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On the determinants of wealth inequality: an overlapping generations approach

Master thesis

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It is not yet sufficiently understood how income inequality shapes the distribution of wealth. In this research, a simple overlapping generations general equilibrium model with heterogeneous agents is proposed where the distribution of earnings is exogenous. This allows to focus on three channels which may translate income into wealth inequality: (i) voluntary bequests, (ii) accidental bequests and (iii) inter-generational income mobility. The model has been calibrated to the US distribution of wealth. It can approximately account for the average wealth distribution as well as other stylized properties of the US economy.

Contents

1. Introduction

Economic inequality has been subject to investigation for many decades. With his seminal article, Kuznets (1955) was one of the first economists who evaluated income inequality and its relation to other macroeconomic variables. In the subsequent decades, a large strand of literature, which is concerned with the distribution of income, has developed (e.g. Persson & Tabellini, 1994; Aghion, 2002; Piketty & Saez, 2003). Contrary, less is known about the ways income inequality shapes the distribution of wealth. Most models which try to explain the distribution of wealth are either Aiyagari-Bewley (AB) or (simulated) Overlapping Generations (OLG) economies or a mixture of both. Many AB models understate wealth inequality (e.g. Aiyagari, 1994; Huggett, 1996) whereas most OLG simulation studies utilize highly complex models (e.g. Gokhale & Kotlikoff, 2002). Among those models which fit the data relatively well, we find pronounced discrepancies concerning the channel through which the empirical distribution is matched. Hence, policy implications vary dramatically as pointed out by De Nardi & Fella (2017). However, an empirical justification for the transmission mechanisms at work is often missing. For instance, Castaneda et al. (2003) assume perfect altruism but present no evidence to support this claim. The question arises whether these channels reflect a good approximation of reality or are mostly based on the researchers priors. Therefore, economists are still striving for a quantitative theory which is supported by empirical evidence and which fits the data well (Cagetti & De Nardi, 2008; Benhabib et al., 2017). In particular, De Nardi & Fella (2017) point out that further exploration of possible bequest motives is needed for a better understanding of the wealth distribution.

In the present study, we propose a parsimonious general equilibrium OLG model with heterogeneous households. The household side of the theory is based on empirical research by Kopczuk & Lupton (2007). They estimate a structural model in which households decide on optimal consumption in the presence of a bequest motive. Utility from bequeathing is added linearly to isoelastic utility from consuming. Hence, marginal utility from consuming decreases in consumption whereas marginal utility from bequeathing remains constant. It implies that poor households intend to leave no bequests whereas rich households prefer to bequeath almost all additional income. Thus, bequests are modeled as a luxury good. This can explain the empirical observation that wealthy households continue to accumulate capital even though they will never be able to consume it. Further, it is appealing as it implies heterogeneous propensities to consume and to bequeath without heterogeneity in preferences as, for instance, in Carroll et al. (2017). Moreover, modeling bequests as a luxury good allows a twofold interpretation. It can be understood as households being (i) altruistic towards descendants but also as households trying to accumulate wealth to (ii) attain social recognition. Both possible interpretations are conditional on a household being sufficiently rich. The general equilibrium model assumes exogenous labor supply and allows for the inter-generational income mobility observed in the data. The distribution of post-taxation labor income is exogenously given. This permits to focus exclusively on voluntary bequests, accidental bequests and inter-generational income mobility as transmission channels for wealth inequality.

The proposed economy can account for the average distribution of wealth in the US while utilizing less parameters than previous models. Further, the model predicts that an increase in inter-generational income mobility slightly decreases the long-run level of wealth inequality. The remainder of this paper is organized as follows. In the second section, the literature is reviewed, including empirical research which investigates why households make bequests as well as theoretical models which try to explain the wealth distribution. In the third section, the theoretical model is developed for a representative household economy. Thereafter, it is augmented to allow for heterogeneous agents, inter-generational income mobility and uncertain lifetime. In the fourth section, different calibration strategies are employed and the results are contrasted across calibrations and relative to the literature. The fifth section concludes.

2. Literature review

2.1. Empirical literature on bequests and capital accumulation

The literature on wealth originates from explaining the size of the capital stock on the aggregate level in the United States (US). On the one hand, Kotlikoff & Summers (1981) claim that the amount of inter-generational transfers is large and therefore must play an important role when explaining the size of the capital stock. On the other hand, Modigliani (1988) finds that around 80 percent of the capital stock can be explained by life-cycle savings. Hence, he attributes less importance on inter-generational transfers. Gale & Scholz (1994) point out that these discrepancies are due to different definitions of inter-generational transfers. Inter-generational transfers are of minor importance if only bequests are considered. Including inter-vivos yields that inter-generational transfers account for 50 to 60 percent of the aggregate capital stock in the US. Their estimate is based on aggregating annual flows. They take the population at a given point in time and sum all transfers received minus transfers given. Both measures include all transactions which households have been engaged during their entire lifetime. Thus, it yields the capital stock which can be attributed to inter-generational transfers.[1] Therefore, it is of interest why people make bequests. The literature distinguishes two competing forces. First, bequests may be accidental due to uncertain lifetime and incomplete annuity markets. Following this line of thought, bequests occur if households die prematurely. Second, bequests could be voluntary if households deliberately save more than they plan to consume. In an empirical estimation, Hurd (1989) finds little evidence in favor of a bequest motive which could rationalize voluntary bequests. He assumes homothetic utility from bequeathing. This implies that even poor households make significant bequests which is hard to reconcile with the data as illustrated by De Nardi & Fella (2017). Further, his identification strategy is problematic as he assumes that parenthood yields a bequest motive while childless households have no bequest motive. Kopczuk & Lupton (2007) find that having children is not a perfect predictor of a bequest motive. In fact, they show that the probability of having a bequest motive increases from around 65 to 75 percent for households with children compared to those who are childless. In contrast to Hurd (1989), they estimate a structural model of household decision-making in which bequeathing is modeled as a luxury good. Their estimation is based on a switching regression which allows to sort households into two groups. One group has a bequest motive while the other has not. The selection is based on household characteristics. They find that

[1] From here on, we will refer to any kind of inter-generational transfers as bequests for brevity.

around 75 percent of the households have a bequest motive. Further, around 14 percent of the elderly population bequeaths due to this motive. More recent empirical research has confirmed that bequests as a luxury good may be relevant, especially for the upper tail of the wealth distribution (De Nardi et al., 2010).

2.2. Theoretical literature on wealth inequality

Modeling the distribution of wealth requires to allow for heterogeneity of agents as it is needed to track an entire distribution. Therefore, the literature started to use OLG simulations to understand how the saving decisions of households translate into wealth inequality (e.g. Atkinson & Harrison, 1978). A more recent model of this kind has been proposed by Gokhale et al. (2001). They study household behavior only in a partial-equilibrium environment. The simulation is built on a relatively rich model which features a detailed demographic structure, marriage, heterogeneous skill endowments, inheritance of skills, taxation and more. Bequests can only be accidental due to uncertain lifetime. They find that intra-cohort wealth inequality can be decreased via bequests if no social security is present whereas bequests increase inequality if social security is available. This originates from the fact that poor households save less in the presence of social security. If these households die prematurely, their descendants tend to inherit less bequests which makes wealth inequality more severe. Although the model has its merit, it relies on the outdated assumption that bequests are only accidental. Further, possible general equilibrium effects cannot be examined. And finally, the model relies on many *ad-hoc* assumptions which are neither supported by theory nor by empirical evidence. For instance, for feasibility, it is assumed that households are infinitely risk-averse. That is, households maximize as if they would never die prematurely. A different modeling strategy which does not necessarily rely on simulations are AB models where households are *ex-ante* identical but face different realizations from a common stochastic process. This makes households *ex-post* heterogeneous. Aiyagari (1994) presented one of the first general equilibrium models of this type where households are infinitely lived and face idiosyncratic labor endowment shocks. He finds that the model is not able to match the wealth inequality observed in the data. While the Gini coefficient for wealth in the US is close to 0.8, the calibrated model predicts only 0.32. Huggett (1996) presents a life-cycle version of this model class. Households face idiosyncratic labor productivity shocks and bequests can only be accidental. In his set-up, accidental bequests are distributed among all agents as lump-sum transfers. He shows that the demographic structure and associated life-cycle savings improve the fit of the model. The predicted Gini coefficient for overall wealth inequality as well as intra-cohort inequality is very close to empirical data. However, the model cannot match the wealth holdings of the top percentile. While around 30 percent of wealth is held by this group, the model predicts less than 14 percent. This leads to the conclusion that the life-cycle structure is an important ingredient to match the empirical distribution of wealth. Nevertheless, the fit in the upper tail of the distribution is not yet satisfactory. Also note that all three presented models assume that no bequest motive is present.

Now, we will present models which depart from this assumption to improve the predictions concerning wealth inequality. De Nardi (2004) augments the life-cycle model from Huggett

(1996) by a bequest motive and inter-generational transmission of skills. The assumption that accidental bequests are distributed among all agents is dropped. Instead she assumes that only direct descendants receive accidental bequests which appears to be more appropriate. The Gini coefficient for wealth comes close to the data, as in the original model. The wealth holdings of the top percentile increase to 18 percent. Although this figure has improved, its magnitude is not satisfactory, given that two additional channels have been introduced. Further, the functional form of the bequest motive is supported by theoretical considerations but not by empirical evidence. Castaneda et al. (2003) present a general equilibrium AB economy where the life-cycle is modeled by stochastically aging households. Their model almost perfectly accounts for the US distribution of wealth. Not only the Gini coefficient but most parts of the distribution are matched. In particular, the top percentiles' wealth holdings are just above 29 percent. Additionally, several other stylized facts are matched, for instance the capital-to-output ratio and alike. The key assumptions are perfect altruism and top income volatility. Perfect altruism implies that, apart from discounting, households care as much about their descendant's utility as they care about their own. However, the authors do not justify this assumption and we are not aware of any empirical evidence in favor of this claim. Top income volatility is the channel through which a high propensity to save among rich households is induced. In their calibrated model, a top income earner faces a risk of around 20 percent that his income drops by a factor of 100 in the subsequent period as pointed out by De Nardi & Fella (2017). Hence, the strong precautionary motive induces the desired savings behavior. There are several empirical studies which confirm that top income is subject to higher fluctuations (e.g. Parker & Vissing-Jorgensen, 2009). However, it is not clear if this can justify the tremendous magnitude of the risk which is implied by their calibration. Further, Hardy & Ziliak (2014) find that income volatility at the bottom is even higher which is at odds with the calibrated transition probabilities.

This literature review is not exhaustive and focuses on aspects of the literature which are directly related to this paper. Other potential transmission mechanisms to match the empirically observed distribution of wealth include entrepreneurial risk, heterogeneity in preferences or heterogeneity in returns to assets. De Nardi & Fella (2017) provide an extensive literature review.

The presented summary shows that economic models have been able to match the distribution of wealth in the US. However, many models lack empirical support for the transmission channels through which the distribution of wealth is matched. In the subsequent section, we will present a simple model which utilizes a bequest motive that is supported by the empirical results from Kopczuk & Lupton (2007). This is important as the different channels which are used in the literature may have dramatically different policy implications (De Nardi & Fella, 2017). Thus, it is crucial to use transmission channels which can be justified empirically. Further, the model accounts for the inter-generational income mobility which is found in the data.

