings of other papers in this literature and OECD data.\footnote{The OECD.Stat database reports that the average labour force participation rate amongst retirees aged 65 or above in OECD countries was 0.145 in 2016.}

### 3.3.2 Restoring pension funding adequacy after an adverse capital quality shock

In this section we describe the restoration policy implemented by DC and DB pension funds and the implications this policy has for the rest of the economy after an unexpected adverse capital quality shock materialises. With the adverse shock to capital quality we aim to replicate the dynamics of a financial crisis such as the one of 2008, but with a
specific interest in the financial situation of pension funds. We consider an adverse shock of 1% to capital quality.¹⁰

### 3.3.2.1 Real pension fund accounting framework

Figure 3.1 provides a plot of pension fund accounting variables and the implemented restoration policy for the real accounting framework. The unexpected adverse capital quality shock depresses the value of the pension fund assets by roughly 2% on impact. Despite the fact that the pension fund issues real promises to participants in a DB system, the value of its liabilities is depressed by roughly 1% on impact due to the response of the real interest rate. Both types of pension funds face a funding deficit of roughly 1% as a result of the adverse capital quality shock. The DB pension fund responds by significantly increasing the contribution rate on labour income, while the DC pension fund gradually writes down the value of previously accumulated pension wealth. In the DB pension system retirees are comparatively well off since the value of their pension wealth is guaranteed. However, the workers are comparatively worse off since they rely on their labour income. This is reflected in the plots of the effective contribution rates of workers and retirees. Figure 3.1 highlights that the effective contribution rate of workers turns positive, while the effective contribution rate of retirees stays negative. The costs to workers of participating in the mandatory pension fund are higher than the benefits and thus the workers subsidise the retirees to guarantee their pension wealth. Even though in the steady state the two pension funds are of equal size, in the recovery they are significantly different because the DB pension fund implements a restoration policy of amassing assets and the DC pension fund implements a restoration policy of cutting liabilities.

Figure 3.2 presents a plot of the key macroeconomic variables in the DB, DC and Laissez-Faire economies. There are two forces counteracting each other in the DB system. On the one hand, since the pension fund contributions are levied as a fraction of labour income, the DB restoration policy distorts labour supply. On the other hand, since retirees have a higher MPCW, guaranteeing the value of previously accumulated pension wealth ensures that wealth is allocated to the group of individuals that, in the margin, exercises a stronger demand for consumption goods. This can be an important consideration in a demand-driven, New-Keynesian model. The numerical simulations indicate that the former effect is stronger than the latter effect. The labour supply distortions imply that the total wealth of workers is depressed, causing aggregate demand to fall. This process is exacerbated by the nominal rigidities which prevent the retail sector from adjusting the

¹⁰We solve for the equilibrium of the model using Dynare. Since we consider a perfect foresight model, the solution does not require linearisation and instead is fully nonlinear.
Figure 3.1: Pension fund restoration policy after a 1% capital quality shock in a New-Keynesian model with a real pension fund framework. DB is denoted by the solid black line, while DC is denoted by the striped blue line.
Figure 3.2: Effect of pension fund restoration policy after a 1% capital quality shock on macroeconomic variables in a New-Keynesian model with a real pension fund framework. DB is denoted by the solid black line, while DC is denoted by the striped blue line and Laissez-Faire is denoted by the dotted red line.
price of output appropriately. Since the retirees are outnumbered by workers, the effect of their higher MPCW is quantitatively unimportant for the determination of macroeconomic aggregates. As a result aggregate output, consumption, investment and capital are all lower compared to the DC and Laissez-Faire economies. Unsurprisingly, figure 3.2 indicates that the DC economy behaves similarly to an economy without a pension fund. In a Laissez-Faire economy agents save for retirement through their private financial wealth which evaporates due to the adverse capital quality shock in a similar fashion as the writing off of previously accumulated pension wealth under the DC pension fund. However, since the accumulated pension wealth is written down gradually over time, retiree consumption is higher, coming at the expense of worker consumption, in the DC economy than in the Laissez-Faire economy.

3.3.2.2 Nominal pension fund accounting framework

Figure 3.3 highlights that the adverse capital quality shock actually leads to a funding surplus for the pension fund in the nominal accounting framework. This is predominantly explained by the movement of the nominal interest rate in response to the unexpected shock and its effects on the liabilities of the pension fund. As in the real pension fund framework, the value of the assets of the fund are depressed by roughly 2% on impact. However, the value of the liabilities drop roughly 4% and 9% in the DB and DC economy, respectively. While in the short term the shock causes the price level to decrease, inflation picks up in the medium term as the economy recovers. Since the pension fund issues nominal promises to fund participants under this accounting framework, the ensuing inflation drives down the value of the fund liabilities substantially.\textsuperscript{11} This holds especially for the DC economy which is characterised by a higher inflation rate and a higher nominal interest rate compared to the DB economy. Since the pension fund faces a funding surplus, it implements a restoration policy which distributes welfare gains over different groups of individuals and cohorts. The DC pension fund increases the revaluation rate which offsets the loss of previously accumulated pension wealth. While the liabilities of the DB pension fund are decreasing in the short term due to the increasing path of the nominal interest rate, the liabilities of the DC pension fund recover quickly due to the marking up of previously accumulated pension wealth. The DB pension fund instead lowers the contribution rate and thus makes the accrual of new pension wealth relatively cheap.\textsuperscript{12}

\textsuperscript{11}Note that the inflation is not caused by a jump in the risk premium since we consider a model without aggregate risk.

\textsuperscript{12}This explains why the assets of the pension fund drop by roughly 5.5\% in the DB case. The fund draws down its assets because it collects less contributions while it continues to fulfil its pension promises to retirees.
The plots of the effective contribution rates highlight this.

Figure 3.4 presents a plot of the key macroeconomic variables in the DB, DC and Laissez-Faire economies. The cheap accrual of new pension wealth under the DB pension system implies that labour supply is subsidised. As a result, the economic downturn is mitigated compared to the DC and Laissez-Faire economies. The comparatively high labour supply leads to a lower wage rate and marginal cost, meaning that the retail firms that can change their prices set a lower reset price. This in turn leads to a lower inflation rate and nominal interest rate along the adjustment path and explains why the liabilities of the pension fund do not fall as much with a DB pension fund as with a DC pension fund.\(^1\) We conclude that a rather small adverse capital quality shock of 1% can have sizeable effects on the finances of a nominally defined pension fund, especially when the pension fund introduces an implicit subsidy or tax on labour supply which influences the pricing decisions of retail firms and in turn the financial position of the pension fund. Since retirees have a lower productivity compared to workers, it is difficult for them to accumulate sufficient additional pension wealth to offset the evaporation of their previously accumulated pension wealth. Therefore, retirees consume less under a DB system compared to a DC system, while the opposite is the case for workers. The effect of the labour supply distortion of the DB pension fund again outweighs the effect of the higher MPCW of retirees. While the DC and the Laissez-Faire economy behave similarly under the real accounting framework, we observe considerable differences between the two under the nominal accounting framework. Figure 3.3 shows that the effective contribution rate of workers increases with the DC pension fund, meaning that the labour supply of workers is distorted downwards. This stems from the fact that accumulating additional pension wealth is less attractive due to the relatively high level of the inflation rate. Workers are affected negatively not only by the implicit tax on labour supply, but also by the fact that their previously accumulated pension wealth is marked up in the first periods after the shock and afterwards, as inflation picks up, written down again. Retirees on the other hand are less reliant on their labour income and, due to their short remaining lifetime, benefit from receiving more pension benefits in the initial periods after the adverse capital quality shock.

\(^{13}\)Figure 3.2 shows that the opposite is the case under the real accounting framework. However, the pension fund finances are unaffected by the inflation rate in the real accounting framework and thus the higher inflation rate in the DB case does not affect the restoration policy of the pension fund.
Figure 3.3: Pension fund restoration policy after a 1% capital quality shock in a New-Keynesian model with a nominal pension fund framework. DB is denoted by the solid black line, while DC is denoted by the striped blue line.
Figure 3.4: Effect of pension fund restoration policy after a 1% capital quality shock on macroeconomic variables in a New-Keynesian model with a nominal pension fund framework. DB is denoted by the solid black line, while DC is denoted by the striped blue line and Laissez-Faire is denoted by the dotted red line.
3.3.3 Welfare effects of pension fund restoration policy

We now turn to an assessment of the welfare effects of the various forms of pension fund restoration policy to see which pension fund system each group of individuals prefers.

The equivalent variation $EV^z$ measures the lump-sum transfer a group of individuals with labour market status $z \in \{w, r\}$, initial private savings $A^z_{t-1}$ and pension entitlements $B^z_{t}$ must receive under scenario 1 to obtain the same utility as in scenario 0. That is, the equivalent variation between scenario 0 and 1 is implicitly defined by:

$$V^z_t(A^z_{t-1}, B^z_{t}, \Gamma^0_t, \Gamma^1_t) = V^z_t(A^z_{t-1}, B^z_{t}, \Gamma^1_t), \ z \in \{w, r\},$$

where $\Gamma^i_t$, a scenario $i$ at period $t$, denotes all relevant aggregate information on factor prices and pension fund restoration policy from period $t$ onwards.\(^{14}\)

Condition (3.25) highlights that total consumption is linear in total lifetime wealth and condition (3.26) highlights that the indirect lifetime utility is linear in total consumption. We use this to calculate the equivalent variation:

$$EV^z_t \left( A^z_{t-1}, A^z_{t-1}, B^z_{t}, B^z_{t}, \Gamma^0_t, \Gamma^1_t \right) = \frac{V^z_t \left( A^z_{t-1}, B^z_{t}, \Gamma^0_t \right) - V^z_t \left( A^z_{t-1}, B^z_{t}, \Gamma^1_t \right)}{\partial A^z_{t-1} \left( 1 + r^1_t \right)}, \ z \in \{w, r\}.$$

Let time period 0 denote the steady state period and period 1 denote the period in which the adverse capital quality shock materialises. Additionally, DC denotes the scenario of the DC economy and DB denotes the scenario of the DB economy. We then consider the equivalent variations of the following three groups of individuals.

<table>
<thead>
<tr>
<th>Group of individuals</th>
<th>Equivalent Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retirees alive at $t = 1$</td>
<td>$EV^r_t \left( A^r_0, A^r_0, B^r_{DB_t}, B^r_{DB_t}, \Gamma^DC_t, \Gamma^DB_t \right)$</td>
</tr>
<tr>
<td>Workers alive at $t = 1$</td>
<td>$EV^w_t \left( A^w_0, A^w_0, B^w_{DB_t}, B^w_{DB_t}, \Gamma^DC_t, \Gamma^DB_t \right)$</td>
</tr>
<tr>
<td>Workers born after $t = 1$</td>
<td>$\sum_{i=2}^{\infty} \Pi^i_{j=2} \left( \frac{1}{1 + r^{'DB_t}} \right) (1 - \omega) \ EV^w_i \left( 0, 0, 0, \Gamma^DC_t, \Gamma^DB_t \right)$</td>
</tr>
</tbody>
</table>

For ease of interpretation, we express the equivalent variations as a share of yearly steady state output. Table 3.4 depicts the welfare effects of switching from a DB pension

\(^{14}\)Note that the equivalent variation is not necessarily symmetric in the environments. Also note that we do not implement the wealth transfers, but consider the equivalent variations to be useful hypotheticals to assess the relative attractiveness of pension fund arrangements.
Retirees alive at \( t = 1 \) & -0.44\% & -0.41\% & +1.45\% \\
Workers alive at \( t = 1 \) & -0.14\% & +0.11\% & -0.36\% \\
Workers born after \( t = 1 \) & +0.07\% & +0.13\% & -0.36\% \\
Total & -0.51\% & -0.17\% & +0.73\%

**Table 3.4:** Welfare effects of switching from a DB pension fund to a DC pension fund in various model environments after an adverse shock to capital quality of 1%. Measured as an equivalent variation showing the transfer of wealth as a percentage of steady state yearly output necessary for indifference between the two pension fund arrangements.

