The Marginal Propensity to Consume in Heterogeneous Agent Models *

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Abstract

We conduct a systematic analysis of heterogeneous agent consumption-saving models to understand whether and how they can generate a large average marginal propensity to consume (MPC). One-asset models without ex-ante heterogeneity feature a trade-off between a high average MPC and a realistic level of aggregate wealth. One-asset models with additional heterogeneity in preferences or rates of return, or behavioral features, can generate high MPCs with the right amount of total wealth, but at the cost of an excessively polarized wealth distribution that understates the wealth held by households in the middle of the distribution. Two-asset models that include both liquid and illiquid assets can resolve these trade-offs without ex-ante heterogeneity or behavioral elements, although these additional features can improve the fit of the model in other dimensions. Across all models, the share and type of hand-to-mouth households is the most important factor that determines the level of the average MPC.

Keywords: Borrowing Constraints, Consumption, Income Risk, Hand-to-Mouth, Heterogeneity, Liquidity, Marginal Propensity to Consume, Market Incompleteness, Wealth Distribution.

JEL codes: D15, D31, D52, E21, E62, E71, G51

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1 Introduction

The marginal propensity to consume (MPC) is the fraction of a small, unanticipated one-time windfall (usually around $500) that a household spends within a given time period (usually one quarter). We conduct a systematic investigation of the size and determinants of the aggregate MPC in heterogeneous agent incomplete markets models – models whose key features are idiosyncratic income risk and a precautionary savings motive. Since the MPC is a central concept in modern macroeconomics, the usefulness of these models is closely tied to their ability to reproduce the evidence on MPCs. But, as we explain, there exists a tension between data on the household wealth distribution and the MPCs generated by baseline versions of these models. Our goal in this paper is to resolve some of the disagreement and confusion among economists about the sources of this tension and the alternative solutions that have been proposed.

A large amount of empirical work suggests a large average MPC (see Jappelli and Pistaferri (2010) for a survey).\(^1\) This collective body of evidence indicates that the average quarterly MPC on non-durable goods and services out of windfalls of $500-$1,000 is between 15% and 25%. Moreover, this average masks substantial heterogeneity in MPCs. Many households have MPCs that are close to zero, but some households have MPCs not far from 1 – with a great deal of variation in between.\(^2\) Some of this heterogeneity is explained by the distribution of liquid wealth and some by fixed individual characteristics, but most is left unexplained by observable data. Finally, there is evidence that households respond more strongly to smaller than windfalls than to larger windfalls, and to negative income shocks than to positive income shocks.

Until recently, this evidence on MPCs made only a guest appearance in modern macroeconomics, because of the representative agent assumption implicit in most models. With a representative agent, or complete markets, there is a single common MPC that is roughly the same size as the interest rate, so these models are unable to speak to the evidence. And since the MPC is so small, the Keynesian multiplier, which determines the general equilibrium propagation of macroeconomic shocks, is small too – even in models with nominal rigidities.

But in the last two decades, macroeconomic models have evolved. Today, the heterogeneous-agent incomplete-markets framework is widely accepted to be a more useful model of the house-
hold sector than the representative agent complete markets framework. As a result, MPCs have regained a focal role. Relative to representative agent models, heterogeneous agent models deliver two realistic features of MPCs: (i) the aggregate MPC can be much larger than the interest rate, and (ii) the distribution of MPCs can be very dispersed. When combined with nominal rigidities, the large aggregate MPC implies that the Keynesian multiplier can be substantially stronger. This has led macroeconomists to revisit the transmission mechanism of fiscal and monetary policy using this newer class of models (Auclert, 2019; Kaplan and Violante, 2014; Kaplan, Moll, and Violante, 2018). One conclusion that has emerged is that indirect general equilibrium effects of policies, which are negligible in representative agent models, play a prominent role in heterogeneous agent models. It follows that to understand the uneven incidence of policies across the income and wealth distribution, it is necessary to go beyond their direct impact and investigate how they affect equilibrium quantities and prices in labor, credit and asset markets. Moreover, it is not just the aggregate MPC, but the entire distribution of MPCs across households that matters for the propagation of macro shocks and the stabilizing effects of fiscal and monetary policies. The cross-sectional correlation between a household’s MPC and the way that its income and wealth is affected by the shock or policy determines whether the aggregate effects are amplified or dampened (Bilbiie, 2020; Patterson et al., 2019; Werning, 2015; Kekre and Lenel, 2021).

From a theoretical perspective, there are a number of reasons why heterogeneous-agent models with uninsurable risk can generate large and heterogeneous MPCs. To begin with, these models feature poor hand-to-mouth (HtM, hereafter) households with zero wealth –or borrowers for which credit constraints bind– who are eager to consume much of any extra liquidity they receive. Moreover, the two-asset (liquid and illiquid) version of the models also features a second type of constrained agents, the wealthy HtM consumers who hold the bulk of their wealth tied up in illiquid form. These agents have consumption responses with respect to small windfalls very much like the canonical HtM households (Kaplan and Violante, 2014; Kaplan, Violante, and Weidner, 2014).