3. Methodological framework

3.1. Representative-agent setting

This section consists of two parts. First, we will present a simple OLG one-sector closed-economy model populated by a dynasty of representative households with two period lifetime. The utility function of each household will be augmented by a bequest motive. After studying the dynamics of this model, we will generalize the model in the second part to allow for household heterogeneity. In particular, we will allow for heterogeneous income. This model features three transmission mechanisms which may translate income into wealth inequality: (i) voluntary bequests due to the bequest motive, (ii) accidental bequests due to uncertain lifetime and (iii) inter-generational income mobility.

Demographic Structure

The general demographic structure of the model is similar to the canonical two period lifetime OLG growth model. Further, agents have an additional control variable to account for voluntary bequests. Figure 1 illustrates the general demographic structure.

t=1	t=2	t=3	t=4	t=5
$\begin{pmatrix} b_1 \\ w_1 \end{pmatrix} \to \begin{pmatrix} c_1^y \\ k_2 \end{pmatrix}$	$\begin{pmatrix} k_2 R_2 \\ 0 \end{pmatrix} \to \begin{pmatrix} c_2^o \\ b_2 \end{pmatrix}$			
	$\begin{pmatrix} b_2 \\ w_2 \end{pmatrix} \to \begin{pmatrix} c_2^y \\ k_3 \end{pmatrix}$	$\begin{pmatrix} k_3 R_3 \\ 0 \end{pmatrix} \to \begin{pmatrix} c_3^o \\ b_3 \end{pmatrix}$		
		$\begin{pmatrix} b_3 \\ w_3 \end{pmatrix} \to \begin{pmatrix} c_3^y \\ k_4 \end{pmatrix}$	$\begin{pmatrix} k_4 R_4 \\ 0 \end{pmatrix} \to \begin{pmatrix} c_4^o \\ b_4 \end{pmatrix}$	
			$\begin{pmatrix} b_4 \\ w_4 \end{pmatrix} \to \begin{pmatrix} c_4^y \\ k_5 \end{pmatrix}$	$\begin{pmatrix} k_5 R_5 \\ 0 \end{pmatrix} \to \begin{pmatrix} c_5^o \\ b_5 \end{pmatrix}$

Figure 1: Overview of the demographic structure

The lower-left vector in each period contains the variables a young household takes as given. Labor income is denoted by w_t and b_t is the received wealth, bequeathed from the old generation, born in period $t-1$. The lower-right vector in each period contains the decision variables of the young household. Consumption in period t, c_t^y is the only control variable. Savings are the residual of income minus consumption and coincide with next period's capital stock k_{t+1}. Thus, it is an endogenous state variable which determines the capital stock of the subsequent period, i.e. $K_{t+1} = N_t k_{t+1}$ where N_t denotes the size of the working population of this economy when the savings are made. When the agent is old, the upper-left vector is taken as given. No labor income is received as the agent is retired. Therefore, the agent must live off his savings plus net interest received $k_{t+1}R_{t+1}$ with $R_{t+1} = 1 + r_{t+1}$. The upper-right vector contains both control variable of the old household. An agent must allocate resources either to consumption c_{t+1}^o or bequeathing wealth to the next generation b_{t+1}. Note that b_{t+1} is only an inter-vivo gift as it is transferred prior death. However, in the literature, a distinction between inter-vivos and bequests is hardly made. Thus, I will refer to b_{t+1} as bequests and leave the exact interpretation to the interested reader.

Households

This model is populated by a continuum of working households with unit mass. It is assumed that the population size is constant across periods. In this environment, any agent born in period t maximizes the following objective:

$$U(c_t^y, c_{t+1}^o, b_{t+1}; y_t, r_{t+1}) = \frac{(c_t^y)^{1-\sigma} - 1}{1-\sigma} + \beta \left\{ \frac{(c_{t+1}^o)^{1-\sigma} - 1}{1-\sigma} + \gamma b_{t+1} \right\} \tag{1}$$

$$\text{s.t. } y_t \equiv w_t + b_t = c_t^y + \frac{c_{t+1}^o + b_{t+1}}{1 + r_{t+1}} \tag{1.a}$$

$$c_t^y \geq 0, \; c_{t+1}^o \geq 0, \; b_{t+1} \geq 0 \tag{1.b}$$

$$\text{with } \sigma > 0, \; \gamma \geq 0, \; 1 > \beta > 0$$

We have a standard utility maximization problem where each agent maximizes lifetime utility (1) with respect to the corresponding lifetime budget constraint (1.a) and the usual non-negativity constraints (1.b). The real rental rate of capital net of depreciation is denoted by $r_{t+1} = q_{t+1} - \delta$, where q_{t+1} is the real rental rate of capital and $\delta \in [0, 1]$ is the depreciation rate. The consumption part of the lifetime utility function is isoelastic with the inter-temporal elasticity of substitution for consumption being $1/\sigma$. The parameter γ governs the marginal utility gain from bequeathing wealth. Thus, γ and σ jointly determine when the household switches from consumption to leaving bequests. If the household is sufficiently poor, the entire income will be spent on consumption. Conversely, if the household is sufficiently rich, additional income must be completely passed on to the next generation if the interest rate were fixed. In the model however, a general-equilibrium effect causes lower interest rates which dampens the bequest volume. Bequeathing can be understood as a luxury good if $\gamma > 0$. Conversely, if $\gamma = 0$, the model reduces to the canonical OLG growth model without any inter-generational transfers. In the remainder of the paper, we will assume $\gamma > 0$ if not mentioned otherwise.

From the utility maximization problem of a household, born in period t, the following first-order conditions can be retrieved, with λ being the Lagrange multiplier of the household's lifetime budget constraint given in equation 1.a.

$$\frac{\partial \mathcal{L}}{\partial c_t^y} = (c_t^y)^{-\sigma} - \lambda \overset{!}{=} 0 \tag{2}$$

$$\frac{\partial \mathcal{L}}{\partial c_{t+1}^o} = \beta (c_{t+1}^o)^{-\sigma} - \lambda (1 + r_{t+1})^{-1} \overset{!}{=} 0 \tag{3}$$

$$\frac{\partial \mathcal{L}}{\partial b_{t+1}} = \gamma \beta - \lambda (1 + r_{t+1})^{-1} \overset{!}{\leq} 0 \tag{4}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = c_t^y + \left(c_{t+1}^o + b_{t+1}\right)(1 + r_{t+1})^{-1} - y_t \overset{!}{=} 0 \tag{5}$$

Note that the inequality in equation 4 results from the non-negativity constraint on b_{t+1}. This inequality holds as an equality if $b_{t+1} > 0$. One can see that equations 3 and 4 give the static trade-off between consumption and bequeathing when the agent is old. As the marginal utility gain of consumption decreases while the marginal utility gain from bequeathing is constant, it follows that there exists a consumption threshold for c_{t+1}^o: $\bar{c}^o \equiv (\gamma)^{-1/\sigma}$. If an old household has sufficient income, i.e. $k_{t+1}(1+r_{t+1}) - \bar{c}^o > 0$, then, all additional wealth will be bequeathed. Further, equations 2 and 3, give the inter-temporal trade-off for consumption. For the case that the household is sufficiently rich, where consumption in $t+1$ is determined by the threshold $\bar{c}^o = c_{t+1}^o$, we can insert this threshold into the Euler equation to obtain consumption of the young household as a function of the interest rate, i.e. $c_t^y(r_{t+1}) = \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma}$. Note that this does not constitute a threshold value as the level of consumption depends on the interest rate r_{t+1}. Combining this with the budget constraint in equation 5, we have to distinguish two cases to determine optimal consumption and bequest paths.

$$c_t^y = \begin{cases} \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} & \text{if } \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} + \frac{(\gamma)^{-1/\sigma}}{1+r_{t+1}} \leq y_t \\ y_t - c_{t+1}^o(1+r_{t+1})^{-1} & \text{otherwise} \end{cases} \tag{6}$$

$$c_{t+1}^o = \begin{cases} (\gamma)^{-1/\sigma} & \text{if } \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} + \frac{(\gamma)^{-1/\sigma}}{1+r_{t+1}} \leq y_t \\ y_t\big\{[(1+r_{t+1})\beta]^{-1/\sigma} + (1+r_{t+1})^{-1}\big\}^{-1} & \text{otherwise} \end{cases} \tag{7}$$

$$b_{t+1} = \begin{cases} \frac{\left(y_t - \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma}\right)}{(1+r_{t+1})^{-1}} - (\gamma)^{-1/\sigma} & \text{if } \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} + \frac{(\gamma)^{-1/\sigma}}{1+r_{t+1}} \leq y_t \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

The first case of equations 6, 7 and 8 describes circumstances under which y_t is sufficiently large such that the consumption threshold $\bar{c}^o$ can be reached. In this case, b_{t+1} can be computed as a residual of income after deducting consumption expenditures. In the other case, when the household is too poor to bequeath, the household will spend his entire resources for consumption, i.e. $b_{t+1} = 0$.[2]

Firms

Similar to the households, we have a continuum of identical firms with unit mass. Each firm faces a static optimization problem where production factors are purchased on competitive spot markets. In each period t, a firm takes the rental rate of capital q_t and the wage w_t as given and maximizes the following objective:

$$\pi(K_t, N_t;\ A_t, q_t, y_t) = A_t F(K_t, N_t) - N_t w_t - K_t q_t \tag{9}$$

$$\text{s.t. } N_t \geq 0,\ K_t \geq 0 \tag{9.a}$$

$$\text{with } F(K_t, N_t) = K_t^\alpha N_t^{1-\alpha}\ , \alpha \in (0,1) \tag{9.b}$$

As this problem is static, the first order conditions of the firm directly imply that the real rental

[2]Note that an old household cannot borrow against his descendants due to the non-negativity constraints in equation 1.b. Therefore, in the second case of equations 6 - 8, c_t^y and c_{t+1}^o have been retrieved from the first-order conditions stated in equations 2 and 3 as well as the the budget constraint 5 where $b_t = 0$ is enforced.

rates must be equal to the marginal product of the respective factor input.

$$q_t = F_1(K_t, N_t) = A_t\alpha\left(\frac{N_t}{K_t}\right)^{1-\alpha}$$
$$w_t = F_2(K_t, N_t) = A_t(1-\alpha)\left(\frac{K_t}{N_t}\right)^{\alpha}$$

Since the population is assumed to be constant and the continuum of working households has unit mass as well as the assumption of exogenous labor supply, the production function can be rewritten as $f(K_t) \equiv F(K_t, 1)$. In other words, the labor market clears only by price adjustment. Hence, q_t and y_t can be expressed as follows:

$$q_t = A_t\alpha\big(K_t\big)^{\alpha-1} \tag{10}$$
$$w_t = A_t(1-\alpha)\big(K_t\big)^{\alpha} \tag{11}$$

Inter-temporal equilibrium

As this study is concerned with the distribution of wealth, we will restrict our attention to stationary equilibria of this economy. Thus, we further assume $A_t = A\ \forall t$.