In the real business cycle model all individuals alive at period \( t = 1 \) prefer a DB pension fund over a DC pension fund, while the future generations prefer the opposite. However, the desirability of a DB pension fund arrangement diminishes in a New-Keynesian environment where aggregate demand becomes important. While it is unsurprising that the group of retirees prefers a DB pension fund in the real accounting framework, all workers now prefer the DC pension fund. To workers, the adverse labour supply distortions in the DB pension fund outweigh the positive effect of allocating more wealth to the group of individuals with the highest MPCW in the margin. Under the nominal accounting framework, the adverse capital quality shock depresses the value of accumulated pension wealth to the extent that retirees prefer the pension funding surplus to be paid out through increases in the valuation of previously accumulated pension wealth rather than through discounts on the accumulation of new pension wealth. Conversely, since workers are still active on the labour market and have relatively less dependence on accumulated pension wealth, workers prefer the pension funding surplus to be distributed through lower contribution rates.

Table 3.4 highlights that there is no preferred pension fund arrangement. Each system distributes welfare losses or gains over different groups of individuals and therefore there is no unanimous agreement between workers, retirees and future generations about optimal pension fund design. The sum of the equivalent variations indicates that in a real

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15. The welfare effects of the real business cycle model are obtained by switching off the New-Keynesian elements described in the model section.

16. This also holds for switching from a DB pension fund to a hybrid pension fund that combines the restoration policy of a DC and DB pension fund by using both the revaluation and contribution instrument.
Table 3.5: Welfare effects of switching from a DB pension fund to a DC pension fund in various model environments after a positive shock to capital quality of 1%. Measured as an equivalent variation showing the transfer of wealth as a percentage of steady state yearly output necessary for indifference between the two pension fund arrangements.

<table>
<thead>
<tr>
<th>Group of individuals</th>
<th>Real business cycle</th>
<th>New-Keynesian Real framework</th>
<th>New-Keynesian Nominal Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retirees alive at $t = 1$</td>
<td>+0.44%</td>
<td>+0.43%</td>
<td>−1.37%</td>
</tr>
<tr>
<td>Workers alive at $t = 1$</td>
<td>+0.15%</td>
<td>−0.04%</td>
<td>+0.14%</td>
</tr>
<tr>
<td>Workers born after $t = 1$</td>
<td>−0.07%</td>
<td>−0.12%</td>
<td>+0.31%</td>
</tr>
<tr>
<td>Total</td>
<td>+0.52%</td>
<td>+0.27%</td>
<td>−0.92%</td>
</tr>
</tbody>
</table>

accounting framework a DB pension fund is preferred and in a nominal accounting framework a DC pension fund is preferred. However, the sum is close to zero and furthermore depends on the rate used to discount the equivalent variations of future generations and the welfare weights attached to different groups of individuals. For simplicity we weigh each group equally and discount with the real interest rate, but one could make sensible arguments for different welfare weights and discount factors. Nevertheless, the welfare effects allow us to draw a consistent conclusion: when the pension fund faces a deficit, retirees prefer the labour market to be distorted and the value of their pension wealth to be guaranteed while workers prefer the opposite. When the pension fund faces a surplus, retirees prefer that the value of their pension wealth is marked up and that the accrual of new pension wealth is relatively expensive while workers prefer the opposite.\(^\text{17}\)

Table 3.5 shows the welfare effects of a positive capital quality shock. The welfare effects in a real business cycle model have the opposite sign of a negative capital quality shock, but the New-Keynesian nominal rigidities lead to asymmetry. For instance, when an adverse shock materialises in an inflation-indexed system, workers have a strong preference for switching to DC. After a positive capital quality shock of equal size, workers have a weaker preference for sticking with DB.\(^\text{18}\) Inspection of the impulse responses indicates that labour supply is depressed more after negative shocks than it is promoted after positive shocks. We relate this asymmetric response to the literature on pension fund design. Since other papers have not considered nominal rigidities, we compare their findings to close the funding gap. As the fraction of the funding gap closure that stems from the revaluation instrument increases, the welfare effect of each group becomes monotonically stronger.\(^\text{17}\) To test the robustness of our findings, we calculate the welfare effects for different values of the intertemporal elasticity of substitution, the size of the pension fund and the closure speed of the funding gap. The results are reported in table A3.3 in section 3.5.4.\(^\text{18}\) This also holds for shock sizes different than 1%.
the inflation-indexed pension funds that are studied here. Bonenkamp & Westerhout (2014) and Draper et al. (2017) conclude for DB pension funds that the welfare gain from intergenerational risk-sharing dominates the cost of labour supply distortions, which is consistent with our findings in a real business cycle model. Since the intergenerational risk-sharing allows future generations to take advantage of earlier realisations of the equity premium, a DB pension fund increases the mean consumption level of fund participants. Despite the higher resulting standard deviation of consumption, agents ex ante prefer DB pension funds over DC pension funds. Our findings in table 3.4 and 3.5 indicate that nominal rigidities cause workers to be negatively affected by adverse shocks, while workers are less positively affected by positive shocks. Compared to the real business cycle model, with a New-Keynesian production specification in Bonenkamp & Westerhout (2014) and Draper et al. (2017) the DB pension fund would be associated with a lower mean consumption level of workers and a higher standard deviation. While our perfect foresight set-up does not allow for a comprehensible assessment of the benefits of intergenerational risk-sharing, the results dampen the appeal of DB pension funds.

3.4 Conclusion

This chapter has provided an assessment of the business cycle effects and distributional implications of pension fund restoration policy by extending a canonical New-Keynesian dynamic general equilibrium model with a tractable demographic structure and a flexible pension fund framework. This model is used to investigate how the economy responds to an unexpected Gertler & Karadi (2011)-type capital quality shock when financial adequacy is restored by revaluing previously accumulated pension wealth (DC) or changing the pension fund contribution rate on labour income (DB). The main result of the chapter is that due to nominal rigidities inflation-indexed DB pension funds (which are closest in design to the pension funds that have been studied in environments without nominal rigidities) significantly distort labour supply decisions and exacerbate economic fluctuations. Additionally, they transmit capital quality shocks asymmetrically: after an adverse shock workers are negatively affected while workers are less positively affected by positive shocks. The intergenerational risk-sharing literature, which has abstracted from nominal rigidities and distortions that materialise at a business cycle frequency, thus overstates the welfare improvement of inflation-indexed DB pension funds by understating their potential for distorting labour supply. The general consensus in favour of DB pension funds in the literature on pension fund design is mirrored by the implemented restoration policies of Dutch pension funds. de Haan (2015) shows that underfunded Dutch pension funds
consider contribution increases first, not indexing previously accumulated pension wealth second and cuts to pensions only as a last resort. Our results indicate that the preference ordering of Dutch pension funds exacerbates economic fluctuations and might not be optimal from a welfare perspective. The results of this chapter can also be related to the wider issue of commitment and stability in pension funds. As pointed out by Gollier (2008), maintaining intergenerational risk-sharing through pension funds after successive poor capital market performances requires strong government enforcement because younger generations will want to switch to individual pension systems. This becomes even more of a concern in a New-Keynesian setting where adverse capital quality shocks hit workers harder than positive ones. For a holistic welfare perspective on pension fund system design, however, the distortions and risk-sharing properties of pension fund systems have to be considered jointly. While the existing literature underestimates the importance of labour supply distortions, this chapter does not consider the risk-sharing properties of different pension fund systems. This is an avenue we aim to explore in future research.

3.5 Appendix

3.5.1 Decision problems of retirees and workers

We introduce some notation in order to make the derivations more readable. While we still solve the decision problems of individual retirees and workers, we drop the superscripts $i$ and $j$. Furthermore, $V^r_2(a^r_t, b^r_{t+1})$ denotes the derivative of the value function of a retiree in period $t + 1$ with respect to per-period pension benefits $b^r_{t+1}$ (i.e., the second state variable). We only show the derivations for the real accounting framework since those for the nominal accounting framework are analogous.

3.5.1.1 Retiree decision problem

A retiree maximises the following objective in period $t$:

$$V^r(a^r_t, b^r_t) = \max_{c^r_t, l^r_t, a^r_t, b^r_{t+1}} \left(\left((c^r_t)^v(1-l^r_t)^{1-v}\right)^{\rho} + \gamma \beta \left(V^r(a^r_t, b^r_{t+1})\right)^{\frac{\rho}{1+\rho}}\right),$$

subject to:

$$a^r_t = \frac{1+r_t}{\gamma} a^r_{t-1} + (1-\tau_t)\xi w_t l^r_t + \mu_t b^r_t - c^r_t,$$

$$b^r_{t+1} = \mu_t b^r_t + \nu_t \xi w_t l^r_t.$$
The first-order condition with respect to $c_t^r$:

$$v(c_t^r)^v \rho - 1 (1 - l_t^r)^{(1-v)^\rho} = \beta \gamma \left(V^r \left(a_t^r, b_t^r \right)\right)^{\rho-1} V_1^r \left(a_t^r, b_t^r+1 \right).$$ (3.27)

The envelope theorem implies that:

$$V_1^r \left(a_{t-1}^r, b_t^r \right) = \left(V^r \left(a_{t-1}^r, b_t^r \right)\right)^{1-v} \frac{1 + r_t}{\gamma} \left(c_t^r\right)^{v\rho - 1} (1 - l_t^r)^{(1-v)^\rho}.$$ (3.28)

Shifting (3.28) one period forward and combining with (3.27) gives the Euler equation:

$$\frac{c_{t+1}^r}{c_t^r} = \beta (1 + r_{t+1}) \frac{\left((c_{t+1}^r\right)^v (1 - l_{t+1}^r)^{(1-v)^\rho})^\rho}{((c_t^r)^v (1 - l_t^r)^{(1-v)^\rho})^\rho}.$$ (3.29)

The first-order condition with respect to $l_t^r$:

$$(1 - v) (c_t^r)^v (1 - l_t^r)^{(1-v)(\rho-1)} = \beta \gamma \left(V^r \left(a_t^r, b_t^r+1 \right)\right)^{\rho-1} V_1^r \left(a_t^r, b_t^r+1 \right) (1 - \tau_t^r) \xi w_t,$$ (3.30)

where we use the linearity of the consumption function in total lifetime wealth to determine that $V_2^r \left(a_t^r, b_t^r+1 \right) = R_{t+1}^r \gamma \sum_{t=r+1}^{\infty} V_1^r \left(a_t^r, b_t^r+1 \right)$ and define $\tau_t^r = \tau_t - (R_t^r - 1) \nu_t$. Working one extra unit of time in period $t$ gives $\mu_{t+1} \nu_t \xi w_t$ additional per-period pension benefits from period $t + 1$ onwards. $V_2^r \left(a_t^r, b_t^r+1 \right)$ denotes the proper valuation of one additional accrued unit of per-period pension benefits. Recall that the annuity factor $R_{t+1}^r = 1 + \mu_{t+1} \gamma w_t$ represents the present discounted value to a retiree in period $t + 1$ of receiving one consumption good each period from period $t + 1$ until death (corrected for future revaluation). One additional accrued unit of per-period pension benefits from period $t + 1$ onwards is therefore equally valuable to a retiree as having $R_{t+1}^r \gamma w_{t+1}$ additional units of $a_t^r$. Combining (3.30) with (3.27):

$$1 - l_t^r = \frac{1 - v}{v} \frac{c_t^r}{(1 - \tau_t^r) \xi w_t}.$$ (3.31)