Uninsurable risk creates two other sources of high MPC. When the utility function displays prudence ($u''' > 0$), the consumption function becomes concave even in the absence of liquidity constraints. Since households want to smooth consumption, they save more ‘for the rainy days’, i.e. future income uncertainty. Since the precautionary saving motive is declining in wealth, consumption increases in wealth also at a decreasing rate. With occasionally binding liquidity constraints, the consumption function becomes concave even in the absence of prudence for

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3 Auclert, Rognlie, and Straub (2018) illustrate how in dynamic stochastic general equilibrium New-Keynesian models what matters is not just the contemporaneous MPC, but its the entire time profile, or the intertemporal MPCs. We return on this point later in the paper.
similar reasons. The precautionary saving motive is aimed at avoiding binding constraints which expose the household to consumption fluctuations and welfare losses. In both cases, MPCs can be large for low levels of wealth, even for unconstrained households. Carroll (2001) and, more recently, Carroll, Holm, and Kimball (2021) contain lucid expositions of these arguments and exhaustive surveys of the literature.

Finally, in these models households can differ due ex-ante characteristics, as opposed to random circumstances. Impatience, high willingness to substitute, low returns on saving or behavioral biases can all be sources of high MPCs (Aguiar, Bils, and Boar, 2020; Carroll, Slacalek, Tokuoka, and White, 2017).

But how close can this class of models come to matching the evidence on MPCs? Which features of the models are most important for their quantitative performance? By solving multiple versions of the model under different calibration strategies, we arrive at five main findings: (i) the canonical one-asset precautionary saving model, plausibly calibrated, yields aggregate quarterly MPCs between 3% and 5%, which is an order of magnitude bigger than corresponding representative agent models, but still far from their empirical counterpart; (ii) calibrations of this model that target liquid wealth or the share of hand-to-mouth individuals succeed in matching the data on MPCs but, because they abstract from 98% of the wealth in the economy are of limited use in general equilibrium applications; (iii) extensions of the model that incorporate either ex-ante heterogeneity or behavioral preferences can match the data on MPCs, but only by vastly understating the amount of wealth held by households in the middle of the distribution - which we label the ‘missing middle’ problem (e.g., median wealth is 5 to 10 times smaller than in the data); (iv) extreme spender-saver models can generate large MPCs without the missing middle problem, but have implausible implications for fiscal policy; (v) the two-asset precautionary savings model has the potential to reconcile all these tensions, but it requires a large gap in returns between illiquid and liquid assets.

**Outline** Section 2 analyzes the canonical one-asset incomplete-markets model. Section 3 extends the one-asset model model in several directions. Section 4 analyzes the two-asset model. Section 5 discusses other concepts of MPCs. Section 6 concludes the paper. The Appendix contains additional details about data, models, calibrations, and simulations.

### 2 One-Asset Models

In this section, we present findings from various versions of a standard one-asset precautionary savings model. Our one asset models are formulated in discrete time, but we also examine a
continuous time version for consistency with the two-asset models in Section 4.

2.1 Baseline One-Asset Model

Environment. The economy is populated by a measure one continuum of households who survive each period with probability \((1 - \delta)\). Conditional on surviving, a households’ time preference factor is given by \(\hat{\beta}\), implying an effective discount factor of \(\beta = \hat{\beta} (1 - \delta) < 1\). Period utility is given by \(u(c_t)\), where \(u\) is strictly increasing and concave, and \(c_t\) denotes consumption expenditures. At each date \(t\), households are endowed with labor income \(y_t\) which follows an exogenous stochastic process described below. Income draws are IID across households. Households can save, but not borrow, in a risk-free asset \(b_t\) with rate of return \(R = 1 + r\). The household problem:

\[
\max_{\{c_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t) \tag{1}
\]

subject to

\[c_t + b_{t+1} = Rb_t + y_t, \quad b_{t+1} \geq 0, \quad b_0 = 0\]

The solution to the household problem yields decision rules for consumption \(c(b, y)\) and next period’s wealth \(b'(b, y)\). These decision rules induce a stationary distribution that we denote by \(\mu(b, y)\), with associated marginal distribution \(\mu(b)\) over wealth.\(^4\)

Parameterization. Consistent with our focus on quarterly MPCs, our baseline discrete time model has a period of one quarter. We set \(\delta = 1/200\) so that the expected adult life span is 50 years. In our baseline parameterization we assume a constant-elasticity utility function \(u(c) = c^{1-\gamma}\) with \(\gamma = 1\) so that \(u(c) = \log c\). We set \(b = 0\) so that there is no borrowing and we set the interest rate to \(r = 0.0025\), or 1% per year. This partial equilibrium approach keeps our exercise especially clear because it allows us to move the interest rate independently of the discount factor and to highlight their respective importance in determining MPCs.\(^5\) We model the process for log income as the sum of two orthogonal components, an AR(1) component and an IID component.

\[^4\text{If the income process has multiple components, then with a slight abuse of notation } y\text{ should be intended as the vector of all income states.}\]