A law of motion for capital can be derived from the savings of young households which coincide with next period's capital stock $K_{t+1} = y_t - c_t^y = w_t + b_t - c_t^y$. As both, b_t and c_t, have two cases, the law of motion for capital consists of an equation with four cases:

$$K_{t+1} = \begin{cases} \textbf{if } K_t(1+A\alpha K_t^{\alpha-1}-\delta) \geq \gamma^{-1/\sigma}\textbf{:} \\ \begin{cases} \textbf{if } \big[(1+A\alpha K_{t+1}^{\alpha-1}-\delta)\gamma\beta\big]^{-1/\sigma} + \dfrac{\gamma^{-1/\sigma}}{1+A\alpha K_{t+1}^{\alpha-1}-\delta} \leq K_t(1+A\alpha K_t^{\alpha-1}-\delta) - \gamma^{-1/\sigma} + A(1-\alpha)K_t^{\alpha}\textbf{:} \\ K_t(1+A\alpha K_t^{\alpha-1}-\delta) - \gamma^{-1/\sigma} + A(1-\alpha)K_t^{\alpha} - \big[(1+A\alpha K_{t+1}^{\alpha-1}-\delta)\gamma\beta\big]^{-1/\sigma} \\ \textbf{otherwise:} \\ \Big(K_t(1+A\alpha K_t^{\alpha-1}-\delta) - \gamma^{-1/\sigma} + A(1-\alpha)K_t^{\alpha}\Big)\Big(1+\beta^{-1/\sigma}\big[1+A\alpha K_{t+1}^{\alpha-1}-\delta\big]^{\frac{\sigma-1}{\sigma}}\Big)^{-1} \end{cases} \\ \textbf{otherwise:} \\ \begin{cases} \textbf{if } \big[(1+A\alpha K_{t+1}^{\alpha-1}-\delta)\gamma\beta\big]^{-1/\sigma} + \dfrac{\gamma^{-1/\sigma}}{(1+A\alpha K_{t+1}^{\alpha-1}-\delta)} \leq A(1-\alpha)K_t^{\alpha}\textbf{:} \\ A(1-\alpha)K_t^{\alpha} - \big[(1+A\alpha K_{t+1}^{\alpha-1}-\delta)\gamma\beta\big]^{-1/\sigma} \\ \textbf{otherwise:} \\ \Big(A(1-\alpha)K_t^{\alpha}\Big)\Big(1+\beta^{-1/\sigma}\big[1+A\alpha K_{t+1}^{\alpha-1}-\delta\big]^{\frac{\sigma-1}{\sigma}}\Big)^{-1} \end{cases} \end{cases} \tag{12}$$

In equation 12, the full blown law of motion for capital is given, where all factor prices have been substituted by the corresponding marginal products. Due to it's complexity, it is only possible to compute possible stationary state solutions by guess-and-verify techniques. First, one needs to solve each case numerically for $K_t = K_{t+1} = K^*$. Then, it is needed to verify whether K^* indeed satisfies the related *if conditions* to confirm that it is indeed a stationary state of this economy. For a more intuitive interpretation of this law of motion, one can substitute factor prices in equation 12 to obtain the following simplified version:

$$K_{t+1} = \begin{cases} \textbf{if } K_t(1+r_t) \geq \gamma^{-1/\sigma}\textbf{:} \\ \left\{ \begin{array}{l} \textbf{if } \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} + \dfrac{\gamma^{-1/\sigma}}{1+r_{t+1}} \leq K_t(1+r_t) - \gamma^{-1/\sigma} + w_t\textbf{:} \\ K_t(1+r_t) - \gamma^{-1/\sigma} + w_t - \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} \\ \textbf{otherwise:} \\ \Big(K_t(1+r_t) - \gamma^{-1/\sigma} + w_t\Big)\Big(1+\beta^{-1/\sigma}\big[1+r_{t+1}\big]^{\frac{\sigma-1}{\sigma}}\Big)^{-1} \end{array} \right\} \\ \textbf{otherwise:} \\ \left\{ \begin{array}{l} \textbf{if } \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} + \dfrac{\gamma^{-1/\sigma}}{1+r_{t+1}} \leq w_t\textbf{:} \\ w_t - \big[(1+r_{t+1})\gamma\beta\big]^{-1/\sigma} \\ \textbf{otherwise:} \\ \Big(w_t\Big)\Big(1+\beta^{-1/\sigma}\big[1+r_{t+1}\big]^{\frac{\sigma-1}{\sigma}}\Big)^{-1} \end{array} \right\} \end{cases} \tag{13}$$

The first case holds true if the currently young agent has received a bequest. The corresponding first sub-case describes next period's capital stock if the young is rich enough to leave a bequest to his descendants while the second sub-case holds true if this agent rather consumes all his wealth. Conversely, the second case holds true if the currently young agent has not received any bequests. Again, the first sub-case holds true if the agent is, nevertheless, rich enough to leave a bequest while there will be no bequests in the second sub-case. Hence, this second sub-case also gives the law of motion for capital if $\gamma = 0$. Given the law of motion for capital, an inter-temporal equilibrium of this model can be defined as follows:

Definition 1. An inter-temporal equilibrium of this economy is a sequence of allocations $\{c_t^y, c_t^o, b_t\}_{t=0}^{\infty}$ and a sequence of capital stocks and associated factor prices $\{K_t, w_t, r_t\}_{t=0}^{\infty}$ such that equations 6, 7, 8, 10, 11 and 12 are satisfied and K_0 is given.

Dynamics

As this model does not permit an analytic solution, we will examine the dynamics of the model by means of a graphical analysis. The below presented solutions have been generated numerically for reasonable parameter values. In particular, we have fixed $\sigma = 2$. This is a reasonable value suggested by the literature (e.g. Hall, 1988). Further, it is needed to fix σ to evaluate different choices for γ as both parameters together determine whether bequests are made.

The left panel of figure 2 shows how the stationary equilibrium capital stock K^* varies through changes in γ. For $\gamma \leq 0.025$, the choice of γ does not matter. The economy can never sustain a capital stock at which consumption is sufficiently high such that bequests are yielding higher marginal utility than additional consumption. If $\gamma > 0.025$, bequests are made. Hence, there is an incentive to save more in order to be able to bequeath. Thus, the equilibrium capital stock increases, although with decreasing magnitude. Further, the capital stock converges as the willingness to save is counteracted by both, a decreasing interest rate as well as the constant depreciation rate. For the given set of parameters, numerical results indicate that $K^* \rightarrow \;\; \approx 37$

as $\gamma \to \infty$.

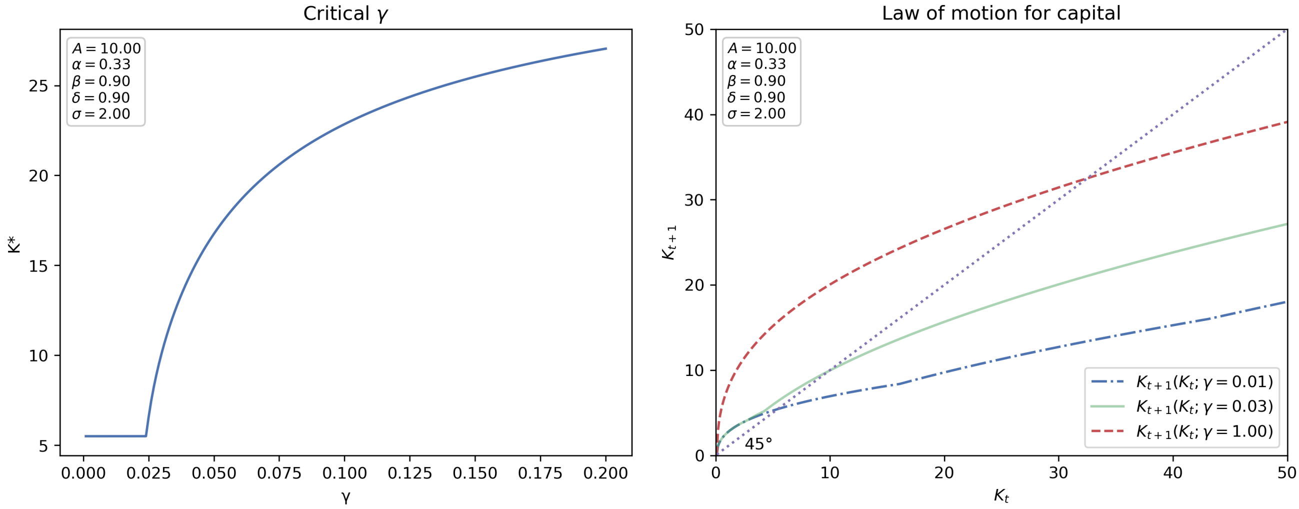

Figure 2: Dynamics of the capital stock for varying values of γ

The law of motion for capital for three distinct choices of γ is depicted in the right panel of figure 2. The dash-dotted blue line shows the case where, in the stationary state, no bequests are made as γ is too low. The solid green line shows the case where γ just exceeds the critical value. Hence, there are bequests in the stationary state. One can see that the law of motion is identical to the no-bequest case for very small capital stocks. However, as the capital stock approaches its fixed point from the left, the two laws of motion diverge as agents start to bequeath in the case of $\gamma = 0.03$. Finally, the dashed red line shows an extreme case with a high value for γ. One can see that the stationary equilibrium capital stock is already close to its above computed least upper-bound of approximately 37. The right panel also shows that there exists a unique stationary equilibrium in every case. Simulations have confirmed the robustness of this finding for $\gamma \in [0, 1]$.

Figure 3 illustrates the behavior of the household. The left panel shows the dynamics of consumption, bequests and capital where $K_0 < K^*$. In the first periods, no bequests are made as all wealth will be consumed. Then, starting in $t = 3$, bequests are made. Thereafter, c_t^y and b_t converge towards the stationary state levels while c_t^o remains constant. The increase in c_t^y is mainly caused by a general equilibrium effect. As the households try to leave more bequests, the capital stock increases and therefore, the rental rate of capital r_t decreases. Hence, the opportunity costs of c_t^y decrease.

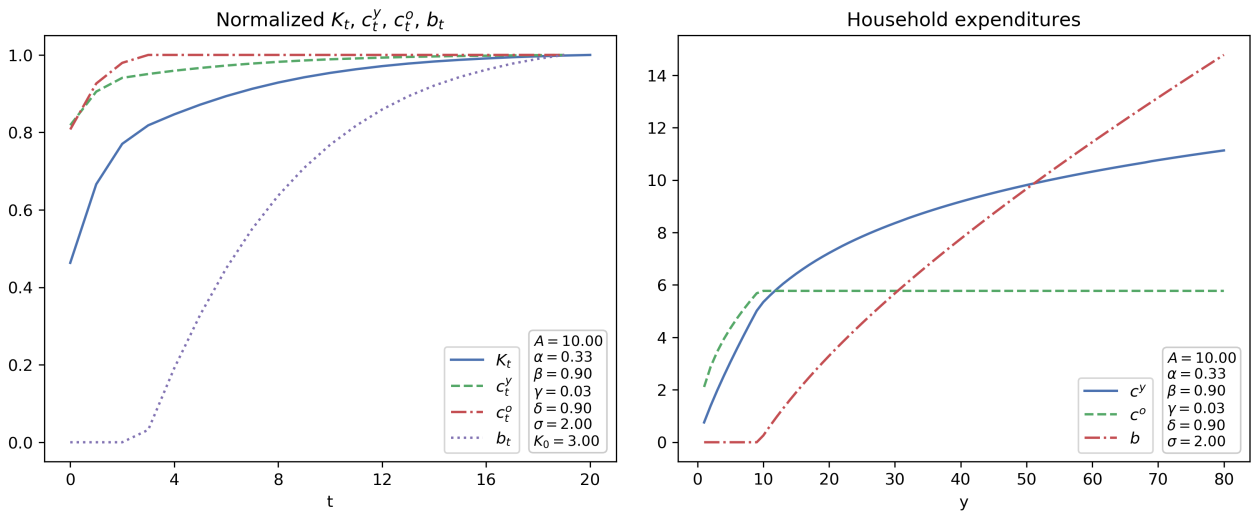

Figure 3: Decision-making of the household

For a better understanding of this effect, the decision-making of the household as a function of income is given in the right panel of figure 3. One can see that the household consumes its entire income until $y \approx 10$. Then, additional income will be either bequeathed or consumed while the agent is young. The latter is due to the above described general equilibrium effect. If the interest rate were fixed, households would bequeath all additional income.