We write the Euler equation solely in terms of consumption by substituting (3.31) into (3.29):

$$\frac{c_{t+1}^r}{c_t^r} = \beta (1 + r_{t+1}) \left(\frac{(1 - \tau_t^r) \xi w_t}{(1 - \tau_t^r) \xi w_{t+1}}\right)^{(1-v)^\rho} \left(\frac{(1 - \tau_t^r) \xi w_{t+1}}{(1 - \tau_t^r) \xi w_{t+1}}\right)^{(1-v)^\rho},$$ (3.32)

where we have used that $\sigma = \frac{1 - \rho}{1 - \rho}$. We define retiree full consumption as $x_t^r \equiv c_t^r + (1 - \cdots$
\( l' \) \((1 - \tau^{r}) \xi w_{t} = \frac{c_{t}'}{v} \), which follows the same Euler equation as \( c_{t}' \):

\[
x_{r} = x_{r}^{\tau-1} \prod_{s=t}^{\tau-1} \left( \beta(1 + r_{s+1}) \left( \frac{(1 - \tau^{r})w_{s}}{(1 - \tau^{r+1})w_{s+1}} \right)^{(1-v)\rho} \right)^{\sigma}, \quad \forall \tau = t, t+1, \ldots
\]

We now derive the full consumption and indirect value function. Let retiree full income \( d_{t}^{r} \) and retiree human wealth \( h_{t}^{r} \) be defined as:

\[
d_{t}^{r} = (1 - \tau^{r})\xi w_{t},
\]

\[
h_{t}^{r} = d_{t}^{r} + \frac{\gamma}{1 + r_{t+1}} h_{t+1}^{r}.
\]

Iterating the budget constraint forwards and imposing a transversality condition gives the lifetime budget constraint and full consumption function:

\[
\sum_{\tau=t}^{\infty} \left( \prod_{s=t}^{\tau-1} \frac{\gamma}{1 + r_{s+1}} \right) x_{r}^{\tau} = \frac{1 + r_{t}}{\gamma} a_{t-1}^{r} + h_{t}^{r} + \mu_{t} b_{t}^{r} R_{t}^{r} \iff x_{t}^{r} = \frac{1}{\Delta_{t}^{r}} \left( \frac{1 + r_{t}}{\gamma} a_{t-1}^{r} + h_{t}^{r} + \mu_{t} b_{t}^{r} R_{t}^{r} \right),
\]

with \( \Delta_{t}^{r} \) the inverse MPCW of retirees (using that \( \sigma = \frac{1}{1-\rho} \) and \( \sigma\rho = \sigma - 1 \):

\[
\Delta_{t}^{r} = 1 + \gamma \beta^{\sigma} \Delta_{t+1}^{r} \left( (1 + r_{t+1}) \left( \frac{(1 - \tau^{r})w_{t}}{(1 - \tau^{r+1})w_{t+1}} \right)^{1-v} \right)^{\sigma-1}.
\]

Writing out the indirect retiree value function:

\[
(V_{t}^{r})^{\rho} = \sum_{s=t}^{\infty} \left( (\beta \gamma)^{s-t} c_{s}^{r} \left( \frac{1 - v}{v} \frac{1}{(1 - \tau^{r})\xi w_{s}} \right)^{1-v} \right)^{\rho} \iff V_{t}^{r} = (\Delta_{t}^{r})^{\frac{1}{\rho}} v x_{t}^{r} \left( \frac{1 - v}{v} \frac{1}{(1 - \tau^{r})\xi w_{t}} \right)^{1-v}.
\]

### 3.5.1.2 Worker decision problem

A worker maximises the following objective in period \( t \):

\[
V^{w}(a_{t-1}^{w}, b_{t}^{w}) = \max_{c_{t}^{w}, l_{t}^{w}, a_{t-1}^{w}, b_{t+1}^{w}} \left( \left( (c_{t}^{w})^{v}(1 - l_{t}^{w})^{1-v} \right)^{\rho} + \beta \left( \omega V^{w}(a_{t}^{w}, b_{t+1}^{w}) + (1 - \omega) V^{r}(a_{t}^{r}, b_{t+1}^{r}) \right)^{\frac{1}{\rho}} \right),
\]

\[ (3.33) \]
subject to the constraints that become operative once he retires and subject to:

\[
a^w_t = (1 + r_t) a^w_{t-1} + (1 - \tau_t) w_t l^w_t + b^w_t - c^w_t,
\]

\[
b^w_{t+1} = \mu_t b^w_t + \nu_t w_{t+1}.
\]

The first-order condition with respect to \(c^w_t\):

\[
v (c^w_t)^{\rho-1} (1 - l^w_t)^{(1-v)\rho} = \beta \left( \omega V^w(a^w_t, b^w_{t+1}) + (1 - \omega) V^r(a^w_t, b^w_{t+1}) \right)^{\rho-1} \left( \omega V^w(a^w_t, b^w_{t+1}) + (1 - \omega) V^r(a^w_t, b^w_{t+1}) \right) ,
\]

where we can find \(V^w(a^w_t, b^w_{t+1})\) and \(V^r(a^w_t, b^w_{t+1})\) using the envelope theorem and shifting the conditions one period forward:

\[
V^w_1(a^w_t, b^w_{t+1}) = \left(V^w(a^w_t, b^w_{t+1})\right)^{1-\rho} v (1 + r_{t+1}) (c^w_{t+1})^{\rho-1} (1 - l^w_{t+1})^{(1-v)\rho} , \tag{3.35}
\]

\[
V^r_1(a^w_t, b^w_{t+1}) = \left(V^r(a^w_t, b^w_{t+1})\right)^{1-\rho} v (1 + r_{t+1}) (c^w_{t+1})^{\rho-1} (1 - l^w_{t+1})^{(1-v)\rho} . \tag{3.36}
\]

The first-order condition with respect to \(l^w_t\):

\[
(1 - v) (c^w_t)^{\rho} (1 - l^w_t)^{(1-v)(\rho-1)} = \beta (1 - \tau_t) w_t \left( \omega V^w(a^w_t, b^w_{t+1}) + (1 - \omega) V^r(a^w_t, b^w_{t+1}) \right)^{\rho-1} \left( \omega V^w(a^w_t, b^w_{t+1}) + (1 - \omega) V^r(a^w_t, b^w_{t+1}) \right) + \
\beta \mu_{t+1} \nu_t w_{t} \left( \omega V^w(a^w_t, b^w_{t+1}) + (1 - \omega) V^r(a^w_t, b^w_{t+1}) \right)^{\rho-1} \
\left( \omega V^w_2(a^w_t, b^w_{t+1}) + (1 - \omega) V^r_2(a^w_t, b^w_{t+1}) \right) . \tag{3.37}
\]

We need to determine the proper valuation of obtaining an additional unit of accrued per-period pension benefits in case the worker remains a worker in period \(t+1\), \(V^w_2(a^w_t, b^w_{t+1})\), and in case the worker retires in period \(t + 1\), \(V^r_2(a^w_t, b^w_{t+1})\). As in section 3.5.1.1 it holds that \(V^r_2(a^w_t, b^w_{t+1}) = R^r_{t+1} V^r_1(a^w_t, b^w_{t+1})\), where \(\gamma\) is omitted since an individual who is a worker in period \(t\) and retired in period \(t+1\) reaps a return on his private financial wealth of \(1 + r_{t+1}\). Anticipating that the worker consumption function is linear in perceived total lifetime wealth, it holds that \(V^w_2(a^w_t, b^w_{t+1}) = R^w_{t+1} V^w_1(a^w_t, b^w_{t+1})\). Recall that the annuity factor \(R^w_{t+1} = \frac{\mu_{t+1}}{1+r_{t+2}} \left( \frac{\omega_{t+2} R^w_{t+2}}{1-r_{t+2}} + (1 - \frac{\omega_{t+2}}{1-r_{t+2}}) R^r_{t+2} \right)\) represents the present discounted value to a worker in period \(t + 1\) of receiving one consumption good each period in which he is retired in the future (corrected for future revaluation \(\mu\) and the subjective reweighting of transition probabilities \(\Omega\)). Using this in (3.37):
(1 - v) (c^w_t)^\rho (1 - l^w_t)^{(1-v)(\rho-1)} = \beta (1 - \tau_t) w_t \left( \omega V^w (a^w_t, b^w_{t+1}) + (1 - \omega) V^r (a^w_t, b^w_{t+1}) \right)^{\rho-1}

\left( \omega V^w (a^w_t, b^w_{t+1}) + (1 - \omega) V^r (a^w_t, b^w_{t+1}) \right) + 

\frac{\mu_{t+1}}{1 + r_{t+1}} \nu_t w_t \left( \omega V^w (a^w_t, b^w_{t+1}) + (1 - \omega) V^r (a^w_t, b^w_{t+1}) \right)^{\rho-1}

\left( \omega R^w_{t+1} V^w_1 (a^w_t, b^w_{t+1}) + (1 - \omega) R^r_{t+1} V^r_1 (a^w_t, b^w_{t+1}) \right).

We conjecture that the following equivalency holds:

\frac{\mu_{t+1}}{1 + r_{t+1}} \left( \omega R^w_{t+1} V^w_1 (a^w_t, b^w_{t+1}) + (1 - \omega) R^r_{t+1} V^r_1 (a^w_t, b^w_{t+1}) \right) = 

R^w_t \left( \omega V^w_1 (a^w_t, b^w_{t+1}) + (1 - \omega) V^r_1 (a^w_t, b^w_{t+1}) \right). \quad (3.38)

After deriving the consumption and indirect value function of the worker, we will verify that the above equivalency indeed holds. This will ensure that all conjectures add up to consistent solutions across all equations characterising the optimal decisions of retirees and workers. Defining \( \tau^w_t = \tau_t - R^w_t \nu_t \) then gives:

(1 - v) (c^w_t)^\rho (1 - l^w_t)^{(1-v)(\rho-1)} = \beta (1 - \tau^w_t) w_t \left( \omega V^w (a^w_t, b^w_{t+1}) + (1 - \omega) V^r (a^w_t, b^w_{t+1}) \right)^{\rho-1}

\left( \omega V^w (a^w_t, b^w_{t+1}) + (1 - \omega) V^r (a^w_t, b^w_{t+1}) \right). \quad (3.39)

Combining (3.39) with (3.34):

1 - l^w_t = \frac{1 - \nu}{v} \frac{c^w_t}{(1 - \tau^w_t) w_t}. \quad (3.40)

We now write the Euler equation solely in terms of consumption. Define worker full consumption as \( x^w_t = c^w_t + (1 - l^w_t) (1 - \tau^w_t) w_t = \frac{c^w_t}{v} \). Substituting this, the optimal labour supply decisions (3.31) and (3.40), and the envelope conditions (3.35) and (3.36) into (3.34), the first-order condition with respect to \( c^w_t \), gives the worker Euler equation:

\( (x^w_t)^{\rho-1} = \beta (1 + r_{t+1}) \left( \frac{1 - \tau^w_t}{1 - \tau^w_{t+1}} w_{t+1} \right)^{(1-v)\rho} \left( \omega V^w (a^w_t, b^w_{t+1}) + (1 - \omega) V^r (a^w_t, b^w_{t+1}) \right)^{\rho-1}

\left( \omega V^w (a^w_t, b^w_{t+1}) \right)^{1-\rho} (x^w_{t+1})^{\rho-1} + (1 - \omega) \left( V^r (a^w_t, b^w_{t+1}) \right)^{1-\rho} (x^r_{t+1})^{\rho-1} \left( \frac{1 - \tau^w_{t+1}}{1 - \tau^w_{t+1} \xi} \right)^{(1-v)\rho} \right).