\[^5\text{In the equilibrium of a closed economy the two would be tightly connected, once a target for the wealth-income ratio is chosen. A number of recent papers in the literature (Auclert, Rognlie, and Straub, 2018; Kaplan, Moll, and Violante, 2018; Wolf, 2020) have demonstrated that one can usefully separate macro questions about the transmission of shocks and the effects of policies into (i) partial-equilibrium response and (ii) general-equilibrium amplification. The analysis in this paper is purely about the size of the initial household response to an income shock, and about how different model assumptions matter and why, not about its general equilibrium implications.}\]
<table>
<thead>
<tr>
<th></th>
<th>(1) Data</th>
<th>(2) Baseline</th>
<th>(3) ( E[a] )</th>
<th>(4) Median(a)</th>
<th>(5) ( E[a] )</th>
<th>(6) Median(a)</th>
<th>(7) HtM</th>
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<td>Quarterly MPC (%)</td>
<td>4.6</td>
<td>2.7</td>
<td>4.3</td>
<td>14.0</td>
<td>33.7</td>
<td>22.0</td>
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<tr>
<td>Annual MPC (%)</td>
<td>14.6</td>
<td>8.5</td>
<td>13.6</td>
<td>40.8</td>
<td>77.4</td>
<td>58.7</td>
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<td>Quarterly MPC of the HtM (%)</td>
<td>28.7</td>
<td>26.3</td>
<td>28.4</td>
<td>33.2</td>
<td>42.1</td>
<td>36.6</td>
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</tr>
<tr>
<td>Share of HtM (%)</td>
<td>14.2</td>
<td>2.5</td>
<td>1.7</td>
<td>2.3</td>
<td>7.5</td>
<td>37.4</td>
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<tr>
<td>Annualized discount factor</td>
<td>0.980</td>
<td>0.988</td>
<td>0.981</td>
<td>0.945</td>
<td>0.826</td>
<td>0.909</td>
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Panel A: Decomposition

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<tr>
<td>Gap with Baseline MPC</td>
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<td>33.7</td>
<td>22.0</td>
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<tr>
<td>Effect of MPC Function</td>
<td>-0.8</td>
<td>-0.1</td>
<td>3.1</td>
<td>11.1</td>
<td>6.0</td>
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<td>Effect of Distribution</td>
<td>-1.3</td>
<td>-0.2</td>
<td>4.6</td>
<td>12.5</td>
<td>7.7</td>
<td></td>
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<tr>
<td>Interaction</td>
<td>0.2</td>
<td>0.0</td>
<td>1.7</td>
<td>5.6</td>
<td>3.7</td>
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Panel B: Wealth Statistics

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<td>4.1</td>
<td>4.1</td>
<td>9.4</td>
<td>4.6</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Median wealth</td>
<td>1.5</td>
<td>1.3</td>
<td>3.5</td>
<td>1.5</td>
<td>0.2</td>
<td>0.0</td>
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<tr>
<td>( a \leq 1000 )</td>
<td>15.1</td>
<td>2.5</td>
<td>1.8</td>
<td>6.2</td>
<td>22.2</td>
<td>42.1</td>
</tr>
<tr>
<td>( a \leq 5000 )</td>
<td>19.5</td>
<td>11.6</td>
<td>7.5</td>
<td>6.2</td>
<td>22.2</td>
<td>42.1</td>
</tr>
<tr>
<td>( a \leq 10000 )</td>
<td>24.6</td>
<td>18.5</td>
<td>11.8</td>
<td>44.3</td>
<td>77.2</td>
<td>60.2</td>
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<tr>
<td>( a \leq 50000 )</td>
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<td>40.3</td>
<td>26.8</td>
<td>79.3</td>
<td>96.4</td>
<td>91.1</td>
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<tr>
<td>( a \leq 100000 )</td>
<td>49.4</td>
<td>51.9</td>
<td>36.0</td>
<td>89.8</td>
<td>99.0</td>
<td>97.1</td>
</tr>
<tr>
<td>Wealth, top 10% share</td>
<td>49.9</td>
<td>46.6</td>
<td>44.6</td>
<td>52.0</td>
<td>56.5</td>
<td>51.6</td>
</tr>
</tbody>
</table>

Table 1: Baseline one-asset model and sensitivity analysis with respect to which moment of the wealth distribution is targeted to set the discount rate.

We assume that shocks to both components arrive stochastically with a Poisson arrival rate of \( 1/4 \), so that shocks are received on average once a year. We estimate the parameters of the income process by matching moments of the household labor income distribution from the Panel Study of Income Dynamics. See Appendix A.1 for details.

**Wealth Distribution.** We choose the effective discount factor \( \beta \) so that mean wealth in the stationary distribution is consistent with mean wealth in the United States. We express all values as multiples of mean annual household earnings, which we define as labor income plus social security income for retired households. Our income and wealth statistics come from the 2019 Survey of Consumer Finances, from which we exclude households in the the top 5% of the wealth...
distribution. See Appendix A.2 for details.\textsuperscript{6} In the bottom 95\% of the population, mean annual earnings is $67,000 and mean net worth is $275,000 or 4.1 times mean annual earnings.

Table 1 (Panel B) reports key wealth statistics from the data (Column 1) and in the baseline model (Column 2), with the discount factor chosen to hit this target. The implied annualized value for $\beta$ is 0.98. Median wealth in the model (1.34) is quite close to its value in the data (1.54) despite not being explicitly targeted. The baseline model generates fewer very low wealth households than in the data. A common definition of hand-to-mouth households in the literature is households whose wealth is less than half their monthly income Kaplan, Violante, and Weidner (2014). According to this definition, only 2\% of households in the model are hand-to-mouth compared with 14\% in the data, because optimizing households seek to save themselves away from hand-to-mouth regions of the asset space (see line labeled ‘Share of HtM’).\textsuperscript{7}

Marginal Propensities to Consume in the Baseline Model \quad Our main object of interest is the quarterly MPC out of a one-time unanticipated windfall of size $x$. For a household with state

\textsuperscript{6}The top 5\% holds 65\% of the total net worth in the economy. We exclude this group from our calibration because the simple precautionary savings models we consider here are not well suited to explain the top tails of the wealth distribution (Benhabib and Bisin, 2018; De Nardi and Fella, 2017) and the top tail of the wealth distribution has a negligible impact on our definition of the average MPC.