3.2. Heterogeneous-agents setting

Heterogeneity of agents

The heterogeneous-agents setting is built on the above presented representative-agent model. Firms remain as in the representative agent version and can be represented by means of a representative firm. Households solve the same maximization problem. Instead of a continuum, a finite number of working households N, constant across periods, is assumed. Each household, or in fact, each dynasty of households is identified by a subscript $i \in \{1, ..., N\}$. Aggregate variables are determined by summation over all households. For instance, the aggregate capital stock is the sum of the capital stock of each dynasty at time t, i.e. $K_t = \sum_{i=1}^{N} k_{it}$. Even though households have no longer unit mass, it is assumed that all working households together supply one unit of labor in a given period t. Thus, each individual household supplies $1/N$ units of labor. Note that this assumption is purely technical and has no economic meaning as the labor supply is inelastic. Moreover, households face heterogeneous labor income which is determined as a share of total labor income. Therefore, we assign each household i, born in period t, an income share θ_{it}. Then, each household's labor income

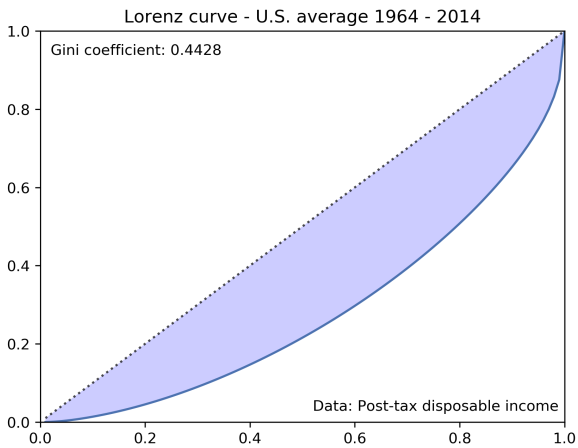

Figure 4: U.S. income distribution

amounts to his income share times the total labor income of the economy in a given period t. Therefore, the lifetime income of household i, born in period t, is given by $y_{it} \equiv \theta_{it} w_t + b_{it}$ with w_t being the aggregate labor income in period t.

Formally, let $p_t : \{1, ..., N\} \mapsto [0, 1]$ be a mapping from the set of agent $\{1, ..., N\}$ to the unit interval, which may vary across periods. The mapping assigns to each agent $i \in \{1, ..., N\}$ the corresponding income share θ_{it}. Further, p_t satisfies $\sum_{i=1}^{N} p_t(i) = 1, \ \forall t$, that is the sum of income shares must always sum to unity. Finally, it is assumed that the income share increases in each household's index for $t = 0$, i.e. $p_0(i) \leq p_0(i+1), \ i = 1, ..., N-1$. Note that the latter is *w.l.o.g.* as assigning income shares in the initial period is completely arbitrary. Nevertheless, it is convenient as it allows to interpret each household as a percentile of the income distribution for $N = 100$. The mapping p_t is based on empirically estimated US income shares of post-tax disposable income, averaged across time.[3] The Lorenz curve of this average income distribution is given in figure 4. Further, as averages are used, it is assumed that$\{\theta \in [0, 1] : \theta = p_t(i), i = 1, .., N\} = \{\theta \in [0, 1] : \theta = p_{t+s}(i), i = 1, .., N\}, \ \forall t, s \geq 0$. This means that the income share of dynasty i may vary across periods whereas the set of all income shares itself is time-invariant.[4]

Inter-generational income mobility

While the set of all income shares does not depend on time, each dynasty needs to be assigned to an income share in every period t. That is, the mapping p_t needs to be defined for all t. For $t = 0$, given the set of all income shares, the mapping is arbitrary as argued in the previous paragraph. In the following, it is explained how to retrieve p_t for $t > 0$ depending on the degree of inter-generational income mobility, where the set of all income shares is given. Inter-generational income mobility is measured as the probability q of any young household i to retrieve the same income share as his direct ancestor. The case without any inter-generational income mobility is implemented for $q = 1$. Then, trivially, $p_t = p_0 \ \forall t$. In contrast, for $q < 1$, it is not trivial to obtain p_t which can be illustrated by the following. If $q \in [1/N, 1)$, then household i may obtain an income share different from his direct ancestor with positive probability, i.e. $\mathbb{P}\big(p_t(i) \neq p_{t+1}(i)\big) > 0 \ \forall i$. Now suppose that i indeed retrieves a different income share in $t+1$. But then, $\exists \ j \in \{1, ..., i-1, i+1, ..., N\}$ with $p_t(j) = p_{t+1}(i)$. Hence, $p_t(j) = p_{t+1}(j)$ becomes infeasible except for the trivial case where $p_t(j) = p_t(i)$. It implies that $\mathbb{P}\big(p_t(j) = p_{t+1}(j)\big) = 0 \neq q$. To handle this problem, the following algorithm will be used. It utilizes a sequence of Bernoulli trials with success probability $\hat{q}$. The algorithm determines p_t by assigning each i to a particular income share. As an alternative, we present a variant of this model in appendix B where inter-generational income mobility is modeled as a Markov chain.

- Repeat the following $N - 1$ times:
    1. Choose $\hat{i} \sim U(\mathcal{I})$ where the set $\mathcal{I}$ contains all i which have not been assigned a new income share and U denotes the uniform distribution.

[3] Data on income shares has been retrieved from the *World Inequality Database*. Data were available for the years from 1964 until 2014.

[4] In fact, the requirement on p_t is even stronger. It is also assumed that the frequency at which each element appears must be identical. This is not explicitly stated to keep the notation simple.

2. Summarize all available income shares in a list $\mathcal{P}$.
3. Compute the distance from $\hat{i}$'s previous income shares to all available income shares $\hat{p} \in \mathcal{P}$.
4. Repeat the following until $\mathcal{P}$ has no entries or $\hat{i}$ has been assigned a new income share:
   a) Take the income share $\hat{p} \in \mathcal{P}$ with the smallest distance to $\hat{i}$'s previous income share. If $\hat{p}$ is not unique, that is $\hat{p}$ and $\hat{p}'$ have the same distance, choose one of them with probabilities $\mathbb{P}(\hat{p}) = \mathbb{P}(\hat{p}') = 0.5$.
   b) Assign the chosen income share to $\hat{i}$ with probability $\hat{q}$. If success, remove $\hat{i}$ from $\mathcal{I}$, i.e. $\mathcal{I} := \mathcal{I}\backslash\{\hat{i}\}$
   c) Remove $\hat{p}$ from $\mathcal{P}$, i.e. $\mathcal{P} := \mathcal{P}\backslash\{\hat{p}\}$

- Summarize all available income shares in a list $\mathcal{P}$ again.
- Repeat the following until $\mathcal{I} = \emptyset$:
  1. Choose $\hat{i} \sim U(\mathcal{I})$
  2. Choose $\hat{p} \in \mathcal{P}$ with $\mathbb{P}(p) = \frac{1}{|\mathcal{P}|}\ \forall p \in \mathcal{P}$.
  3. Assign $\hat{p}$ to $\hat{i}$ and let $\mathcal{I} := \mathcal{I}\backslash\{\hat{i}\}$ and let $\mathcal{P}$, i.e. $\mathcal{P} := \mathcal{P}\backslash\{\hat{p}\}$.

The intuition behind the algorithm can be sketched as follows. Suppose no household has been assigned yet, that is $\mathcal{I} = \{1, ..., N\}$. Now, some household $i \in \mathcal{I}$ will be selected. Then, we have $\mathbb{P}\big(p_t(i) = p_{t+1}(i)\big) = \hat{q}$. If however, the Bernoulli trial implies that $p_t(i) \neq p_{t+1}(i)$, then i may get assigned to the next larger (smaller) income share with probability $\hat{q}$. Hence, the *ex-ante* probability to obtain the next larger (smaller) income share is $(1 - \hat{q}) \cdot \hat{q} \cdot 0.5$ as it is equally likely to obtain a larger (smaller) income share. Note that this reasoning only applies if there exist larger (smaller) income shares. Conversely, if i's direct ancestor was the top income earner, i cannot obtain a larger income share. Moreover, $\hat{q}$ only gives an upper bound on the actual probability of i to receive the income share of it's direct ancestor. This follows from the above illustrated fact that whenever i is selected, q coincides with $\hat{q}$ times the probability that i's direct ancestor's income share is still available. The left panel of figure 5 shows simulated probabilities for the direct descendant of the household that held the median income share in the previous period. On the horizontal axis, plus (minus) 1 indicates whether a larger (smaller) income share has been retrieved. N still refers to the number of working households while N_{MC} refers to the number of repetitions of the Monte Carlo experiment. For $\hat{q} = 0.6$, one can directly see that the implied actual probability $q < 0.6$ as well as the approximately symmetric probability to obtain a larger (smaller) income share.

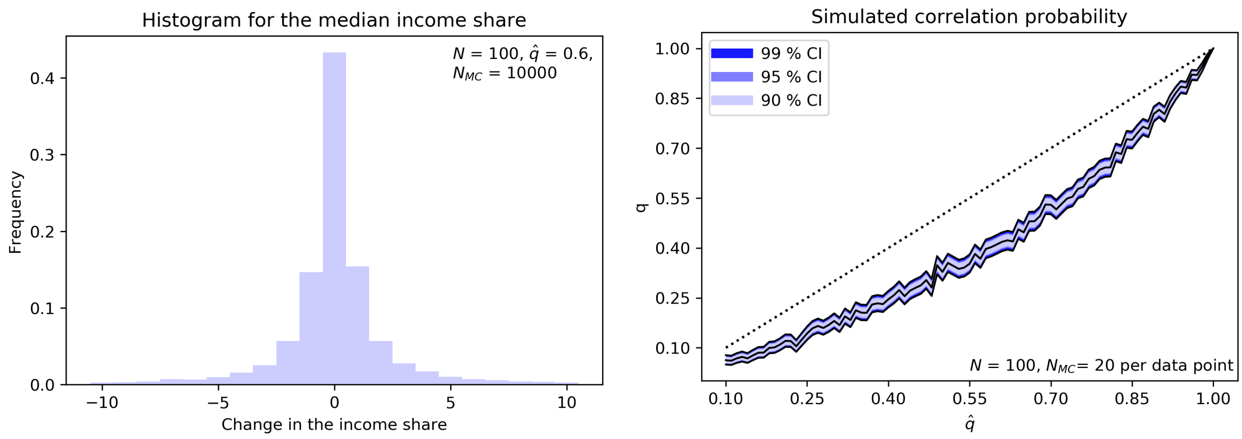

Figure 5: Algorithm performance

The right panel of figure 5 shows the implied relation between $\hat{q}$ and q. Clopper-Pearson confidence intervals are displayed as the algorithm can be evaluated as a sequence of Bernoulli trials. In each round of the Monte Carlo simulation, it is called a success if a household obtains the same income share as his direct ancestor. The fraction of successes over the number of household follows a binomial distribution. One can see that the confidence intervals are already relatively tight for $N_{MC} = 20$. If N_{MC} becomes large enough, the simulated mapping $q(\hat{q})$ becomes smooth and approximately bijective. That is, $\forall q \in [1/N, 1),\ \exists!\ \hat{q} \in [1/N, 1)$ such that $\mathbb{E}q(\hat{q}) = q$. This implies that one can implement any q by choosing an appropriate $\hat{q}$ and N_{MC} sufficiently large. In what follow, we will only refer to q and suppress the $\hat{q}$ that is needed to implement it.