In section 3.5.1.1 we have shown that \( V^r_t = (\Delta^r_t)^{\frac{1}{\rho}} v \Delta^r_t \left( \frac{1 - v}{v} \frac{1}{(1 - r_t) \xi w_t} \right)^{1-v} \). Conjec-
ture similarly that \( V_t^w = (\Delta_t^w)^{\frac{1}{\rho}} v x_t^w \left( \frac{1-v}{(1-\tau_t^w)w_t} \right)^{1-v} \). Denote with \( \Omega_t = \omega + (1 - \omega) \left( \frac{1-\tau_t^w}{1-\tau_t} \xi \right)^{1-v} \left( \frac{\Delta_t^w}{\Delta_t^r} \right)^{1-\sigma} \). Plugging these in the above condition and cancelling out terms:

\[
\omega x_{t+1}^w + (1 - \omega) x_{t+1}^r \left( \frac{1-\tau_{t+1}^w}{1-\tau_{t+1}^r} \xi \right)^{1-v} \left( \frac{\Delta_{t+1}^w}{\Delta_{t+1}^r} \right)^{1-\sigma} = x_t^w \left( \beta(1+r_{t+1}) \Omega_{t+1} \left( \frac{(1-\tau_{t+1}^w)w_{t+1}}{w_t} \right) (1-\sigma) \right) \quad \text{for } \sigma = 1.
\]

We can now show that, using (3.41), our conjecture for the value function implies an elegant difference equation for \( \Delta_t^w \). Plugging the indirect value functions and optimal worker decisions in the worker decision problem of (3.33):

\[
\left( \frac{(\Delta_t^w)^{\frac{1}{\rho}} v x_t^w \left( \frac{1-v}{(1-\tau_t^w)w_t} \right)^{1-v}}{\beta} \right) = \left( v x_t^w \left( \frac{1-v}{(1-\tau_t^w)w_t} \right)^{1-v} + \beta \left( \omega \left( \frac{\Delta_{t+1}^w}{\Delta_{t+1}^r} \right)^{\frac{1}{\rho}} v x_{t+1}^w \left( \frac{1-v}{(1-\tau_{t+1}^w)w_{t+1}} \right)^{1-v} \right) + (1 - \omega) \left( \frac{\Delta_{t+1}^r}{\rho} v x_{t+1}^r \left( \frac{1-v}{(1-\tau_{t+1}^r)\xi w_{t+1}} \right)^{1-v} \right)^{\rho} \right)
\]

\[
\Delta_t^w = 1 + \beta^\sigma \Delta_{t+1}^w \left( (1+r_{t+1}) \Omega_{t+1} \left( \frac{(1-\tau_{t+1}^w)w_{t+1}}{w_t} \right) (1-\sigma) \right) \quad \text{for } \sigma = 1.
\]

Using (3.41) we can show that the difference equation for \( \Delta_t^w \) given by (3.42) is consistent with the following full consumption function:

\[
x_t^w = \frac{1}{\Delta_t^w} \left( (1+r_t) a_t^w + h_t^w + \mu_t d_t^w R_t^w \right),
\]

\[
d_t^w = (1-\tau_t^w) w_t + f_t^w,
\]

\[
h_t^w = d_t^w + \frac{1}{1+r_{t+1}} \left( \frac{\omega}{\Omega_{t+1}} h_{t+1}^w + (1-\omega) h_{t+1}^r \right),
\]

where \( h_t^w \) is the perceived human wealth of a worker and \( d_t^w \) worker full income. Substituting the above full consumption function in (3.41) indeed gives the same difference equation for \( \Delta_t^w \):
Lastly, we return to the worker first-order condition for labour. Now that we have

\[ \omega \frac{1}{\Delta_{t+1}^w} \left( (1 + r_{t+1}) a_t^w + h_{t+1}^w + \mu_{t+1} b_{t+1}^w R_{t+1}^w \right) + \\
(1 - \omega) \left( \left( \frac{1 - \tau_{t+1}^w}{1 - r_{t+1}^w} \right)^{1-a} \left( \frac{1}{\Delta_{t+1}^w} \right)^{\alpha} \frac{1}{\Delta_{t+1}^w} \left( (1 + r_{t+1}) a_t^w + h_{t+1}^w + \mu_{t+1} b_{t+1}^w R_{t+1}^w \right) = \\
\left( \beta (1 + r_{t+1}) \Omega_{t+1} + \left( \frac{(1 - \tau_{t+1}^w) w_t}{(1 - r_{t+1}^w) w_{t+1}} \right)^{(1-a)} \right)^{\sigma} \frac{1}{\Delta_{t+1}^w} \left( (1 + r_{t+1}) a_t^w + h_{t+1}^w + \mu_{t+1} b_{t+1}^w R_{t+1}^w \right) \right) \]

\[ \Delta_t^w \left( \frac{a_t^w + h_t^w - d_t^w + b_{t+1}^w R_{t+1}^w}{1 + r_t} a_{t-1}^w + h_{t-1}^w + \mu_t b_t^w R_t^w \right) = \beta^\sigma \Delta_{t+1}^w \left( (1 + r_{t+1}) \Omega_{t+1} + \left( \frac{(1 - \tau_{t+1}^w) w_t}{(1 - r_{t+1}^w) w_{t+1}} \right)^{(1-a)} \right)^{\sigma-1} \]

where we use that \( 1 - \frac{1}{\Delta_t^w} = \frac{a_t^w + h_t^w - d_t^w + b_{t+1}^w R_{t+1}^w}{1 + r_t} a_{t-1}^w + h_{t-1}^w + \mu_t b_t^w R_t^w \), which can be shown using the worker budget constraint:

\[ a_t^w = (1 + r_t) a_{t-1}^w + (1 - \tau_t) w_t l_t^w + f_t^w - c_t^w \leftrightarrow \\
a_t^w + h_t^w = (1 + r_t) a_{t-1}^w + h_{t-1}^w + d_t^w - d_t^w + (r_t - \tau_t) w_t l_t^w \leftrightarrow \\
a_t^w + h_t^w - d_t^w = (1 + r_t) a_{t-1}^w + h_{t-1}^w - R_t^w \left( h_{t-1}^w - \mu_t b_t^w \right) - d_t^w \leftrightarrow \\
a_t^w + h_t^w - d_t^w + b_{t+1}^w R_{t+1}^w = (1 + r_t) a_{t-1}^w + h_{t-1}^w + \mu_t b_t^w R_t^w \\
- \frac{1}{\Delta_t^w} \left( (1 + r_t) a_{t-1}^w + h_{t-1}^w + \mu_t b_t^w R_t^w \right) \leftrightarrow \\
1 - \frac{1}{\Delta_t^w} = \frac{a_t^w + h_t^w - d_t^w + b_{t+1}^w R_{t+1}^w}{1 + r_t} a_{t-1}^w + h_{t-1}^w + \mu_t b_t^w R_t^w. \]

This confirms that our conjectures of the worker full consumption function and the worker indirect value function are mutually consistent and are similar in shape to those of the retiree.

Lastly, we return to the worker first-order condition for labour. Now that we have derived the expressions for the subjective reweighting of transition probabilities \( \Omega_t \) and the indirect value functions of the worker \( V_t^w \) and retiree \( V_t^r \), we show that the assumed equivalency (3.38) indeed holds.

\[ \frac{\mu_{t+1}}{1 + r_{t+1}} \left( \omega R_{t+1}^w V_1^w (a_t^w, b_{t+1}^w) + (1 - \omega) R_{t+1}^w V_1^r (a_t^w, b_{t+1}^w) \right) = \\
R_t^w \left( \omega V_1^w (a_t^w, b_{t+1}^w) + (1 - \omega) V_1^r (a_t^w, b_{t+1}^w) \right) \leftrightarrow \\
\omega R_{t+1}^w V_1^w (a_t^w, b_{t+1}^w) + (1 - \omega) R_{t+1}^w V_1^r (a_t^w, b_{t+1}^w) = \\
\left( \frac{\omega}{\Omega_{t+1}} R_{t+1}^w + (1 - \frac{\omega}{\Omega_{t+1}}) R_{t+1}^r \right) \left( \omega V_1^w (a_t^w, b_{t+1}^w) + (1 - \omega) V_1^r (a_t^w, b_{t+1}^w) \right) \leftrightarrow \]

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\[
\omega \left( R^{w}_{t+1} - R^{r}_{t+1} \right) V^{w}_{1} \left( a^{w}_{t}, b^{w}_{t+1} \right) = \frac{\omega}{\Omega^{t+1}} \left( R^{w}_{t+1} - R^{r}_{t+1} \right) \left( \omega V^{w}_{1} \left( a^{w}_{t}, b^{w}_{t+1} \right) + (1 - \omega) V^{r}_{1} \left( a^{w}_{t}, b^{w}_{t+1} \right) \right) \iff \\
\Omega^{t+1} = \omega + (1 - \omega) \frac{V^{r}_{1} \left( a^{w}_{t}, b^{w}_{t+1} \right)}{V^{w}_{1} \left( a^{w}_{t}, b^{w}_{t+1} \right)} \\
\Omega^{t+1} = \omega + (1 - \omega) \left( \frac{1 - \tau^{w}_{t+1}}{1 - \tau^{r}_{t+1}} \xi^{w} \right)^{1 - \nu} \left( \frac{\Delta^{w}_{t+1}}{\Delta^{r}_{t+1}} \right)^{1 - \nu},
\]

where in the last line we use that, for an individual who is working in period \(t\) and retires in period \(t + 1\), \(V^{r}_{1} \left( a^{w}_{t}, b^{w}_{t+1} \right) = \left( 1 + r_{t+1} \right) \left( \Delta^{r}_{t} \right)^{1 - \nu} \left( \frac{1 - \nu}{1 - \nu} \right) \left( \xi^{w} \right)^{1 - \nu} \), while \(V^{w}_{1} \left( a^{w}_{t}, b^{w}_{t+1} \right) = \left( 1 - \tau^{w}_{t+1} \right) \left( \Delta^{w}_{t+1} \right)^{1 - \nu} \left( \frac{1 - \nu}{1 - \nu} \right) \left( \xi^{w} \right)^{1 - \nu} \). This expression for \(\Omega^{t+1}\) is identical to how it is defined above, therefore confirming our conjecture.