\textsuperscript{7}This feature is robust to other definitions. Fewer than 1\% have zero or negative wealth, compared with 11\% in the data; 3\% hold less than $1,000, compared with 15\% in the data; and 12\% hold less than $5,000, compared with 20\% in the data.
vector \((b, y)\) at the time when the windfall is received, the impact MPC (or MPC at horizon 0) is:

\[
m_0(x; b, y) = \frac{c(b + x, y) - c(b, y)}{x}. \tag{2}
\]

We focus on MPCs out of \(x = $500\) windfalls, which is the approximate size of common stimulus programs from which MPCs were measured in the literature.\(^8\) Average MPCs are reported in Panel A of Table 1. The average quarterly MPC in the baseline model is 4.6%. Figure 1 displays the MPC as a function of wealth for a household with mean income, \(m_0 ($500; b, \bar{y})\), superimposed over the stationary wealth distribution. Note how the MPC quickly converges to the MPC under certainty, \(1 - \beta\), as wealth rises. The quarterly MPC of HtM households is very high, nearly 29%, but at a level of wealth of around 0.5 (about $35,000) the effects of concavity of the consumption function on the MPC have already dissipated: it is only households with very low levels of wealth that contribute to generating an MPC that is substantially above \(1 - \beta\). This is a theme that will resurface as we explore richer versions of the model.

**Decomposition Relative to Certainty Benchmark.** Without income uncertainty or borrowing constraints, the consumption function is linear in wealth, with constant slope \(m^*_0\), as given by the formula:\(^9\)

\[
c_0 = m^*_0 \left[ rb_0 + \sum_{t=0}^{\infty} \left( \frac{1}{R} \right)^t y_t \right] , \quad \text{with} \quad m^*_0 = 1 - R^{-1} \left[ R \beta \right]^{1/\gamma}. \tag{3}
\]

We refer to \(m^*_0\) as the certainty MPC. It is decreasing in the discount factor and, provided that \(\beta R < 1\), is decreasing in the IES \(1/\gamma\). With log-utility \((\gamma = 1)\), the MPC is equal to the effective discount rate, \(m^* = 1 - \beta\), which in our baseline calibration would give a quarterly MPC of 0.5%, nearly one order of magnitude lower than in our baseline one-asset precautionary savings model.

To better understand why the precautionary savings model with uncertainty generates a larger average MPC (4.6% vs 0.5%), we propose a decomposition of the difference between the MPCs in the two models. Let \(m^{BC}_0(b)\) be the MPC function in a model that is identical to the baseline model, except that household income is deterministic and all households receive the average level of income. Despite the absence of income risk, if \(\beta R < 1\) the consumption function in this model is concave because of the presence of a borrowing constraint (Helpman, 1981). The

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\(^8\)In Section 5 we explore MPCs out of other size windfalls and losses over other durations.  
\(^9\)See appendix B.3 for the derivation of equation (3).
average MPC in the baseline model $\bar{m}_0$ can then be written as:

$$
\bar{m}_0 = m_0^\text{Certainty} + \int_B \left[ m_0^{BC}(b) - m_0^\text{Certainty} \right] d\mu(b) + \int_{B \times Y} \left[ m_0(b, y) - m_0^{BC}(b) \right] d\mu(b, y).
$$

The first term is the certainty MPC, the second term captures the role of borrowing constraints paired with the desire to frontload consumption (i.e. $\beta R < 1$) absent income risk, and the final term captures the additional effect of uninsurable risk and precautionary savings.

Performing this decomposition reveals that the bulk of the gap with the certainty MPC (68%) is explained by the presence of borrowing constraints coupled with a declining optimal consumption profile, even absent idiosyncratic uncertainty. The residual (38%) is accounted for by the precautionary saving motive caused by uninsurable income risk. Thus, perhaps surprisingly, a strong force toward concavity of the consumption function emerges even without income uncertainty.\(^{10}\)

### 2.2 Alternative Calibrations of the Baseline

We conduct an extensive sensitivity analysis of the baseline model. Unless otherwise specified, we always recalibrate the discount factor so that each version of the model has the same ratio of mean wealth to mean earnings of 4.1.

**Deviations Between Heterogeneous-Agent Models.** To understand why different versions of the baseline model yield different MPCs, we propose a decomposition of the difference in average MPCs across models. The average MPC can be larger in one model than in another either because the consumption function is steeper, or because the distribution of households is more concentrated in steeper regions of the state space. Let $\mu^*$ and $m_0^*$ be the distribution and average MPC in the baseline model from Section 2.1. We can then write the average MPC in an alternative model as:

\(^{10}\)Of course, in general equilibrium it is income uncertainty that pushes the interest rate below the discount rate.
\[ m_0 = m_0^\star + \int_{B \times Y} [m_0(b, y) - m_0^\star] \, d\mu^\star(b, y) + \int_{B \times Y} m_0^\star(b, y) \, [d\mu(b, y) - d\mu^\star(b, y)] \]

The component labeled ‘Consumption Function’ captures the difference in average MPCs that arises because the consumption functions are different in the two models. The component labeled ‘Distribution’ captures the difference in average MPCs that arises because the stationary distributions of the two models put different mass in different parts of the state space. The component labeled ‘Interaction’ arises because of the interaction between these two effects.