Uncertain lifetime

Besides the bequest motive and inter-generational income mobility, accidental bequests may be another important transmission channel. To allow for accidental bequests, it is needed to introduce uncertain lifetime. Usually, if households live for many periods, one can simply multiply the survival probability with the instantaneous utility function. This approach is not appropriate in a setting with two period lifetime. It would imply that households either die at retirement or survive the entire retirement period. Instead, we follow Gokhale et al. (2001) and assume infinite risk-aversion. That is, households optimize as if they would live for two entire periods with certainty. However, with some probability, they die prematurely. An alternative justification would be that living two entire periods corresponds to expected life-time. Then, one could claim that the behavior of households who live longer is not explicitly modeled but does not alter the predictions of the model. It could be argued that these households receive some implicit lump-sum transfer to afford their basic necessities. This explanation is appropriate for households which do not bequeath. It is likely that these households would simply consume their transfers without substantial impact on other agents. Only for those households who planned to make bequests, this justification is problematic. As these households still have positive wealth at the end of the second period, it is not clear whether these households would adjust the amount of bequests to achieve a different level of consumption when living longer.

In the model, lifetime uncertainty is captured by the independent and identically distributed

random variable φ_{it}. This random variable has finite, discrete support $S = \{\underline{s}_1, ..., \overline{s}_M\}$ with $s_j \in [0,1], j = 1, ..., M$, $\underline{s}_1 = 0$ and $\overline{s}_M = 1$. The random variable φ_{it} gives the percentage share of the retirement period for which household i is alive. Hence, the household dies at retirement if $\hat{\varphi}_{it} = \underline{s}_1$ where the hat denotes a realization of the random variable φ_{it}. Conversely, the household lives his entire retirement period if $\hat{\varphi}_{it} = \overline{s}_M$. Therefore, for any $\hat{\varphi}_{it}$, we have $\hat{c}^o_{t+1} = \hat{\varphi}_{it} c^o_{t+1}$ and $\hat{b}^a_{t+1} = (1 - \hat{\varphi}_{it}) c^o_{t+1}$. That is, each household consumes only a fraction $\hat{\varphi}_{it}$ of the planned consumption and the remainder becomes an accidental bequest. Now, $\hat{c}^o_{t+1}$ denotes actual consumption as a result of $\hat{\varphi}_{it}$. Similar, $\hat{b}^a_{t+1}$ denotes the accidental bequest which also follows residually from planned consumption c^o_{t+1} minus actual consumption $\hat{c}^o_{t+1}$.
The set S has been derived from the US age distribution averaged across time periods from 1980 until 2013.[5] First, age corresponding to the lower bound $\underline{s}_1$ needs to be determined. That is the average retirement age. According to *OECD* data, the average retirement age between 1970 and 2014 was roughly 65 years.[6] Now, $\mathbb{P}(\underline{s}_1)$ follows from the observed relative frequency of 65 year olds among the retired population. Similarly, $\overline{s}_M$ corresponds to the expected lifetime. Averaged across periods from 1964 to 2014, life expectancy amounts to 75 years.[7] As before, $\mathbb{P}(s), \forall s \in S$ is given by the relative frequency of the corresponding age group. We are aware that this figure is not a precise estimate of the actual probability to die. However, it can be considered as a good approximation, given that averages across time periods are used.

Dynamics

In this section, we present the dynamics of the model with heterogeneous agents. Special emphasis is given to illustrate how the three transmission channels affect aggregate dynamics of the model.
To study the dynamics, the model parameters need to be calibrated. First, we fix $\alpha = 0.33$, $\beta = 0.9$, $\delta = 0.9$, and $\sigma = 2$ which are the same parameter values as in the representative-agent setting. These values are well established in the literature. Further, the number of dynasties of households which also gives the number of working households is $N = 100$. This allows to interpret each household as a percentile. Total factor productivity is $A = 1000$. It is scaled up proportionally to the number of working households, that is the total factor productivity from the representative-agent model times the number of working households in the current set-up. The distribution and support of φ_{it} has been retrieved from empirical data as explained above. For inter-generational income mobility, there is no general consensus in the literature. However, most studies recommend an average inter-generational income elasticity of about 0.5 (e.g. Palomino et al. (2018), Solon (1992) or Zimmerman (1992)). Although, q is not exactly an elasticity, setting $q = 0.5$ appears to be a reasonable approximation. Hence, we are left with γ as a single free parameter to match the empirically observed distribution of wealth. In particular, we use the Gini coefficient of the US wealth distribution, averaged across time, as a calibration target.[8] This preliminary calibration procedure yields $\gamma = 0.00004$. The employed

[5]The data has been retrieved from the *International Data Base* from the US Census Bureau.
[6]This number has been computed from data given in an *OECD* publication.
[7]This number has been computed from *Worldbank*'s database.
[8]Data on the distribution of wealth has been retrieved from the *World Inequality Database*. Data were available for the years from 1964 until 2014.

solution algorithm can be found in appendix A.

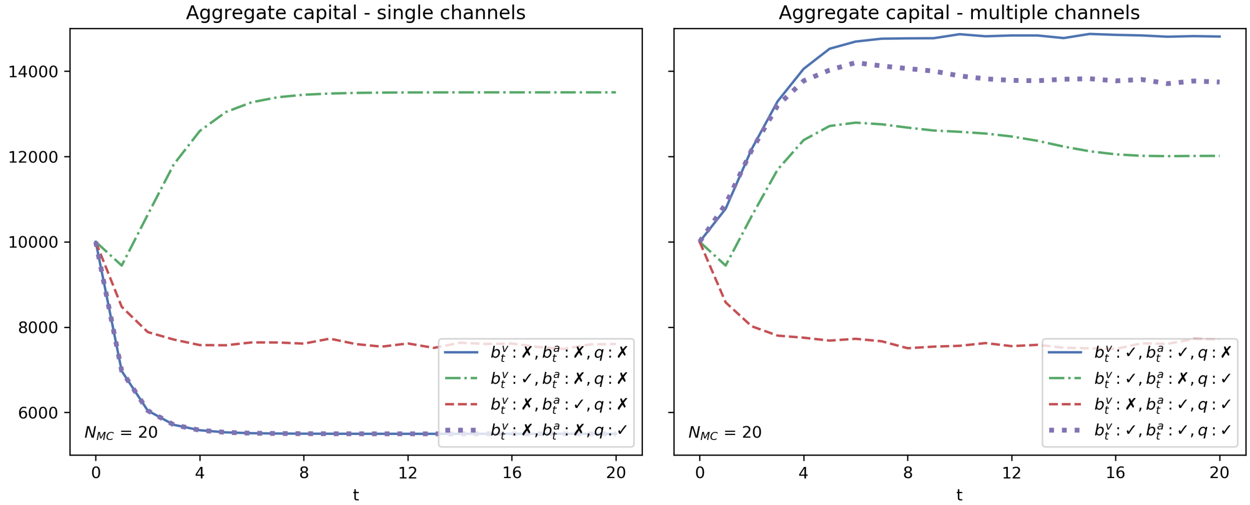

Figure 6: Simulated time series for aggregate capital

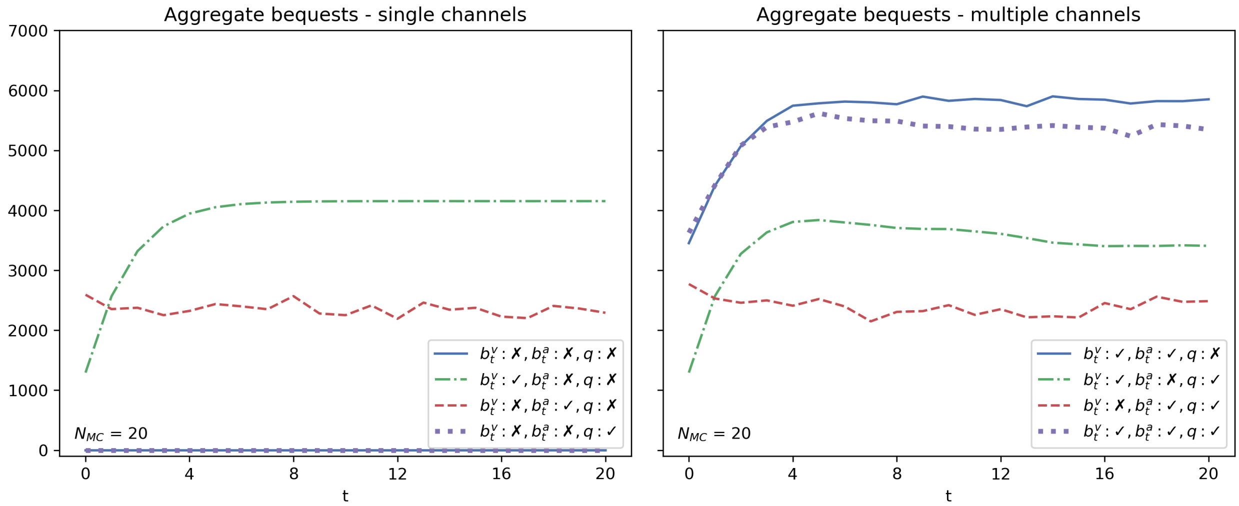

Figure 7: Simulated time series for aggregate bequests

In figure 6 and 7, simulated time-series for aggregate capital and aggregate bequests are given for various scenarios. The left panels show time-series where only one potential transmission channel is at work as well as the case where no channel is active. The right panels show cases where either two or all channels are used. In the legend, b_t^v and b_t^a refers to voluntary and accidental bequests respectively. Inter-generation income mobility is indicated by q. Juxtaposing the baseline scenario (left panels, solid lines) against the case with inter-generational income mobility(left panels, dotted lines), one can see that allowing for inter-generational income mobility has no effect on the aggregate level as long as no bequests are made. This is consistent with our expectations because the distribution of income has no influence on the aggregate level as long as preferences are homothetic ($\gamma = 0$). Comparing scenarios where either only voluntary bequests (left panels, dash-dotted lines) or only accidental bequests (left panels, dashed lines) are present, we find that the effect of voluntary bequests on the aggregate capital stock is more pronounced. Concerning bequests, we observe a similar pattern. This conforms to our priors as voluntary bequests are modeled as a luxury good. Therefore, only rich households bequeath high amounts. In contrast, in the presence of accidental bequests, rich and poor households are equally likely to bequeath. Therefore, we might observe more bequeathing households. However, the average amount of bequests tends to be low. Further, juxtaposing accidental bequests with (right panels, dashed lines) and without inter-generational income mobility (left panels, dashed lines), one can see that there are no significant differences if we allow for inter-generational income mobility. In contrast, for voluntary bequests, we find that inter-generational income mobility dampens the effect on both, capital and bequests (right panels, dash-dotted lines). Consistently, inter-generational income mobility has a similar effect if both bequest types are present (right panels, dotted lines). In the subsequent section, different calibrations and the implied results concerning the distribution of wealth will be presented.