### 3.5.2 Decision problems of firms and government

#### 3.5.2.1 Final goods sector

There is a continuum of retail firms, indexed by \(z \in [0, 1]\). The perfectly competitive final goods sector assembles the differentiated retail goods according to:

\[
Y^{z}_{t} = \left( \int_{0}^{1} (Y^{z}_{z,t})^{rac{-1}{\epsilon - 1}} dz \right)^{\frac{1}{\epsilon - 1}}, \tag{3.43}
\]

where \(\epsilon > 1\) is the elasticity of demand for the intermediate goods purchased from different retail firms. Each retail good \(Y^{z}_{z,t}\) is produced by one retail firm (which is also indexed by \(z\)) and sold at the nominal price \(P^{z}_{z,t}\). The final goods producing sector maximises profits taking all prices (\(P^{t}_{t}\), the nominal price of the final good, and \(P^{z}_{z,t}, \forall z \in [0, 1]\)) as given:

\[
\max_{Y^{z}_{z,t}} P^{t}_{t} Y^{z}_{t} - \int_{0}^{1} P^{z}_{z,t} Y^{z}_{z,t} dz.
\]

Using (3.43) and differentiating with respect to a particular \(Y^{z}_{z,t}\) gives rise to the following demand function for the output of a particular retail good \(z\) producing firm:

\[
Y^{z}_{z,t} = Y^{z}_{t} \left( \frac{P^{z}_{z,t}}{P^{t}_{t}} \right)^{-\epsilon}, \tag{3.44}
\]

Imposing zero profits in the final goods sector maximisation problem yields that the price of the final good can be understood as an average of the retail firm prices:

\[
P^{t}_{t} = \left( \int_{0}^{1} (P^{z}_{z,t})^{1 - \epsilon} dz \right)^{\frac{1}{1 - \epsilon}}. \tag{3.45}
\]
3.5.2.2 Capital producing sector

At the end of period $t$, the competitive capital producing sector purchases the remaining stock of capital $(1-\delta)\zeta_t K_{t-1}$ from the intermediate goods producing firms at the real price $q_t$. This capital is combined with $I_t$ units of investment (in the form of output purchased from final goods producers) to produce next period’s beginning of period stock of capital $K_t$. This stock of capital is then sold to the intermediate goods producing firms at the real price $q_t$. The capital producing sector faces convex adjustment costs when transforming final goods into capital. Capital evolves as follows:

$$K_t = (1-\delta)\zeta_t K_{t-1} + \left(1 - S\left[\frac{I_t}{I_{t-1}}\right]\right)I_t,$$

(3.46)

with $S\left[\frac{I_t}{I_{t-1}}\right] = \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - 1\right)^2$. This capital evolution specification contains investment adjustment costs in the sense that investing $I_t$ final goods in period $t$ will only increase tomorrow’s capital stock by $\left(1 - S\left[\frac{I_t}{I_{t-1}}\right]\right)I_t$. This specification is similar to Fernández-Villaverde & Rubio-Ramírez (2006) and Christiano et al. (2005), and $\kappa$ (the second derivative of $S\left[\frac{I_t}{I_{t-1}}\right]$) represents the severity of the investment adjustment costs. In period $t$ the profits of the capital producing sector are given by

$$\Pi^c_t = q_t K_t - q_t (1-\delta)\zeta_t K_{t-1} - I_t.$$

The capital producing sector maximises the present discounted value of profits, where we substitute (3.46) in $\Pi^c_t$:

$$\max_{\{I_{t+i}\}_{i=0}^{\infty}} \sum_{i=0}^{\infty} \left(\prod_{s=1}^{i} \frac{1}{1 + r_{t+s}}\right) \left(q_{t+i} \left(1 - S\left[\frac{I_{t+i}}{I_{t+i-1}}\right]\right) I_{t+i} - I_{t+i}\right).$$

Profits (which can arise outside of the steady state) are redistributed lump sum to the group of workers. Differentiating with respect to investment $I_t$ gives the following condition for the investment path:

$$1 = q_t \left(1 - S\left[\frac{I_t}{I_{t-1}}\right] + \frac{I_t}{I_{t-1}} S'\left[\frac{I_t}{I_{t-1}}\right]\right) + \frac{q_{t+1}}{1 + r_{t+1}} \left(\frac{I_{t+1}}{I_{t}}\right)^2 S\left[\frac{I_{t+1}}{I_{t}}\right].$$

3.5.2.3 Intermediate goods sector

There is a continuum of competitive intermediate good producing firms indexed by $j \in [0, 1]$. The intermediate good $j$ is produced by the intermediate good $j$ producer according to:

$$Y_{j,t} = (\zeta_t K_{j-1}^\alpha (L_{j,t})^{1-\alpha},$$

(3.47)

$$\log(\zeta_t) = \rho_\zeta \log(\zeta_{t-1}) + \varepsilon_t.$$
Capital quality is denoted by $\zeta_t$, follows an AR(1)-process and is subject to the unanticipated shock $\varepsilon_t$. $L_{j,t}$ and $K_{j,t-1}$ denote the employed labour and capital by the intermediate good $j$ producing firm. As previously mentioned, the intermediate good producing firms purchase their employed capital for period $t+1$ from the capital producing sector in period $t$ and therefore capital used for production in period $t$ is indexed by $t-1$. A negative realisation of $\varepsilon_t$ decreases the quality of the capital stock such that the effective capital used in production in period $t$ is $\zeta_t K_{j,t-1}$. The intermediate good producing firms produce output $Y_{j,t}$ and hire labour $L_{j,t}$ at a unit cost of $w_t$. The markets for labour and capital are perfectly competitive and so the intermediate good $j$ producing firm takes their prices as given. The intermediate good producers sell their output to the retail firms at the real price $m_{ct}$. After production, the remaining effective capital stock is sold back to the capital producing sector at the real price $q_t$. The intermediate good producing firms finance their capital purchases each period by obtaining funds from the households and the pension fund. We assume that there are no frictions in the process of obtaining these funds. The intermediate good producing firms offer the households and the pension fund a perfectly state-contingent security, which is best interpreted as equity.

The period $t$ profits of the intermediate good $j$ producing firm are given by:

$$\Pi^i_{j,t} = m_{ct} (\zeta_t K_{j,t-1})^\alpha (L_{j,t})^{1-\alpha} + q_t (1-\delta) \zeta_t K_{j,t-1} - w_t L_{j,t} - (1+r_t) q_{t-1} K_{j,t-1},$$

which consists of the sale of output to retail firms $m_{ct} (\zeta_t K_{j,t-1})^\alpha (L_{j,t})^{1-\alpha}$, the sale of the remaining capital stock to the capital producing sector $q_t (1-\delta) \zeta_t K_{j,t-1}$, the hiring of labour $w_t L_{j,t}$ and the repayment of previous period’s borrowed funds $(1+r_t) q_{t-1} K_{j,t-1}$. The intermediate good $j$ producing firm maximises the present discounted value of profits taking all prices as given:

$$\max_{\{K_{j,t+i}, L_{j,t+i}\}_{t=0}^{\infty}} \prod_{i=0}^{\infty} \left( \frac{1}{1+r_{t+s}} \right) \Pi^i_{j,t+i}.$$

Differentiating with respect to $L_{j,t}$ and $K_{j,t}$ gives the following first-order conditions for labour and capital, respectively:

$$w_t = (1-\alpha) m_{ct} \frac{Y_{j,t}}{L_{j,t}}, \quad (3.48)$$

$$q_t = \frac{1}{1+r_{t+1}} \left( \alpha m_{ct+1} \frac{Y_{j,t+1}}{K_{j,t}} + q_{t+1} (1-\delta) \zeta_{t+1} \right).$$

Since the intermediate goods sector is perfectly competitive, per-period profits are zero state-by-state. Using (3.48) in $\Pi^i_{j,t} = 0$ gives the required ex post return on capital the
intermediate good producing firms pay out to the households and pension fund, confirming
the perfectly state-contingent nature of the traded security:

\[ 1 + r_t = \frac{\alpha mc_t Y_{j,t} \gamma_{j,t-1}}{q_{t-1}} + q_t (1 - \delta) \zeta_t. \] (3.49)

Rewriting (3.48) and (3.49) gives the factor demands:

\[ L_{j,t} = (1 - \alpha) mc_t Y_{j,t}, \] \hspace{1cm} (3.50)

\[ K_{j,t-1} = \frac{\alpha mc_t Y_{j,t}}{q_{t-1} (1 + r_t) - q_t (1 - \delta) \zeta_t}. \] \hspace{1cm} (3.51)

From this it follows that all intermediate good producing firms employ the same capital-
labour ratio:

\[ \frac{K_{j,t-1}}{L_{j,t}} = \frac{K_{t-1}}{L_t} = \frac{\alpha}{1 - \alpha} \frac{w_t}{q_{t-1} (1 + r_t) - q_t (1 - \delta) \zeta_t}. \]

Substituting the factor demands into the production function of the intermediate good
producer, we obtain the real intermediate good price $mc_t$:

\[ mc_t = \left( \frac{w_t}{1 - \alpha} \right)^{1-\alpha} \left( \frac{q_{t-1} (1 + r_t) - q_t (1 - \delta) \zeta_t}{\zeta_t \alpha} \right)^{\alpha}. \]

### 3.5.2.4 Retail sector

After purchasing output from the intermediate good producing firms at the real price $mc_t$, the retail firms convert the intermediate goods sector output into retail goods which are sold to the final goods sector at the nominal price $P_{z,t}$. The intermediate goods are converted one-to-one into retail goods, which entails that the retailers simply repackage the intermediate goods. We assume that each retail firm produces a differentiated retail
good $Y_{z,t}$ such that it operates in a monopolistically competitive market and charges a markup over the input price $mc_t$. Additionally, we introduce nominal rigidities by means of Calvo (1983)-type pricing frictions. By construction, each period a fraction $1 - \theta$ of retail firms can adjust its price (which it will do so in an optimal fashion, taking into account the probability that it might not be able to change its price in future periods) and a fraction $\theta$ of firms cannot adjust its price. Denote with $P^*_{z,t}$ the nominal optimal reset price in period $t$ of retail firm $z$ that can change its price. Since the group of workers are assumed to receive the profits of the retail firms, the appropriate pricing kernel used to value profits received in $i$ periods is $\beta^i \Lambda_{w,1-i}$ with $\Lambda_t = v (\Delta w_t)^{\frac{1}{1-w} \left( \frac{1-v}{v} \frac{1}{(1-r_t^{1-v} w_t)} \right)^{1-v}}$, being the marginal value to a worker of receiving one additional unit of lifetime wealth in period.
When retail firm \( z \) is allowed to change its price in period \( t \), it solves the following optimisation problem:

\[
\max_{P_{i,t}} \sum_{i=0}^{\infty} (\beta \theta)^i \frac{\Lambda_{t+i}}{\Lambda_t} \left( \frac{P_{i,t}^*}{P_{t+i}} - mc_{t+i} \right) Y_{z,t+i}, \text{s.t. } Y_{z,t+i} = Y_{t+i} \left( \frac{P_{i,t}^*}{P_{t+i}} \right)^{-\epsilon}.
\]