**Target for Wealth-Income Ratio.** In Table 1 we report MPCs under alternative aggregate wealth targets. We start by considering a higher target for mean wealth based on the full population without dropping the wealthiest 5% of households, which is $750,000, corresponding to a ratio of 9.4 to mean earnings (Column 3). The average MPC under this calibration drops to 2.7%, driven mostly by the smaller fraction of low wealth households. With this calibration median wealth is 3.5, over twice as large as in the data. Next, we target median wealth instead of mean wealth, which gives an average MPC that is almost unchanged from the baseline because median wealth in the baseline model is already close to the value in the data, despite not being explicitly targeted (Column 4).

In Columns 5 and 6 we report results from what is known in the literature as a liquid wealth calibration. Rather than measuring wealth in the SCF as net worth, we include only liquid wealth, which we define as bank accounts and directly held stocks and bond net of credit card debt (see A.2 for details). The ratio of mean liquid wealth to mean income is only 0.56. The logic behind this calibration is that liquid wealth is a better measure of the funds that households can readily access to smooth consumption against unexpected income fluctuations. When we target mean liquid wealth, the quarterly MPC is 14%, much higher than in the baseline and closer to empirical estimates (Column 4). When we target median liquid wealth ($3,100 or 0.05 times as average earnings), the average quarterly MPC rises to 33% (Column 6). By targeting a lower amount of aggregate wealth, the liquid wealth calibrations generate large MPCs by making the discount factor significantly lower than in the baseline. The lower discount factor raises both the number of low wealth households and the level of the certainty MPC \((1 - \beta)\). This observation suggests that a more direct strategy is to choose the discount factor to match the fraction of hand-to-
mouth households in the data. When we target 14% of hand-to-mouth households, the average quarterly MPC is 22%, in between the mean and median liquid wealth calibrations (Column 7).

The MPC decomposition reveals that in all three of these calibrations, the steeper consumption function and the larger mass of households at low wealth levels both play similar roles in accounting for the higher MPC.

Despite the apparent success of liquid wealth calibrations at generating high MPCs, it is important to note that these calibrations are difficult to integrate into modern dynamic macroeconomic models, because they necessitate abstracting from essentially the entire stock of aggregate assets owned by the household sector. This limits the usefulness of these calibrations in general equilibrium models with capital (either land, housing or productive capital). For example, the calibration that matches mean liquid wealth in the data (column 5) effectively abstracts from 85% of the wealth in our baseline sample (which excludes the top 5%), or 98% of total wealth. The calibrations in columns 6 and 7 miss an even larger share of total wealth.

**Interest rate**  Table 2 shows that lowering the interest rate from 1% p.a. to 0% p.a has a negligible effect on the MPC. Raising the interest rate to 5% p.a. increases the average quarterly MPC by around half a percentage point. A higher interest rates leads to a calibration with a lower discount factor, which raises the certainty MPC. This is confirmed by the decomposition which shows that the entirety of the difference in MPC relative to the baseline is due to the consumption function.

**Curvature in Utility**  Table 2 also shows that changing the curvature parameter of the CRRA utility function $\gamma$ away from $\gamma = 1$ has only a small effect on the average MPC. Higher risk aversion and lower intertemporal elasticity of substitution (higher $\gamma$) strengthens the precautionary savings motive and concavifies the consumption function. Because of this higher desire for saving, a lower discount factor is required to generate the same amount of aggregate wealth. These forces increase the MPC at all wealth levels. There is, however, an offsetting force: the stronger precautionary motive means that there are fewer households close to the borrowing constraint in the stationary distribution, for a given aggregate amount of wealth. Column 5 shows that for a coefficient of relative risk aversion of $\gamma = 6$, the latter effect dominates and the average quarterly MPC falls from 4.6% to 3.0%. The decomposition shows that the 1.6 percentage point lower MPC is comprised of a 0.5 percentage point increase from the lower discount factor, offset by a 2.1 percentage point fall from the smaller fraction of low wealth households. For example, relative to the baseline, median wealth is almost twice as large in the $\gamma = 6$ economy. Because of CRRA utility, this analysis does not separate the effects of changing risk aversion from those of
<table>
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<th>(1) Baseline</th>
<th>(2) r = 0%</th>
<th>(3) r = 5%</th>
<th>(4) RRA=0.5</th>
<th>(5) RRA=6</th>
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<tr>
<td>Quarterly MPC (%)</td>
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<tr>
<td>Share of HtM (%)</td>
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<td>2.4</td>
<td>2.5</td>
<td>3.3</td>
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<tr>
<td>Annualized discount factor</td>
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<td>0.990</td>
<td>0.944</td>
<td>0.986</td>
<td>0.840</td>
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</table>

**Panel A: Decomposition**

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<tr>
<td>Gap with Baseline MPC</td>
<td>-0.2</td>
<td>0.6</td>
<td>0.7</td>
<td>-1.6</td>
<td></td>
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<tr>
<td>Effect of MPC Function</td>
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<td>0.7</td>
<td>0.1</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Effect of Distribution</td>
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<td>-0.1</td>
<td>0.6</td>
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<td>Interaction</td>
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<td>0.0</td>
<td>0.1</td>
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</tr>
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**Panel B: Wealth Statistics**