4. Results

4.1. Calibration

In this section, we will present four different calibration strategies and the implied parameter values. Furthermore, several empirical observations will be contrasted against the corresponding model predictions. As in the preliminary calibration, we fix $\alpha = 0.33,\ \beta = 0.9,\ \delta = 0.9,\ q = 0.5$ and $N = 100$ across all calibrations. All parameter values are reported in table 1. In the first two columns, we have chosen σ and A as in the representative-agent setting but multiplied the productivity measure by the number of households. Thus, γ will be used as the only free parameter. In the first column of table 1, we target the Gini coefficient for wealth. In the second column, we targeted the share of voluntarily bequeathing households among the retired population. The latter is given by the empirical estimate of 14 percent (Kopczuk & Lupton, 2007). This alternative calibration target can be used as an additional robustness check. In columns three and four, we use the parameter estimates from Kopczuk & Lupton (2007) to calibrate the model. Hence, σ and γ are directly taken from their most successful empirical specification. However, their estimation is based on a partial equilibrium set-up where only households are modeled. Thus, it is needed to calibrate the production sector of this economy accordingly. We use A as a free parameter. Again, we first target the Gini coefficient for wealth (iii) and the share of voluntarily bequeathing households thereafter (iv).

The differences in γ and A across calibration targets are hard to interpret. Nevertheless, we believe that the chosen parameter values do not differ dramatically. In table 2, we compare the performance of the different calibrations. In the first row of column 5 (US), we present the Gini coefficient for the US wealth distribution, averaged across years. The other estimates in this column have been taken from empirical research as indicated in the notes below the table.

Concerning the Gini coefficient for wealth, one can see hardly any differences across calibrations. Compared to the empirically observed distribution, the model slightly understates wealth inequality if the parameter values are based on the empirical estimates. The share of voluntarily bequeathing households of one cohort will be overstated if the Gini coefficient is targeted. However, when the share of voluntarily bequeathing households is targeted, the Gini coefficient does not change significantly. This can be considered as additional evidence concerning the robustness of the results. In the third row, we report the share of the capital stock which can be explained by bequests. Gale & Scholz (1994) find that up to 60 percent of the US capital stock are due to bequests and inter-generational transfers. However, the estimate is sensitive to the definition of inter-generational transfers. If educational expenses are excluded, the estimate drops to approximately 50 percent. We use the lower estimate as spending on education is not explicitly modeled. It is only implicitly included in inter-generational income mobility. Therefore, it is more appropriate to use the lower estimate. We must conclude that the model overstates this figure in all calibrations. It is likely that this is an artefact of the stylized demographic structure. In the model, households live for two equally-sized periods. Although, empirically, the average retirement period is only 10 years. Hence, combining the stylized demographic structure with empirically observed survival probabilities might be problematic. In the last row, we report the correlation between lifetime income and wealth at retirement. One can see that this figure cannot be matched. This stems from limited household heterogeneity in the model. In fact, there are only two relevant groups of households: poor households do not bequeath voluntarily and thus, have *de-facto* homothetic preferences. Rich households make bequests and spend most additional income on bequeathing. Within each group, households behave similar. This leads to the counterfactual correlation between lifetime income and wealth at retirement.

	(i)	(ii)	(iii)	(iv)
Target	Gini	Share of b_t^v	Gini	Share of b_t^v
Free parameter	γ	γ	A	A
Parameter values				
A	$1,000$	$1,000$	$63,000$	$56,000$
α	0.33	0.33	0.33	0.33
β	0.90	0.90	0.90	0.90
γ	$1.10 \cdot 10^{-4}$	$8.53 \cdot 10^{-5}$	$3.36 \cdot 10^{-17}$	$3.36 \cdot 10^{-17}$
δ	0.90	0.90	0.90	0.90
σ	2.00	2.00	3.52	3.52
q	0.50	0.50	0.50	0.50

Table 1: Parameter values for different calibrations

	(i)	(ii)	(iii)	(iv)	(US)
Gini coefficient for wealth	0.80	0.80	0.79	0.79	0.80
	(0.007)	(0.008)	(0.007)	(0.007)	
Share of b_t^v among retired population	0.18	0.14	0.21	0.14	0.14^a
	(0.021)	(0.020)	(0.023)	(0.020)	
Share of capital due to b_t^v and b_t^a	0.65	0.64	0.68	0.66	0.50^b
	(0.008)	(0.009)	(0.007)	(0.009)	
Corr. between lifetime income and retirement wealth	1.00	0.99	1.00	1.00	0.61^c
	(0.001)	(0.001)	(0.001)	(0.001)	

a) Kopczuk & Lupton (2007) find that around 14 percent of their sample reach the consumption threshold (satiation consumption) in the last period of their life. b) Gale & Scholz (1994) find an estimate of 50 percent, college expenditures are excluded. c) Hendricks (2007) uses the Panel Study of Income Dynamics to retrieve this estimate. Our results are averages across Monte Carlo simulations with $N_{MC} = 500$. Standard deviations across Monte Carlo simulations are in parenthesis.

Table 2: Predictions for different calibrations

4.2. Discussion

In this section we examine the results in more detail and evaluate them relative to the literature. In figure 8 and 9, we show the predicted Lorenz curves for each calibration as well as the empirically observed average Lorenz curve for wealth in the US economy. The simulated Lorenz curves correspond to the approximate stationary distributions of the model. In particular, we show the average distribution after 40 periods averaged across Monte Carlo simulations to control for stochastic influences.

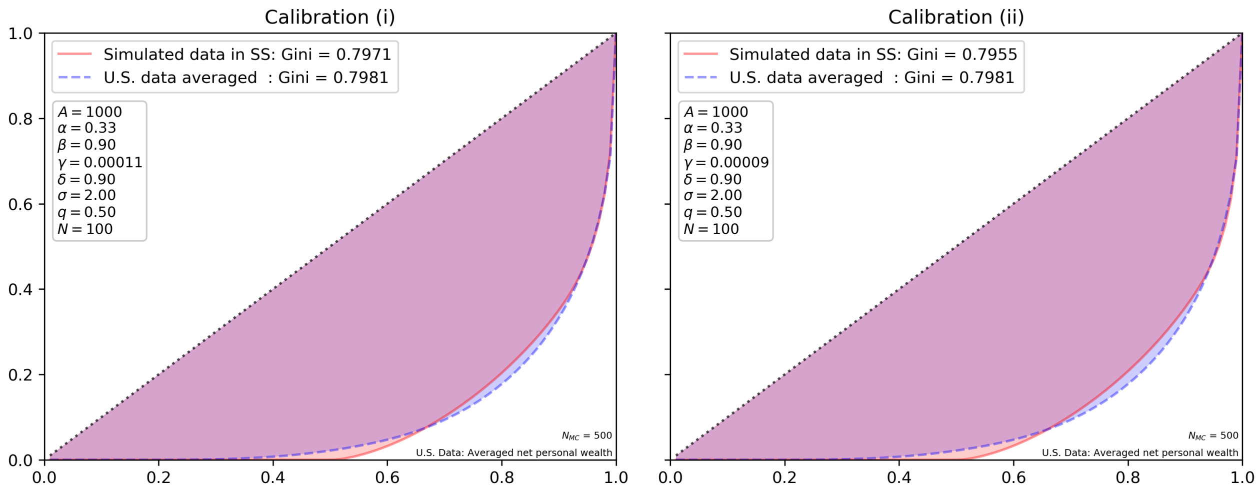

Figure 8: Lorenz curves - Calibrated by choosing γ

From a first visual examination, one can see that the results across calibration are relatively close to each other. This underscores the robustness of the estimates. Concerning the fit of the model, we see that inequality is overstated between the 40th and the 65th percentile. This mismatch is by construction. The simple demographic structure implies that 50 percent of the population is young and works. Therefore, these households have not yet accrued any wealth.

In the upper tail, the fit comes close to the actual data. This conforms with our priors as bequests are a luxury good. Allowing for this channel should mainly improve the fit in the upper tail of the distribution. Between the 65th and the 90th percentile, we see that the model understates wealth inequality. A potential explanation is the lack of social security. Accidental bequests may dampen inequality if no social security is present (Gokhale et al., 2001).

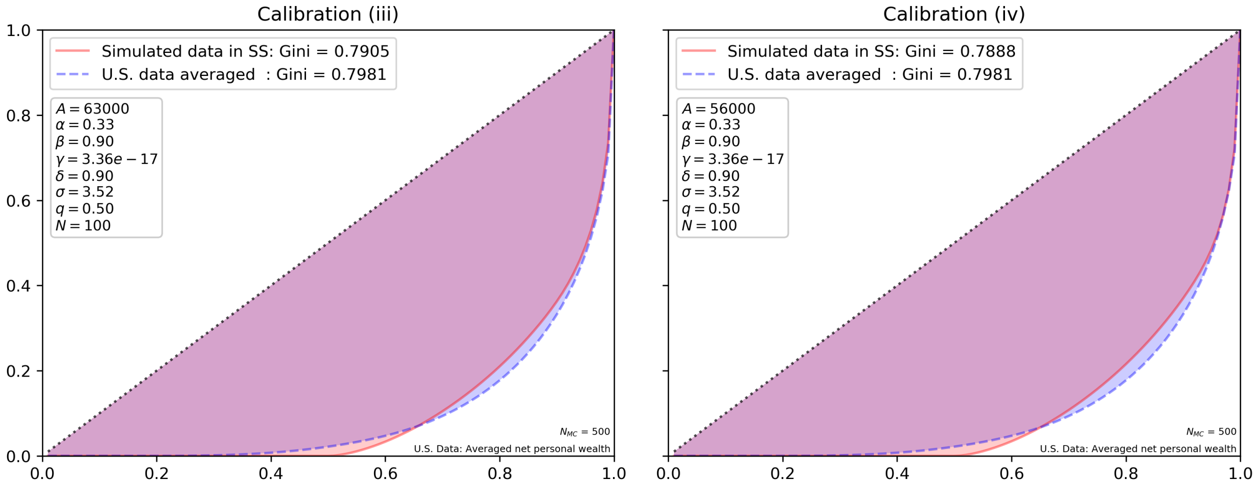

Figure 9: Lorenz curves - Calibrated by choosing A

In table 3, we compare our results to the predictions from the reviewed literature. Note that researchers have targeted the US wealth distribution at different points in time. Thus, the results can only be used for an approximate comparison across models. Concerning our results, we find that the predictions hardly differ across calibrations. Although, it is surprising that the fit in the upper tail is best if the share of deliberately bequeathing households is targeted, as in calibration (ii). Our results for the Gini coefficient are comparable with those found in the successful literature (e.g. Castaneda et al., 2003; De Nardi, 2004). Further, our model is more parsimonious. De Nardi (2004) uses 2 parameters to model bequests as a luxury good whereas we rely on only 1 free parameter. Castaneda et al. (2003) present a large model and run an extensive calibration with 37 free parameters. This allows them to target not only the Gini coefficient but also several stylized facts as well as additional points on the Lorenz curve. Thus, it is not surprising that their model performs very well in a quantitative comparison. Concerning the upper tail of the distribution, their model almost perfectly matches the top percentile. However, this is directly induced by their calibration of the earnings process. In the stationary state, less than 1 percent of the population obtains the maximal endowment of labor efficiency units. This group than saves a substantial share of income for precautionary reasons as illustrated in the literature review. Except for this economy, we outperform all other theories in terms of the top percentile as well as in terms of the Gini coefficient.