Profit maximisation yields the following first-order condition:

\[
\sum_{i=0}^{\infty} (\beta \theta)^i \Lambda_{t+i} \left( (1 - \epsilon) \frac{P_{i,t}^*}{P_t} \left( \prod_{s=1}^{i} \frac{1}{\Pi_{t+s}} \right)^{1-\epsilon} + \epsilon mc_{t+i} \left( \prod_{s=1}^{i} \frac{1}{\Pi_{t+s}} \right)^{-\epsilon} \right) Y_{t+i} = 0,
\]

where \( \Pi_{t+s} = \frac{P_{t+s}^v}{P_{t+s-1}} \). Reorganising and realising that the symmetric nature of the economic environment implies that all price adjusting firms will choose the same price, i.e. \( P_t^* = P_{z,t}^* \) \( \forall z \), yields the following condition characterising the optimal real reset price \( \Pi_t^* = \frac{P_t^*}{P_t} \):

\[
\Pi_t^* = \frac{\epsilon}{\epsilon - 1} \sum_{i=0}^{\infty} (\beta \theta)^i \Lambda_{t+i} \left( \frac{P_{i,t}^*}{P_t} \right)^{\epsilon} Y_{t+i},
\]

(3.52)

To express the first-order condition (3.52) recursively, we write it as \( \Pi_t^* = \frac{\epsilon}{\epsilon - 1} g_t^1 \) with:

\[
g_t^1 = \Lambda_t mc_t Y_t + \beta \theta (\Pi_{t+1})^{\epsilon} g_{t+1}^1,
\]

\[
g_t^2 = \Lambda_t Y_t + \beta \theta (\Pi_{t+1})^{\epsilon-1} g_{t+1}^2.
\]

Because of the Calvo-pricing rigidity a share \( 1 - \theta \) of retail firms can adjust its price and sets it to \( P_{z,t} = P_t^* \) and a share \( \theta \) of retail firms cannot adjust its price and has to set it to \( P_{z,t} = P_{z,t-1} \). This gives in (3.45) the evolution of the aggregate price level as a geometric average of the past aggregate price level and the current optimal price:

\[
1 = \theta (\Pi_t)^{\epsilon-1} + (1 - \theta) (\Pi_t)^{1-\epsilon}.
\]

### 3.5.2.5 Government and central bank

Since the government is non-Ricardian in this model, we elect to minimise the role of the fiscal authority so as to not distort our research findings regarding the macroeconomic implications of pension fund restoration policy. As such, we rule out government purchases. We suppose that the central bank follows a Taylor rule with interest rate smoothing. The monetary authority responds to deviations of inflation from the target inflation rate \( \bar{\Pi} \)
and to deviations of output from steady state output $\bar{Y}$:

$$\frac{1 + i_t}{1 + i} = \left(\frac{1 + i_{t-1}}{1 + i}\right)^{\eta_i} \left(\frac{\Pi_t}{\Pi}\right)^{\eta_{\Pi}} \left(\frac{Y_t}{\bar{Y}}\right)^{\eta_Y} 1 - \eta_i,$$

where $\bar{i}$ is the steady-state nominal interest rate, $\eta_i \in (0, 1)$ the interest rate smoothing parameter, $\eta_{\Pi}$ the inflation coefficient and $\eta_Y$ the output coefficient. Additionally, the Fisher relation holds:

$$1 + i_t = \Pi_{t+1} (1 + r_{t+1}).$$

### 3.5.2.6 Aggregation

For the output markets to clear it is required that

$$\int_0^1 Y_{z,t} dz = \int_0^1 Y_{j,t} dj = Y_t \int_0^1 \left(\frac{P_{z,t}}{F_t}\right)^{-\epsilon} dz,$$

for the labour market to clear it is required that $\int_0^1 L_{j,t} dj = L_t$ and for the capital market to clear it is required that $\int_0^1 K_{j,t} dj = K_t$. Integrating the factor demand conditions (3.50) and (3.51) over $j$ gives the aggregate factor demand conditions:

$$L_t = (1 - \alpha \gamma c_t) Y_t v_t^p,$$

$$K_{t-1} = \frac{\alpha mc_t Y_t v_t^p}{q_{t-1}(1 + r_t) - q_t(1 - \delta)} \zeta_t,$$

where $v_t^p = \int_0^1 \left(\frac{P_{z,t}}{F_t}\right)^{-\epsilon} dz$ is a measure of price dispersion. Because of the Calvo-pricing rigidity a share $1 - \theta$ of retail firms can adjust its price and sets it to $P_{z,t} = P^*_t$ and a share $\theta$ of retail firms cannot adjust its price and has to set it to $P_{z,t} = P_{z,t-1}$. This allows us to express $v_t^p$ recursively:

$$v_t^p = (1 - \theta) (\Pi_t^*)^{-\epsilon} + \theta (\Pi_t)^{\epsilon} v_{t-1}^p.$$

Aggregate supply is obtained through integrating (3.47) over $j$ and using that $\frac{K_{j,t-1}}{L_{j,t}} = \frac{K_{t-1}}{L_t}, \forall j$ and that $\int_0^1 L_{j,t} dj = L_t$:

$$Y_t v_t^p = (\zeta_t K_{t-1})^{\alpha} (L_t)^{\gamma - \alpha},$$

$$Y_t = C_t + I_t.$$

Savings market clearing requires that the total value of savings (which is the sum of the private savings of workers and retirees and the end-of-period assets of the pension
fund) equates the total value of the capital stock:

\[ A_t^w + A_t^r + \frac{A_{t+1}^f}{1 + r_{t+1}} = q_t K_t. \]

Aggregate profits (comprised of those of the retail sector and the capital goods sector) are given by:

\[ F_t = (1 - mc_t v_t^p) Y_t + q_t \left( 1 - S \left[ \frac{I_t}{I_{t-1}} \right] \right) I_t - I_t. \] (3.56)

### 3.5.3 Equilibrium conditions

#### 3.5.3.1 Pension fund

Private annuity factors of retirees and workers:

\[
R_t^r = 1 + \gamma \frac{\mu_{t+1}}{(\Pi_{t+1})^{\text{acc}} (1 + r_{t+1})} R_{t+1}^r, \\
R_t^w = \frac{\mu_{t+1}}{(\Pi_{t+1})^{\text{acc}} (1 + r_{t+1})} \left( \frac{\omega}{\Omega_{t+1}} R_{t+1}^w + (1 - \frac{\omega}{\Omega_{t+1}}) R_{t+1}^r \right).
\]

Pension fund annuity factors of retirees and workers:

\[
R_{t}^{r,f} = 1 + \frac{\gamma}{(\Pi_{t+1})^{\text{acc}} (1 + r_{t+1})} R_{t+1}^{r,f}, \\
R_{t}^{w,f} = \frac{1}{(\Pi_{t+1})^{\text{acc}} (1 + r_{t+1})} \left( \omega R_{t+1}^{w,f} + (1 - \omega) R_{t+1}^{r,f} \right).
\]

Aggregate per-period pension benefits of retirees and workers:

\[
(\Pi_t)^{\text{acc}} B_t^r = \gamma \left( \mu_{t-1} B_{t-1}^r + \nu_{t-1} w_{t-1} L_{t-1}^r \right) + (1 - \omega) \left( \mu_{t-1} B_{t-1}^w + \nu_{t-1} w_{t-1} L_{t-1}^w \right), \\
(\Pi_t)^{\text{acc}} B_t^w = \omega \left( \mu_{t-1} B_{t-1}^w + \nu_{t-1} w_{t-1} L_{t-1}^w \right).
\]

Pension fund assets and liabilities:

\[
A_t^f = (1 + r_t) \left( A_{t-1}^f + \tau_{t-1} w_{t-1} L_{t-1} - \mu_{t-1} B_{t-1}^r \right), \\
L_t^f = R_t^{r,f} B_t^r + R_t^{w,f} B_t^w.
\]

Pension fund restoration policy is set such that the following condition is satisfied:
This gives the following pension fund policy in the DB case (with $\bar{\nu}$ exogenously given):

$$
\mu_t = 1,
\nu_t = \bar{\nu},
$$

$$
\frac{1 + r_{t+1} - \nu}{1 + r_{t+1}} (A^f_t - \bar{f}r L^f_t) = \bar{f}r \left( \frac{1 - \bar{f}r}{\bar{f}r} \mu_t B^r_t + (\mu_t - 1)L^f_t + \nu_t w_t \left( \left( R^{r,f}_{t+1} \xi L^r_t + R^{w,f}_{t} L^w_t \right) - \tau w_t L_t. \right) \right)
$$

This gives the following pension fund policy in the DC case (with $\bar{\tau}$ and $\bar{\nu}$ exogenously given):

$$
\tau_t = \bar{\tau},
\nu_t = \bar{\nu},
$$

$$
\frac{1 + r_{t+1} - \nu}{1 + r_{t+1}} (A^f_t - \bar{f}r L^f_t) = \bar{f}r \left( \frac{1 - \bar{f}r}{\bar{f}r} \mu_t B^r_t + (\mu_t - 1)L^f_t + \bar{\nu} w_t \left( \left( R^{r,f}_{t+1} \xi L^r_t + R^{w,f}_{t} L^w_t \right) - \bar{\tau} w_t L_t. \right) \right)
$$

### 3.5.3.2 Workers and retirees

Inverse MPCW of retirees and workers:

$$
\Delta^r_t = 1 + \gamma \beta^\sigma \Delta^r_{t+1} \left( (1 + r_{t+1}) \left( \frac{(1 - \tau^r_t) w_t}{(1 - \tau^r_{t+1}) w_{t+1}} \right) \right)^{1-v} \sigma^{-1},
$$

$$
\Delta^w_t = 1 + \beta^\sigma \Delta^w_{t+1} \left( (1 + r_{t+1}) \Omega_{t+1} \left( \frac{(1 - \tau^w_t) w_t}{(1 - \tau^w_{t+1}) w_{t+1}} \right) \right)^{1-v} \sigma^{-1}.
$$

Subjective reweighting of transition probabilities:

$$
\Omega_t = \omega + (1 - \omega) \left( \frac{1 - \tau^w_t}{1 - \tau^r_t} \xi \right)^{1-v} \left( \frac{\Delta^w_t}{\Delta^r_t} \right)^{1-\sigma}.
$$
Effective contribution rates on labour:
\[
\tau^r_t = \tau_t - (R^r_t - 1) \nu_t, \\
\tau^w_t = \tau_t - R^w_t \nu_t.
\]

Aggregate full consumption of retirees and workers:
\[
X^z_t = \frac{1}{\Delta^z_t} \left( (1 + r_t)A^z_{t-1} + H^z_t + \mu_t B_t^r R_t^r \right), \quad z \in \{w, r\}.
\]

Aggregate human wealth of retirees and workers:
\[
H^r_t = D^r_t + \gamma \frac{1}{1 + r_{t+1}} H^r_{t+1}, \\
H^w_t = D^w_t + \frac{1}{1 + r_{t+1}} \left( \frac{\omega}{\Omega_{t+1}} H^w_{t+1} + (1 - \frac{\omega}{\Omega_{t+1}}) \frac{1}{\psi} H^r_{t+1} \right).
\]

Aggregate full income of retirees and workers:
\[
D^r_t = N^r(1 - \tau^r_t)\xi w_t, \\
D^w_t = N^w(1 - \tau^w_t)w_t + F_t.
\]