<p>| | | | | | |</p>
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<tbody>
<tr>
<td>Mean wealth</td>
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<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Median wealth</td>
<td>1.3</td>
<td>1.4</td>
<td>1.4</td>
<td>1.1</td>
<td>2.3</td>
</tr>
<tr>
<td>$a \leq $1000</td>
<td>2.5</td>
<td>2.5</td>
<td>2.4</td>
<td>3.4</td>
<td>0.6</td>
</tr>
<tr>
<td>$a \leq $5000</td>
<td>11.6</td>
<td>11.6</td>
<td>11.1</td>
<td>13.9</td>
<td>3.1</td>
</tr>
<tr>
<td>$a \leq $10000</td>
<td>18.5</td>
<td>18.4</td>
<td>17.8</td>
<td>21.4</td>
<td>6.7</td>
</tr>
<tr>
<td>$a \leq $50000</td>
<td>40.3</td>
<td>40.1</td>
<td>39.5</td>
<td>43.3</td>
<td>24.8</td>
</tr>
<tr>
<td>$a \leq $100000</td>
<td>51.9</td>
<td>51.6</td>
<td>51.2</td>
<td>54.2</td>
<td>38.8</td>
</tr>
<tr>
<td>Wealth, top 10% share</td>
<td>46.6</td>
<td>46.2</td>
<td>45.9</td>
<td>48.6</td>
<td>36.3</td>
</tr>
</tbody>
</table>

Table 2: Baseline one-asset model and sensitivity analysis with respect to the interest rate (annualized values) and the relative risk aversion (RRA) coefficient $\gamma$ in the utility function.
changing the IES. In Section 3 we generalize preferences and perform this analysis.

**Model Frequency.** In Table E.1 in the Appendix we also report results for the baseline calibration with a model period of one year rather than one quarter, and for a continuous time version of the model. The average annual MPC in the annual model is 14.3%, essentially the same as the average annual MPC in the quarterly model, which is 14.6%.\(^{11}\) The quarterly MPC in the continuous time version of the model is 3.0%, slightly lower than our baseline discrete time model.\(^{12}\)

**Income Process.** We also considered several alternative income processes to the one in our baseline model, including: (i) setting \(\lambda_\eta = \lambda_\varepsilon = 1\) so that income shocks arrive on average once each quarter, rather than once each year; (ii) estimating the arrival rates \(\{\lambda_\eta, \lambda_\varepsilon\}\) alongside the other parameters by targeting the kurtosis of income growth rates at different lags in addition to the variance of income growth rates; (iii) estimating an annual income process and converting the parameter estimates into quarterly values using the approach in Krueger, Mitman, and Perri (2016); (iv) eliminating transitory shocks. We also considered alternative processes in the annual version of the model including: (i) the process in Carroll, Hall, and Zeldes (1992); (ii) a version with a random walk rather than an AR(1) component; (iii) a version with individual-specific fixed effects. Details for all these statistical representations of income dynamics can be found in Table A.2.

Table E.2 summarizes our results. In all cases, the MPCs are very close to the baseline model. The only version that generates a meaningfully higher MPC is the version without transitory shocks, for which the average quarterly MPC is 5.9%. There are two offsetting forces. On the one hand, without transitory shocks the precautionary saving motive is weaker and the consumption function is less concave, which lowers the average MPC by 2.3 percentage points. On the other hand, the weaker precautionary motive, leads to a larger fraction of households close to the borrowing constraint in the stationary distribution (18% of HtM households compared with 2% in the baseline). This raises the average quarterly MPC by 3.7 percentage points.

**Survival and Bequests.** We also examined sensitivity to different assumptions about the survival rate, how the assets of the deceased are distributed and what how the assets of new-born

---

\(^{11}\)This is lower than one would obtain by cumulating the quarterly MPC over four quarters, using the formula \(m_4 = (1 + m_0)^4 - 1\), which is often erroneously used in the literature. Applying this formula would yield an annual MPC of 19.7%, 35% higher than the correct annual MPC.

\(^{12}\)The discrete and continuous time models are not strictly comparable because of necessary differences in the income process. Table A.2 contains parameter estimates for the corresponding income processes. The wealth and MPC statistics are, however, very similar. This ensures that when we move to the continuous time two-asset model in Section 4, the differences are not being driven by the switch to continuous time.
Table 3: One-asset model with heterogeneity in the effective discount factor $\beta$ (annualized values) and in the rate of return $r$ (annualized values). Column (8) S-S corresponds to the Spender-Saver model.

Households are determined. As long as the discount factor is always recalibrated to match the same amount of aggregate wealth, none of these assumptions matters. See Table E.3 in the Appendix.

### 3 Extensions of the One-Asset Model

#### 3.1 Ex-Ante Heterogeneity

In this section, we extend the one-asset model to allow for various forms of ex-ante heterogeneity.
3.1.1 Heterogeneity in Discount Factors

We start by allowing for heterogeneity in households’ discount factors $\beta$. We consider a discretized uniform distribution for $\beta$ (annualized) with 5 equally spaced grid points between $[\beta - 2\Delta, \beta + 2\Delta]$. We choose the mid-point $\beta$ to match average wealth of 4.1 as in previous calibrations. Table 3 reports results for versions with a moderate amount of heterogeneity ($\Delta = 0.005$, Column 2) and with a large amount of heterogeneity ($\Delta = 0.01$, Column 3). For both calibrations, the median effective discount factor is substantially lower than in the baseline economy. The reason is that in these economies there is a subset of very patient households who have a strong intertemporal savings motive, and it is these households who hold the bulk of aggregate wealth. This can be seen from the much higher share of wealth held by the top 10% households (88% and 79%) compared to the model without discount factor heterogeneity (47%). The model can therefore match the target for mean wealth while still allowing for a large fraction of households to be impatient. Consequently, the models with discount factor heterogeneity match well the very bottom of the wealth distribution. For example in the calibration with $\Delta = 0.01$, 14% of households are hand-to-mouth, as in the data.