	Gini	Bottom 40 %	Top 5 %	Top 1 %
US average (1964-2014)	0.80	0.01	0.53	0.29
Aiyagari (1994)[a]	0.38	14.90	13.10	3.20
Huggett (1996)	0.76	0.00	35.60	11.80
Castaneda et al. (2003)	0.79	1.42	48.06	29.85
De Nardi (2004)	0.76	0.00	42.00	18.00
(i)	0.80	0.00	0.53	0.28
	(0.007)	(0.000)	(0.020)	(0.040)
(ii)	0.80	0.00	0.53	0.29
	(0.008)	(0.000)	(0.020)	(0.040)
(iii)	0.79	0.00	0.51	0.26
	(0.007)	(0.000)	(0.020)	(0.040)
(iv)	0.79	0.00	0.51	0.28
	(0.007)	(0.000)	(0.020)	(0.040)

a) Aiyagari's results have been retrieved from the literature review in Castaneda et al. (2003). Our results are averages across Monte Carlo simulations with $N_{MC} = 500$. Standard deviations across Monte Carlo simulations are in parenthesis.

Table 3: Predicted wealth inequality relative to the literature

Finally, we illustrate the dynamics of the Gini coefficient in figure 10 for calibrations (ii) and (iv). The corresponding illustrations for calibrations (i) and (iii) have been suppressed as the results are similar. We show the average Gini coefficient as well as the indicated confidence bands. The depicted dynamics originate from the fact that we assume that the initial distribution of wealth coincides with the distribution of income. Hence, initial wealth is distributed relatively equal compared with the long-run level of wealth inequality. In both panels we only vary inter-generational income mobility while all other parameters remain as before. The case without any inter-generational income mobility ($q = 1$) is given as solid line. One can see that wealth inequality is more severe. If inter-generational income mobility is large ($q = 1/N$, dash-dotted line), the long-run Gini coefficient drops by less than 6 points. Hence, inter-generational income mobility has a modest effect on the long-run level of wealth inequality. Comparing this scenario to the one with the inter-generational income mobility which is suggested by the literature ($q = 0.5$, dashed line), we find that the Gini coefficient may drop up to 4 points if inter-generational income mobility could be increased. Hence, the theory suggests that more inter-generational income mobility may lower the long-run level of wealth inequality. However, the magnitude of this effect tends to be small.

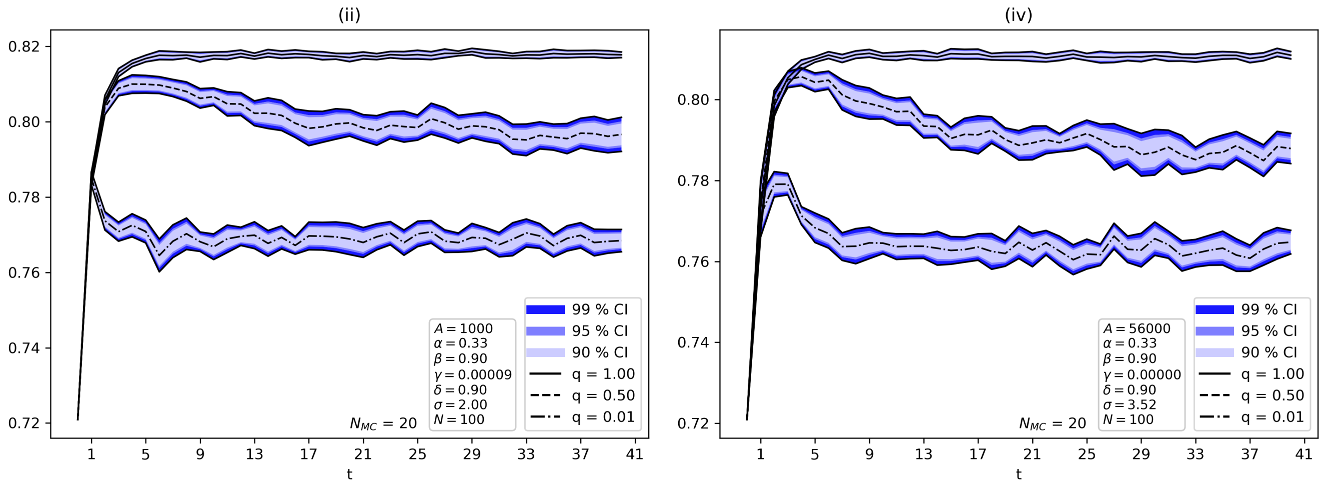

Figure 10: Time series of the Gini coefficient

In conclusion, we believe that the fit of the model is satisfactory given how stylized the model is. The key advantage of the proposed theory relies on the fact that it is supported by empirical evidence. However, the stylized demographic structure prevents us from comparing the implied dynamics against the data and makes policy evaluation difficult. Thus, this research should be considered as proof of concept that the empirical work by Kopczuk & Lupton (2007) can account for the distribution of wealth if incorporated in a macroeconomic general equilibrium framework.

5. Concluding remarks

In this research, we try to elicit how income inequality and savings behavior influence the distribution of wealth holdings. Our quantitative theory is based on rational utility maximizing households with finite lifetime. Besides life-cycle savings, we consider three potential transmission mechanisms for wealth inequality: (i) voluntary bequests, (ii) accidental bequests and (iii) inter-generational income mobility. Voluntary bequests are modeled as an extra term in each households utility function where bequeathing is a luxury good. Accidental bequests may occur due to uncertain lifetime. And finally, inter-generational income mobility can be considered as a proxy for inter-generational transmission of human capital and alike. Calibrating the model to the US economy, we find that the model can approximately account for the average distribution of wealth. In particular, voluntary bequests are a crucial ingredient to match the upper tail of the empirically observed distribution of wealth. Furthermore, additional stylized properties can be matched without being targeted in the calibration procedure.
While other models can also approximately reproduce the distribution of wealth (e.g. Castaneda et al., 2003; De Nardi, 2004) , the merit of our theory is twofold: First, our specification is more parsimonious and achieves similar results with less (free) parameters. Second, our model is based on preceding empirical research and empirical data. The bequest motive has been established by Kopczuk & Lupton (2007). Our measure for inter-generational income mobility has been set to a value comparable to Corak (2013) and the survival rates have been retrieved from empirical data.

Of course, the present article is subject to limitations. Several limitations arise from the stylized demographic structure. The demographics prevent us from conducting sound policy analysis. It further restricts the examination of the dynamics of wealth inequality. And lastly, it requires to model uncertain lifetime in a not fully satisfactory way. Further, the way inter-generational income mobility is treated is not yet satisfactory. The proposed algorithm cannot substitute a quantitative theory of income mobility which has not yet been developed. For instance, it is not clear how bequests and inter-vivos interact with income mobility and how this can be treated in a quantitative framework. Thus, this paper mainly serves as a proof of concept that the household decision-making from Kopczuk & Lupton (2007) can be successfully embedded in a general equilibrium framework to account for the average US distribution of wealth.

We identified two potential avenues for further research. First, it would be useful to generalize the demographic structure of our model such that households live for more than 2 periods. This could permit to overcome the above listed shortcomings concerning the demographic structure. The development or adaption of a suitable numerical solution method must be the centerpiece of such research. Second, more empirical work concerning transmission channels for wealth inequality is needed. De Nardi & Fella (2017) highlight that policy recommendations dramatically vary, depending on the transmission channel. Therefore, more empirical results are needed to identify the most appropriate transmission channels. We consider this as especially important because empirical evidence should always be a prerequisite for any policy analysis.

A. Solution algorithm

The demographic structure of the model permits a simple numerical solution routine. When households optimize in period t, all variables except for the rental rate of capital r_{t+1} are known. Further, the household's optimal decision in terms of c_t^y uniquely determines the capital stock K_{t+1}. The rental rate of capital is a function of K_{t+1} and exogenous parameters. Thus, r_{t+1} is pinned down by K_{t+1}, i.e. $r_{t+1}(K_{t+1})$. Further note that the consumption of a young household is also determined by r_{t+1} which implies $c_t^y(r_{t+1})$. The following algorithm exploits these relations.

1. Take a myopic initial guess for r_{t+1}: $r_{t+1}^g = r_t$.
2. Compute the implied capital stock: $K_{t+1}^g = K_{t+1}(r_{t+1}^g)$.
3. Compute the deviation between guess and implied interest rate: $\Delta^g = r_{t+1}(K_{t+1}^g) - r_{t+1}^g$.
4. if $\Delta^g \geq \epsilon$, then let $r_{t+1}^g = r_{t+1}^g + \Delta^g$ and go to step 2.[9]

Note that ϵ denotes the desired precision. The algorithm terminates if the deviation between the expected and the actual rental rate is below ϵ. Thus, we have a forward-shooting algorithm which is comparable to standard Jacobi or Gauss-Seidel iteration procedures.
For the representative-household version, this algorithm is not needed because the dynamics are uniquely defined by the law of motion for capital as given in equation 12. However, with heterogeneous agent, the law of motion becomes inconvenient as it would need to allow for 4 cases for each dynasty. Hence, the law of motion may have 4^N distinct cases. The present algorithm is a convenient alternative.

B. Inter-generational income mobility as Markov chain

In the present paper, inter-generational income mobility has been modeled by the algorithm described in section 3. This modeling strategy has been chosen as it guarantees that each empirically observed income share can only be assigned once. This ensures that all shares add up to unity, i.e. $\sum_{i=1}^{N} \theta_{it} = 1,\ \forall t$. If instead, income shares are determined by a Markov chain, this is not guaranteed. It may happen that two households end up in the same state of the Markov chain and hence, $\sum_{i=1}^{N} \theta_{it} = 1,\ \forall t$ need not hold. In this section, we model inter-generational income mobility by a Markov chain which is part of an algorithm to circumvent this issue. That is, the distribution of income shares is governed by a Markov process. In a second step, all income shares are re-scaled in order to ensure that all shares add up to 1. For this exercise, we again assume $N = 100$ and use empirically observed income shares. Hence, the transition matrix has dimension 100×100 where each state corresponds to an income share. To obtain transition probabilities comparable to those used in the algorithmic approach, we define the initial transition matrix $\hat{P}$ as follows.

[9] The statement $r_{t+1}^g = r_{t+1}^g + \Delta^g$ is poor mathematical notation. We nevertheless use it for readability. It means that r_{t+1}^g will be updated by adding Δ^g to the current value of r_{t+1}^g

$$\hat{P} = \begin{pmatrix} q & q(1-q) & q(1-q)^2 & \cdots & \cdots & q(1-q)^{N-1} \\ q(1-q) & q & q(1-q) & q(1-q)^2 & \cdots & q(1-q)^{N-2} \\ \vdots & & \vdots & & & \vdots \\ q(1-q)^{i-1} & q(1-q)^{i-2} & \cdots & q & \cdots & q(1-q)^{N-i} \\ \vdots & & \vdots & & & \vdots \\ q(1-q)^{N-2} & \cdots & q(1-q)^2 & q(1-q) & q & q(1-q) \\ q(1-q)^{N-1} & \cdots & \cdots & q(1-q)^2 & q(1-q) & q \end{pmatrix}$$

Recall that our measure for inter-generational income mobility was q and note that i refers to the respective row of the matrix. However, nothing guarantees that rows sum up to 1. Hence, we need to transform each row by multiplying each element of each row with a row-specific scalar r_i to ensure this property. As the sum of every row is a (real) scalar $s_i = \sum_{j=1}^{N} \hat{P}_{ij}$, it follows that there exist exactly one $r_i \in \mathbb{R}$ such that $s_i r_i = 1$ holds. This is a basic property of the real numbers. Therefore, the actual transition matrix P is as follows where r_i is chosen such that all rows add up to 1.

$$P = \begin{pmatrix} r_1 q & r_1 q(1-q) & r_1 q(1-q)^2 & \cdots & \cdots & r_1 q(1-q)^{N-1} \\ r_2 q(1-q) & r_2 q & r_2 q(1-q) & r_2 q(1-q)^2 & \cdots & r_2 q(1-q)^{N-2} \\ \vdots & & \vdots & & & \vdots \\ r_i q(1-q)^{i-1} & r_i q(1-q)^{i-2} & \cdots & r_i q & \cdots & r_i q(1-q)^{N-i} \\ \vdots & & \vdots & & & \vdots \\ r_{N-1} q(1-q)^{N-2} & \cdots & r_{N-1} q(1-q)^2 & r_{N-1} q(1-q) & r_{N-1} q & r_{N-1} q(1-q) \\ r_N q(1-q)^{N-1} & \cdots & \cdots & r_N q(1-q)^2 & r_N q(1-q) & r_N q \end{pmatrix}$$

In this exercise, we fix $q = 0.5$ as in the original calibrations. The vector π which solves $(I - P)\pi = 0$ gives a stationary distribution of this Markov chain. This distribution comes close to a uniform distribution in the center but has not enough mass in its tails. However, this cannot be avoided if we want a transition matrix which is comparable to the algorithm. The left panel of figure 11 shows that the differences between the empirical distribution and the stationary distribution of the Markov chain are still acceptable.