Aggregate consumption of retirees, workers and total population:
\[
C^z_t = v X^z_t, \quad z \in \{w, r\}, \\
C_t = C^r_t + C^w_t.
\]

Aggregate labour supply of retirees, workers and total population, where \(w^r_t = \xi w_t\) and \(w^w_t = w_t\):
\[
L^z_t = N^z - \frac{(1 - v)X^z_t}{(1 - \tau^w_t)w^z_t}, \quad z \in \{w, r\}, \\
L_t = L^w_t + \xi L^r_t.
\]

Aggregate private savings of retirees and workers:
\[
A^r_t = (1 + r_t)A^r_{t-1} + \mu_t B_t^r + (1 - \tau_t)\xi w_t L^r_t - C^r_t + \frac{1 - \omega}{\omega} A^w_t, \\
A^w_t = \omega \left( (1 + r_t)A^w_{t-1} + (1 - \tau_t)w_t L^w_t + F_t - C^w_t \right).
\]
3.5.3.3 Firms and government

Production function:

\[ Y_t v_t^p = (\zeta_t K_{t-1})^\alpha (L_t)^{1-\alpha}. \]

Aggregate resource constraint:

\[ Y_t = C_t + I_t. \]

Marginal cost:

\[ mc_t = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \left(q_{t-1}(1+r_t) - q_t(1-\delta)\zeta_t\right)^\alpha. \]

Real interest rate:

\[ 1 + r_t = \frac{\alpha mc_t v_t^p Y_t}{K_{t-1}} + q_t(1-\delta)\zeta_t. \]

Capital stock law of motion:

\[ K_t = (1-\delta)\zeta_t K_{t-1} + \left(1 - S\left[\frac{I_t}{I_{t-1}}\right]\right) I_t. \]

Adjustment costs percentage:

\[ S\left[\frac{I_t}{I_{t-1}}\right] = \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - 1\right)^2. \]

Investment:

\[ 1 = q_t \left(1 - S\left[\frac{I_t}{I_{t-1}}\right] + \frac{I_t}{I_{t-1}} S\left[\frac{I_t}{I_{t-1}}\right]\right) + \frac{q_{t+1}}{1 + r_{t+1}} \left(\frac{I_{t+1}}{I_t}\right)^2 S\left[\frac{I_{t+1}}{I_t}\right]. \]

Market clearing for savings:

\[ A_t^w + A_t^r + \frac{A_{t+1}^f}{1 + r_{t+1}} = q_t K_t. \]

Optimal real reset price:

\[ \Pi_t^* = \frac{\epsilon}{\epsilon - 1} \frac{g_t^1}{g_t^2}. \]

\[ g_t^1 = \Lambda_t mc_t Y_t + \beta \theta (\Pi_{t+1})^\epsilon g_{t+1}^1, \]

\[ g_t^2 = \Lambda_t Y_t + \beta \theta (\Pi_{t+1})^{\epsilon-1} g_{t+1}^2. \]
Pricing kernel of intermediate goods producing firms:

\[ \Lambda_t = v (\Delta_{t}^w)^{\frac{\sigma - 1}{\sigma}} \left( \frac{1 - v}{v} \frac{1}{(1 - \tau_{t}^w)w_t} \right)^{1 - v}. \]

Evolution of aggregate price level:

\[ 1 = \theta (\Pi_t)^{\epsilon - 1} + (1 - \theta) (\Pi_t^*)^{1 - \epsilon}. \]

Price dispersion:

\[ v_t^p = (1 - \theta) (\Pi_t^*)^{-\epsilon} + \theta (\Pi_t)^\epsilon v_{t-1}^p. \]

Profits:

\[ F_t = (1 - mc_t v_t^p) Y_t + q_t \left( 1 - S \left( \frac{I_t}{I_{t-1}} \right) \right) I_t - I_t. \]

Fisher relation:

\[ 1 + i_t = \Pi_{t+1} (1 + r_{t+1}). \]

Monetary policy rule:

\[ \frac{1 + i_t}{1 + i} = \left( \frac{1 + i_{t-1}}{1 + i} \right)^{\eta_i} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\eta_{\Pi}} \left( \frac{Y_t}{Y} \right)^{\eta_Y} \right)^{1 - \eta_i}. \]

Capital quality:

\[ \log(\zeta_t) = \rho \zeta \log(\zeta_{t-1}) + \varepsilon_t. \]

### 3.5.4 Sensitivity analyses

We perform sensitivity analyses with respect to the intertemporal elasticity of substitution, the size of the pension fund balance sheet and the pension funding gap half-life. The welfare effects are reported in tables A3.1, A3.2 and A3.3.

Within the literature of adapted Gertler (1999)-models the calibrated values of the intertemporal elasticity of substitution range between \( \frac{1}{4} \) and \( \frac{1}{2} \). We adjust the accrual and contribution rates such that the size of the pension fund remains \( \frac{A_t^f}{I_t^f} = 0.88 \) in the steady state. In the real accounting framework retirees more strongly prefer a DB pension fund for higher levels of \( \sigma \) because the funding gap is larger after the adverse capital quality shock materialises. The workers who are alive at \( t = 1 \) also more strongly prefer a DB pension fund, because at a higher level of \( \sigma \) the subjective reweighting of transition probabilities variable \( \Omega \) is higher, implying that they are more eager to have the value of
their previously accumulated pension wealth guaranteed. The workers born after $t = 1$, on the other hand, do not have previously accumulated pension wealth and are negatively affected by their distorted labour supply for higher levels of $\sigma$. In the nominal accounting framework the effects are the opposite. For lower values of $\sigma$ the funding surplus is larger due to a higher inflation path. Retirees then more strongly prefer a DC pension fund, while the opposite holds for all workers who more strongly prefer the cheap accrual of new pension wealth to a revaluation of previously accumulated pension wealth.

We consider both a smaller pension fund (with pension fund assets equal to 50% of yearly output, the OECD average in 2016) and a larger one (with pension fund assets equal to 125% of yearly output, the weighted OECD average in 2016). The reported results for the default calibration are qualitatively maintained and with the stakes simply scaled up. The only exception comes from the welfare of the future generations in a nominal accounting framework, who have a less pronounced preference for the DB pension fund when it manages more assets. This stems from the fact that the funding gap is larger for the smaller pension fund due to a higher path for inflation. In the DB system the effective contribution rate on labour income is therefore lower (in terms of relative deviation from its steady state value) for the smaller pension fund compared to the larger pension fund.

Lastly, we consider slower recoveries with a half-life of two and four years. When the pension fund postpones the closure of its funding gap in the real accounting framework, retirees in the meantime receive a pension that more closely matches what was promised to them before the adverse capital quality shock materialised. As such, the retiree preference for either type of pension fund diminishes. The workers alive at $t = 1$ have a similar preference, because with a longer half-life labour supply is distorted comparatively less in the first periods after the adverse capital quality shock and more in future periods. The workers born after $t = 1$ are on the receiving end of these distortions and therefore more strongly prefer a DC pension fund as the closure speed becomes lower. In the nominal accounting framework, the individuals alive in period $t = 1$ have a stronger preference for their preferred pension system when the recovery speed is higher because then the funding surplus is distributed more quickly. The future generations, however, more strongly prefer a DB pension fund with a longer recovery as they then capture a larger portion of the cheap accrual of new pension wealth.
### Real business cycle

<table>
<thead>
<tr>
<th></th>
<th>Retirees alive at $t = 1$</th>
<th>Workers alive at $t = 1$</th>
<th>Workers born after $t = 1$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma = \frac{1}{4}$</td>
<td>-0.35%</td>
<td>-0.08%</td>
<td>+0.06%</td>
<td>-0.37%</td>
</tr>
<tr>
<td>$\sigma = \frac{1}{3}$</td>
<td>-0.44%</td>
<td>-0.14%</td>
<td>+0.07%</td>
<td>-0.51%</td>
</tr>
<tr>
<td>$\sigma = \frac{1}{2}$</td>
<td>-0.50%</td>
<td>-0.28%</td>
<td>+0.08%</td>
<td>-0.70%</td>
</tr>
<tr>
<td>$\frac{A_f^I}{4Y} = 0.50$</td>
<td>-0.22%</td>
<td>-0.07%</td>
<td>+0.04%</td>
<td>-0.25%</td>
</tr>
<tr>
<td>$\frac{A_f^I}{4Y} = 0.88$</td>
<td>-0.44%</td>
<td>-0.14%</td>
<td>+0.07%</td>
<td>-0.51%</td>
</tr>
<tr>
<td>$\frac{A_f^I}{4Y} = 1.25$</td>
<td>-0.72%</td>
<td>-0.22%</td>
<td>+0.10%</td>
<td>-0.84%</td>
</tr>
<tr>
<td>Half-life = 1 year</td>
<td>-0.44%</td>
<td>-0.14%</td>
<td>+0.07%</td>
<td>-0.51%</td>
</tr>
<tr>
<td>Half-life = 2 years</td>
<td>-0.41%</td>
<td>-0.25%</td>
<td>+0.09%</td>
<td>-0.57%</td>
</tr>
<tr>
<td>Half-life = 4 years</td>
<td>-0.37%</td>
<td>-0.39%</td>
<td>+0.12%</td>
<td>-0.64%</td>
</tr>
</tbody>
</table>

**Table A3.1:** Welfare effects of switching from a DB pension fund to a DC pension fund for various parameter changes to the baseline calibration. Obtained in the real business cycle version of the model. Measured as an equivalent variation showing the transfer of wealth as a percentage of steady state yearly output necessary for indifference between the two pension fund arrangements. The baseline calibration is characterised by $\sigma = \frac{1}{3}$, $\frac{A_f^I}{4Y} = 0.88$ and half-life = 1 year.
### New-Keynesian, real framework

<table>
<thead>
<tr>
<th>Parameter Changes</th>
<th>Retirees alive at ( t = 1 )</th>
<th>Workers alive at ( t = 1 )</th>
<th>Workers born after ( t = 1 )</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma = \frac{1}{4} )</td>
<td>-0.31%</td>
<td>+0.16%</td>
<td>+0.08%</td>
<td>-0.07%</td>
</tr>
<tr>
<td>( \sigma = \frac{1}{3} )</td>
<td>-0.41%</td>
<td>+0.11%</td>
<td>+0.13%</td>
<td>-0.17%</td>
</tr>
<tr>
<td>( \sigma = \frac{1}{2} )</td>
<td>-0.47%</td>
<td>+0.00%</td>
<td>+0.16%</td>
<td>-0.31%</td>
</tr>
<tr>
<td>( \frac{\lambda'}{\lambda Y} = 0.50 )</td>
<td>-0.21%</td>
<td>+0.08%</td>
<td>+0.07%</td>
<td>-0.06%</td>
</tr>
<tr>
<td>( \frac{\lambda'}{\lambda Y} = 0.88 )</td>
<td>-0.41%</td>
<td>+0.11%</td>
<td>+0.13%</td>
<td>-0.17%</td>
</tr>
<tr>
<td>( \frac{\lambda'}{\lambda Y} = 1.25 )</td>
<td>-0.67%</td>
<td>+0.11%</td>
<td>+0.21%</td>
<td>-0.35%</td>
</tr>
<tr>
<td>Half-life = 1 year</td>
<td>-0.41%</td>
<td>+0.11%</td>
<td>+0.13%</td>
<td>-0.17%</td>
</tr>
<tr>
<td>Half-life = 2 years</td>
<td>-0.37%</td>
<td>+0.01%</td>
<td>+0.17%</td>
<td>-0.19%</td>
</tr>
<tr>
<td>Half-life = 4 years</td>
<td>-0.32%</td>
<td>-0.14%</td>
<td>+0.22%</td>
<td>-0.23%</td>
</tr>
</tbody>
</table>