The average quarterly MPC in the models with discount factor heterogeneity are much higher than in the baseline model, and with enough heterogeneity, these models can approach the target empirical values. With $\Delta = 0.01$, the average MPC is nearly 19%, four times as large as the baseline model. While both the shape of the MPC function and the stationary wealth distribution contribute to the higher MPC, the majority of the effect comes from the larger fraction of low
wealth households. Figure 2 displays the MPC functions for high and low $\beta$ households overlaid on the stationary wealth distribution for the two groups of households. The figure illustrates how the impatient households are not only amassed near to the borrowing constraint, but have higher MPCs at all levels of wealth.

We also examine a version of the model in which households switch randomly between different discount factors. We assume that a household draws a new value of $\beta$ with probability $p$, independent of its current value. The models with stochastic discount factors generate a lower average MPC compared with a model with the same stationary distribution of $\beta$, but with fixed heterogeneity. The reason is that in the model with stochastic discount factors there is a weaker correlation between wealth and discount factors. In the stochastic $\beta$ model, some low-wealth households who were previously impatient then become patient and quickly accumulate wealth. The wealth distribution is therefore less concentrated at the bottom, which is evident in the lower share of HtM households and higher value of median wealth.

Although the models with discount factor heterogeneity feature a large average MPC while generating the key features of the two tails of the wealth distribution, these models typically fail in reproducing the wealth distribution everywhere in between. For example in the model with $\Delta = 0.1$, despite matching the fraction of very wealth-poor households (14% hand-to-mouth, 10% with wealth less than $1,000) the model’s wealth distribution is excessively squeezed toward the bottom and has far too many households with wealth just above this threshold: median wealth is ten times smaller than in the data and 75% of households have wealth below $50,000, compared with only 38% in the data. This problem, which we label the ‘missing middle’ is a recurring issue that arises in many of the versions of the model with heterogeneity that we examine below. Comparing figures 1 and 2 clearly illustrates this shortcoming.

### 3.1.2 Heterogeneity in Rates of Return

In the last two columns of Table 3, we report results for an economy with fixed heterogeneity in $r$, uniformly distributed over $\{-1\%, 1\%, 3\%\}$ p.a. (Column 6), and over $\{-3\%, 1\%, 5\%\}$ p.a. (Column 7). Heterogeneity in rates of return generates similar results to heterogeneity in discount factors. For example in the calibration in Column 7, 7% of households are hand-to-mouth, the top 10% share is 74% and the aggregate quarterly MPC reaches nearly 12%. These economies, however, also feature the missing middle problem, with median wealth levels much lower than in the data.

---

13We set $\Delta = 0.01$ and consider annual switching rates of 0.02, so that the expected duration of a discounting regime has the same expected duration of a lifetime (Column 4); and of 0.1., so that the expected duration is equal to a decade (Column 5).
Heterogeneity in Risk Aversion and Elasticity of Intertemporal Substitution

We now allow for heterogeneity in the curvature parameter $\gamma$ in the CRRA utility function. The distribution of $\gamma$ is a discretized uniform with 5 geometrically spaced grid points in the interval $[\frac{1}{\gamma}, \bar{\gamma}]$. In Table E.4 in the Appendix, we report results for a moderate amount of heterogeneity ($\bar{\gamma} = e^2 = 7.4$, Column 3) and a large amount of heterogeneity ($\bar{\gamma} = e^3 = 20.1$, Column 4). In both cases we set the mid-point to $\gamma = e^0 = 1$ as in the baseline model. With enough heterogeneity in $\gamma$, these calibrations yield very large average MPCs, because of the large shares of households in the tails of the wealth distribution. For example the model in Column 3, which has values of $\gamma$ ranging from 0.14 to 7.4, gives an average quarterly MPC of 17%. Most of the wealth is held by the high risk aversion / low IES households, and the top 10% wealth share is around 67%. The large MPC is driven by the low risk aversion / high IES households, and 20% of households are hand-to-mouth. The decomposition reveals that it is indeed this different distribution of households relative to the baseline model, rather than the shape of the MPC function, that is the most important factor in generating a larger MPC. Like the previous calibrations with heterogeneity, however, this economy suffers from the same missing middle problem: a disproportionate share of households is wealth-poor and median wealth is much lower than in the data.

To distinguish the roles of risk aversion and intertemporal substitution in generating the high degree of wealth concentration and large MPC in this last calibration, we generalize our preferences to those of Epstein and Zin (1991):

$$U_t = \left\{ (1 - \beta) c_t^{1-\theta} + \beta \left( \mathbb{E}_t \left[ U_{t+1}^{1-\gamma} \right] \right)^{1-\gamma} \right\}^{1/\gamma}$$

(4)

where $\gamma$ is the coefficient of relative risk aversion and $1/\theta$ the IES.

In Table E.5 we report results for various values of $\gamma$ and $\theta$. Without preference heterogeneity, varying either of these two parameters has only a very small impact on the average MPC once the discount factor is recalibrated to match the same average wealth target.