We have found a Markov chain which governs the distribution of income shares where each state of the transition matrix corresponds to an empirically observed income share. To fix the above illustrated problem that all shares may not sum up to 1, we proceed as follows. Let $\hat{\Theta}_t = (\hat{\theta}_{1t}, ..., \hat{\theta}_{Nt})'$ denote the vector which contains the time t realization for each household which follow the above described Markov chain. Again, from the basic properties of the real numbers we have that exactly one scalar $r_t \in \mathbb{R}$ exists such that $r_t \sum_{i=1}^{N} \hat{\theta}_{it} = 1, \ \forall t$ holds. Thus, in a second step, we determine the actual distribution of income shares as $\Theta = (r_t \hat{\theta}_{1t}, ..., r_t \hat{\theta}_{Nt})' = (\theta_{1t}, ..., \theta_{Nt})', \forall t$.

	(i)	(v)	(US)
Gini coefficient for wealth	0.80	0.80	0.80
	(0.007)	(0.026)	
Share of b_t^v among retired population	0.18	0.18	0.14^a
	(0.021)	(0.038)	
Share of capital due to b_t^v and b_t^a	0.65	0.66	0.50^b
	(0.008)	(0.027)	
Corr. between lifetime income and retirement wealth	1.00	1.00	0.61^c
	(0.001)	(0.002)	

Column (i) and (v) shows the results for the first calibration strategy. In (i), inter-generational income mobility is modeled by the given algorithm and in column (v) inter-generational income mobility is modeled by a Markov chain.
a) Kopczuk & Lupton (2007) find that around 14 percent of their sample reach the consumption threshold (satiation consumption) in the last period of their life. b) Gale & Scholz (1994) find an estimate of 50 percent, college expenditures are excluded. c) Hendricks (2007) uses the Panel Study of Income Dynamics to retrieve this estimate. Our results are averages across Monte Carlo simulations with $N_{MC} = 500$. Standard deviations across Monte Carlo simulations are in parenthesis.

Table 4: Predictions for different strategies of modeling inter-generational income mobility

Now we present the results for calibration (i) as well as a variant of this calibration where we model inter-generational income mobility by the above described procedure. The latter is indicated as (v) in table 4. One can see that the point estimates hardly changed but the economy becomes more volatile using this alternative modeling approach. This follows from the needed re-scaling of the transition probabilities. The choice of $q = 0.5$ implies $\sum_{j=1}^{N} \hat{P}_{ij} \geq 1$ for $i = 1, ..., N$ and $\sum_{j=1}^{N} \hat{P}_{ij} > 1$ for $i = 2, ..., N-1$. That is 98 rows must be divided by a number larger than 1 to obtain P. Hence, the implied degree of inter-generational income mobility is larger than desired. Unfortunately, this cannot be avoided if one wants transition probabilities which are comparable to those implied by the algorithm. However, the magnitude of the standard deviations is still acceptable. Hence, this additional exercise underscores the robustness of the model. To examine the implied distribution in more detail, we have plotted the corresponding Lorenz curve of calibration (v) in the right panel of figure 11. One can see that the fit is as good as in the original calibrations (i) to (iv).

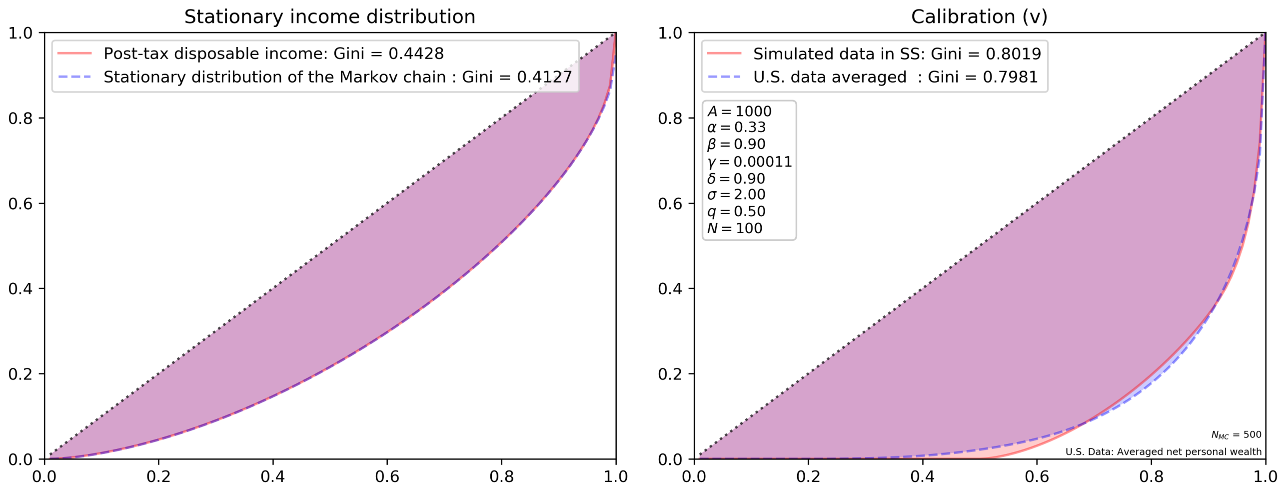

Figure 11: Lorenz curves - Labor income as Markov chain

Lastly, we present the corresponding dynamics of the Gini coefficient for calibration (v) in figure 12. First of all, one can see that the confidence bands become larger compared to all other scenarios. Note that we also increased the number of Monte Carlo repetitions from 20 to 50 compared to the previous calibrations. With only 20 repetitions, the confidence bands would have been very big and inconvenient to examine. This conforms with our previous observation that the standard deviations have increased. Nevertheless, the average prediction is close to what we have seen in calibrations (i) to (iv).

Although this supplementary exercise stresses the robustness of the main results, it can not replace further investigations concerning inter-generational income mobility as transmission channel for wealth inequality. A quantitative and micro-founded theory of inter-generational income mobility would be beneficial for this class of models.

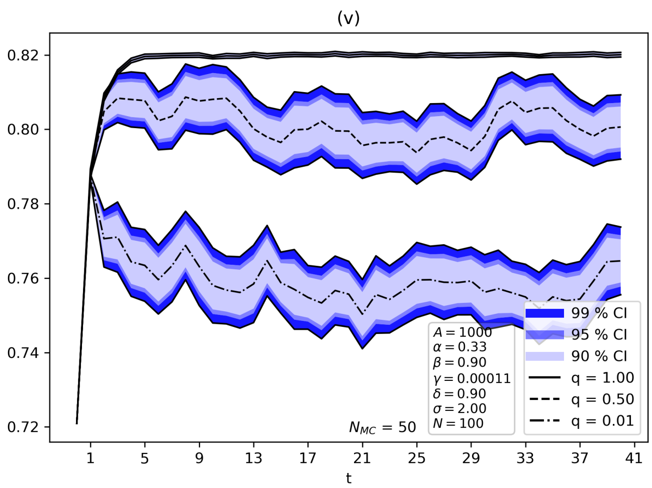

Figure 12: Time series of the Gini coefficient

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Abstract (EN)
It is not yet sufficiently understood how income inequality shapes the distribution of wealth. In this research, a simple overlapping generations general equilibrium model with heterogeneous agents is proposed where the distribution of earnings is exogenous. This allows to focus on three channels which may translate income into wealth inequality: (i) voluntary bequests, (ii) accidental bequests and (iii) inter-generational income mobility. The model has been calibrated to the US distribution of wealth. It can approximately account for the average wealth distribution as well as other stylized properties of the US economy.

Abstract (DE)

Es ist nicht hinreichend erklärt inwiefern Einkommensungleichheit die Vermögensverteilung beeinflusst. In dieser Arbeit präsentieren wir ein einfaches allgemeines Gleichgewichtsmodell mit überlappenden Generationen und heterogenen Agenten, in welchem die Verteilung der Arbeitseinkommen exogen ist. Wir konzentrieren uns auf drei potenzielle Wirkungskanäle durch welche Einkommensungleichheit die Vermögensverteilung beeinflusst: (i) geplantes Vererben, (ii) ungeplantes Vererben und (iii) Einkommensmobilität. Wir kalibrieren unser Model auf die US Volkswirtschaft und stellen fest, dass es die durchschnittliche Vermögensverteilung, sowie weitere empirische Merkmale reproduzieren kann.

Summary (EN)

The present thesis is concerned with the distribution of wealth. In particular, we examine how income inequality shapes the distribution of wealth. We present a simple overlapping generations general equilibrium model which takes the distribution of labor income as exogenously given. Our one-sector closed-economy model is populated by households which live for 2 periods and supply labor inelastically. Households are heterogeneous with respect to their lifetime income. In this setting, we consider three potential transmission channels for wealth inequality: (i) voluntary bequest, (ii) accidental bequests and (iii) inter-generational income mobility. Results indicate that our theory can approximately account for the US distribution of wealth, averaged across time. To underscore the robustness of our results, we present several calibration strategies as well as two different approaches to model inter-generational income mobility. Across all settings, our predictions are very close to the data.

Zusammenfassung (DE)

In der vorliegenden Arbeit wird untersucht inwiefern Einkommensungleichheit zur Verteilung von Vermögen beiträgt. Wir entwickeln ein allgemeines Gleichgewichtsmodell mit überlappenden Generationen von Haushalten, die für zwei Perioden leben. In diesem Modell einer geschlossenen Einsektor Ökonomie ist die Einkommensverteilung exogen und das Arbeitskräfteangebot unelastisch. Die Haushalte sind heterogen hinsichtlich ihres Einkommens. In diesem Modell untersuchen wir insbesondere drei potenzielle Wirkungskanäle, welche die Vermögensverteilung beeinflussen: (i) geplantes Vererben, (ii) ungeplantes Vererben und (iii) Einkommensmobilität. Die Ergebnisse zeigen, dass unsere Theorie die US Vermögensverteilung approximativ reproduzieren kann. Um die Robustheit der Ergebnisse zu gewährleisten präsentieren wir verschiedene Kalibrierungen, sowie zwei unterschiedliche Ansätze für die Modellierung von Einkommensmobilität. Unsere Vorhersagen kommen der empirisch beobachtbaren Verteilungen in allen Varianten sehr nahe.