**Table A3.2:** Welfare effects of switching from a DB pension fund to a DC pension fund for various parameter changes to the baseline calibration. Obtained in the New-Keynesian version of the model with the real pension fund accounting framework. Measured as an equivalent variation showing the transfer of wealth as a percentage of steady state yearly output necessary for indifference between the two pension fund arrangements. The baseline calibration is characterised by \( \sigma = \frac{1}{3} \), \( \frac{\lambda'}{\lambda Y} = 0.88 \) and half-life = 1 year.
New-Keynesian, nominal framework

<table>
<thead>
<tr>
<th>Parameter Change</th>
<th>Retirees alive at $t = 1$</th>
<th>Workers alive at $t = 1$</th>
<th>Workers born after $t = 1$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma = \frac{1}{4}$</td>
<td>+1.90%</td>
<td>-0.52%</td>
<td>-0.56%</td>
<td>+0.82%</td>
</tr>
<tr>
<td>$\sigma = \frac{1}{3}$</td>
<td>+1.45%</td>
<td>-0.36%</td>
<td>-0.36%</td>
<td>+0.73%</td>
</tr>
<tr>
<td>$\sigma = \frac{1}{2}$</td>
<td>+0.97%</td>
<td>-0.06%</td>
<td>-0.21%</td>
<td>+0.70%</td>
</tr>
<tr>
<td>$\frac{A_f}{IY} = 0.50$</td>
<td>+1.11%</td>
<td>-0.01%</td>
<td>-0.43%</td>
<td>+0.67%</td>
</tr>
<tr>
<td>$\frac{A_f}{IY} = 0.88$</td>
<td>+1.45%</td>
<td>-0.36%</td>
<td>-0.36%</td>
<td>+0.73%</td>
</tr>
<tr>
<td>$\frac{A_f}{IY} = 1.25$</td>
<td>+1.52%</td>
<td>-0.66%</td>
<td>-0.24%</td>
<td>+0.62%</td>
</tr>
<tr>
<td>Half-life = 1 year</td>
<td>+1.45%</td>
<td>-0.36%</td>
<td>-0.36%</td>
<td>+0.73%</td>
</tr>
<tr>
<td>Half-life = 2 years</td>
<td>+1.31%</td>
<td>-0.01%</td>
<td>-0.46%</td>
<td>+0.84%</td>
</tr>
<tr>
<td>Half-life = 4 years</td>
<td>+1.13%</td>
<td>+0.46%</td>
<td>-0.58%</td>
<td>+1.01%</td>
</tr>
</tbody>
</table>

Table A3.3: Welfare effects of switching from a DB pension fund to a DC pension fund for various parameter changes to the baseline calibration. Obtained in the New-Keynesian version of the model with the nominal pension fund accounting framework. Measured as an equivalent variation showing the transfer of wealth as a percentage of steady state yearly output necessary for indifference between the two pension fund arrangements. The baseline calibration is characterised by $\sigma = \frac{1}{3}$, $\frac{A_f}{IY} = 0.88$ and half-life = 1 year.
Bibliography


Summary

This dissertation studies the importance of pension funding and housing within the financial portfolios of Dutch households, and their effect on consumption decisions. It consists of three chapters.

The first chapter considers the design of pension systems that provide both adequate income during retirement and liquidity during the accumulation phase of benefits. Households allocate large portions of their income to illiquid durable goods and pension plans. Governments often subsidise or mandate participation in the latter to ensure adequate retirement saving. This comes at the expense of decreased resilience to adverse shocks and distorted accumulation of durables during working life. We construct a life-cycle model with pensions and durables to study the effects of different pension plan designs. Contributions are irreversible until retirement and non-collateralisable, while purchasing durables is subject to adjustment costs and borrowing constraints. Despite this illiquidity, households keep little precautionary savings because of utility from durables and longevity insurance from pension plans. We calibrate the model to the pension system of the Netherlands where households face a rigid contribution mandate. Our model replicates the illiquid financial portfolios of Dutch households and indicates that flexibilisation policies (such as voluntary participation, richer contribution mandates and early withdrawal) improve household liquidity and welfare.

The second chapter brings together administrative data and expenditure survey waves from Statistics Netherlands (the Dutch national statistical office) to compare various imputation methods and to empirically investigate the determinants of household spending. Imputation methods are often applied to study household consumption behaviour since administrative data based on tax records does not contain information on consumption, while expenditure surveys generally do not include sufficiently rich income and wealth information. Previous literature has imputed consumption with administrative data using the household budget constraint. We introduce an alternative approach where expenditure surveys are supplemented with information from unlinkable administrative data using overlapping variables. We compare the two imputation methods by exploiting the Dutch
expenditure survey that is linkable to administrative data and apply both methods to study household consumption behaviour. We present evidence for heterogeneity in the marginal propensity to consume out of income and wealth due to the effects of low cash-on-hand, negative housing equity and mandatory pension fund participation.

The third chapter studies the macroeconomic consequences of the different ways in which pension funds can close funding gaps. When the financial positions of pension funds worsen, regulations prescribe that pension funds reduce the gap between their assets (invested contributions) and their liabilities (accumulated pension promises). We quantify the business cycle effects and distributional implications of various types of restoration policies. We extend a canonical New-Keynesian model with a tractable demographic structure and, as a novelty, a flexible pension fund framework. Fund participants accumulate inflation-indexed or non-indexed benefits and funding adequacy is restored by revaluing previously accumulated pension wealth (Defined Contribution) or changing the pension fund contribution rate on labour income (Defined Benefit). Economies with indexed Defined Contribution pension funds respond similarly to adverse capital quality shocks as economies without pension funds. Indexed Defined Benefit pension funds, however, distort labour supply decisions and exacerbate economic fluctuations. While indexed Defined Benefit pension funds achieve intergenerational risk-sharing, welfare analyses indicate that the negative effects of the induced distortions are sizeable.
Samenvatting

Dit proefschrift bestudeert het belang van pensioen- en huisvermogen binnen de financiële portefeuilles van Nederlandse huishoudens, en het effect daarvan op hun consumptiebeslissingen. Het bestaat uit drie hoofdstukken.

Het eerste hoofdstuk beschouwt de vormgeving van pensioenstelsels die zowel voldoende inkomen tijdens de pensionering als liquiditeit tijdens de opbouwfase van uitkeringen bieden. Huishoudens wijzen grote delen van hun inkomen toe aan illiqüide duurzame goederen en pensioenregelingen. Overheden subsidiëren of verplichten doorgaans deelname aan laatstgenoemde om voldoende pensioensparen af te dwingen. Dit gaat ten koste van een verminderde weerstand tegen ongunstige schokken en een verstoorde accumulatie van duurzame goederen tijdens het beroepsleven. We bouwen een levenscyclusmodel dat pensioenen en duurzame goederen bevat om de effecten van verschillende pensioenregelingen te bestuderen. Ingelegde premies zijn onomkeerbaar tot pensionering en er kan niet geleend worden met opgebouwde aanspraken als onderpand, terwijl de aankoop van duurzame goederen onderhevig is aan aanpassingskosten en leenlimieten. Ondanks deze illiqüiditeit houden huishoudens weinig spaargeld uit voorzorg aan vanwege het nut van duurzame goederen en de langlevenverzekering die pensioenregelingen bieden. We stemmen het model af op het Nederlandse pensioenstelsel waarin huishoudens te maken hebben met een rigide premiemandaat. Ons model replicateert de illiqüide financiële portefeuilles van Nederlandse huishoudens en geeft aan dat flexibiliseringsbeleid (zoals vrijwillige deelname, rijkere premiemandaten en vervroegde uitkering) de liquiditeit en de welvaart van huishoudens verbetert.

Het tweede hoofdstuk brengt administratieve data en uitgavenenquêtes van het Centraal Bureau voor de Statistiek samen om verschillende imputatiemethoden te vergelijken en om de determinanten van bestedingen door huishoudens empirisch te onderzoeken. Imputatiemethoden worden vaak toegepast om het consumptiegeldrag van huishoudens te bestuderen, aangezien administratieve data op basis van belastinggegevens geen informatie over bestedingen bevatten, terwijl uitgavenenquêtes over het algemeen onvoldoende rijke informatie over inkomen en vermogen bevatten. De bestaande literatuur heeft binnen ad-
administratieve data bestedingen geïmputeerd middels de budgetrestrictie van huishoudens. We introduceren een alternatieve aanpak waarbij uitgavenenquêtes worden aangevuld met informatie uit niet-koppelbare administratieve data met behulp van overlappende variabelen. We vergelijken de twee imputatiemethoden door gebruik te maken van het Nederlandse uitgavenonderzoek dat koppelbaar is aan de administratieve data en passen beide methoden toe om het consumptiegeld van huishoudens te bestuderen. We presenteren bewijs voor heterogeniteit in de marginale consumptieneiging uit inkomens en vermogen als gevolg van geringe beschikking over spaargeld, het eigen huis dat onder water staat en verplichte deelname aan pensioenregelingen.

Het derde hoofdstuk bestudeert de macro-economische gevolgen van de verschillende manieren waarop pensioenfondsen financieringstekorten kunnen dichten. Wanneer de financiële positie van pensioenfondsen verslechtert, schrijft wetgeving voor dat pensioenfondsen het gat tussen hun vermogen (belegde premies) en hun verplichtingen (opgebouwde pensioentoezeggingen) verkleinen. We kwantificeren de conjunctuureffecten en de verdelingsimplicaties van verschillende soorten herstelbeleid. We breiden daarvoor een kanoniek Nieuw-Keynesiaans model uit met een beheersbare demografische structuur en, als nieuwigheid, een flexibel pensioenfondskader. Fondsdeelnemers accumuleren inflatiegeïndexeerde of niet-geïndexeerde pensioentoezeggingen. Te lage dekkingsgraden worden hersteld middels het herwaarderen van eerder gedane pensioentoezeggingen (Defined Contribution) of door het premiepercentage op arbeidsinkomen te wijzigen (Defined Benefit). Economieën met geïndexeerde Defined Contribution pensioenfondsen reageren vergelijkbaar op ongunstige schokken in kapitaalkwaliteit als economieën zonder pensioenfondsen. Geïndexeerde Defined Benefit pensioenfondsen verstoren echter beslissingen over het arbeidsaanbod van huishoudens en verergeren economische schommelingen. Hoewel geïndexeerde Defined Benefit pensioenfondsen intergenerationele risicodeling faciliteren, wijzen welvaartsanalyses uit dat de negatieve effecten van de veroorzaakte verstoringen aanzienlijk zijn.
List of Authors

Chapters 1 and 2 are independent work. Chapter 3 is based on my MPhil thesis written at the Tinbergen Institute and co-authored by dr. W.E. Romp, who was my MPhil thesis supervisor. Since then, the MPhil thesis has been revised and published at the academic journal Macroeconomic Dynamics in 2020. The chapter in this dissertation is based on the published version of the MPhil thesis, which is available at https://doi.org/10.1017/S1365100518001049.
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