Table 4 introduces heterogeneity in these parameters. Allowing for heterogeneity in risk aversion barely has any effect on the average MPC. However, with heterogeneity in the IES, the model is able to generate large average MPCs, implying that the results described above with CRRA preferences are being driven by the heterogeneity in the IES rather than in risk aversion. For example, with a geometric uniform distribution of $\theta$ ranging from $e^{-3} = 0.05$ to $e^3 = 20$, the average quarterly MPC is around 20%. Households with a high IES are willing to absorb consumption fluctuations, and so hold only small buffer stocks of wealth. This calibration, however, suffers from a similar missing middle problem to other versions of the model with heterogeneity.
<table>
<thead>
<tr>
<th></th>
<th>(1) Baseline</th>
<th>(2) Het IES</th>
<th>(3) Het IES</th>
<th>(4) Temptation</th>
<th>(5) Temptation</th>
<th>(6) Temptation</th>
<th>(7) Het Temptation</th>
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<td></td>
<td>e⁻¹, . . . , e¹</td>
<td>e⁻², . . . , e²</td>
<td>e⁻³, . . . , e³</td>
<td></td>
<td></td>
<td>0.01, 0.05, 0.1</td>
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<tr>
<td><strong>Set of Temptation</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quarterly MPC (%)</td>
<td>4.6</td>
<td>6.6</td>
<td>10.9</td>
<td>20.8</td>
<td>6.4</td>
<td>19.1</td>
<td>21.4</td>
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<tr>
<td>Annual MPC (%)</td>
<td>14.6</td>
<td>20.1</td>
<td>29.9</td>
<td>39.2</td>
<td>19.0</td>
<td>46.2</td>
<td>47.7</td>
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<tr>
<td>Quarterly MPC of the HtM (%)</td>
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<td>30.5</td>
<td>34.4</td>
<td>66.2</td>
<td>31.4</td>
<td>39.3</td>
<td>45.1</td>
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<tr>
<td>Share of HtM (%)</td>
<td>2.5</td>
<td>4.0</td>
<td>11.1</td>
<td>20.9</td>
<td>4.0</td>
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<td>Annualized discount factor</td>
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<td>0.977</td>
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<td>0.982</td>
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<td>0.988</td>
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**Panel A: Decomposition**

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<th>(6)</th>
<th>(7)</th>
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<tbody>
<tr>
<td>Gap with Baseline MPC</td>
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<td>6.3</td>
<td>16.2</td>
<td>1.8</td>
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<td>16.8</td>
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<tr>
<td>Effect of MPC Function</td>
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<td>3.1</td>
<td>0.4</td>
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<tr>
<td>Effect of Distribution</td>
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<td>6.0</td>
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<td>8.3</td>
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<tr>
<td>Interaction</td>
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<td>7.1</td>
<td>0.2</td>
<td>4.4</td>
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**Panel B: Wealth Statistics**

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<th>(6)</th>
<th>(7)</th>
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<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
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<td>4.1</td>
</tr>
<tr>
<td>Median wealth</td>
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<td>0.5</td>
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<tr>
<td>a ≤ $1000</td>
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<td>60.9</td>
<td>46.2</td>
<td>69.4</td>
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<td>a ≤ $100000</td>
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<td>58.1</td>
<td>64.7</td>
<td>68.3</td>
<td>55.9</td>
<td>73.6</td>
<td>71.5</td>
</tr>
<tr>
<td>Wealth, top 10% share</td>
<td>46.6</td>
<td>55.7</td>
<td>62.8</td>
<td>67.9</td>
<td>49.8</td>
<td>70.6</td>
<td>70.1</td>
</tr>
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</table>

Table 4: Columns (2)-(4): one-asset model with Epstein-Zin preferences and heterogeneity in risk aversion and in the IES. Columns (5)-(7): one asset model with Gul-Pesendorfer preferences
3.2 Behavioral Preferences

In this section we explore alternative behavioral models for preferences that have been proposed in the literature as ways to generate higher MPCs.

3.2.1 Temptation and Self-control

Gul and Pesendorfer (2001) proposed a model of temptation and self-control in which consumers are tempted to consume according to a preference specification that overweights current consumption, but can exert some degree of self-control. These preferences have recently gained popularity in the quantitative macro literature (Krusell, Kuruşçu, and Smith Jr, 2010, 2002; Atanasio, Kovacs, and Moran, 2020; Nakajima, 2017; Pavoni and Yazici, 2017). We consider the limiting formulation in which consumers are tempted to consume according to preferences that place no weight on future consumption. The degree of temptation is governed by an additional parameter $\phi \in [0, \infty]$. It is straightforward to show that for $\phi > 0$, the temptation and self-control model generates a modified Euler equation in which the effective discount factor is decreasing in the average propensity to consume, which has the effect of making poor households act as if they are more myopic than wealthier households.\(^{14}\) We describe the setup formally in Appendix C.1.

Table 4 reports results for values of the temptation parameter $\phi \in \{0.01, 0.05\}$. The calibrations with a high degree of temptation can generate a large MPC without ex-ante heterogeneity, while still matching the target for mean wealth. For example, with $\phi = 0.05$ the average quarterly MPC is 19%. The decomposition reveals that the shape of the consumption function plays only a minor role and that the large MPC is due to the much more dispersed wealth distribution than in the baseline model. This arises because low-wealth households have a lower effective discount rate than high wealth households, which leads to a large mass of households near the borrowing constraint. In this calibration, median wealth is around $10,000, i.e. less than one-tenth than in the data. Allowing for heterogeneity in $\phi$, centered around a median value of 0.05 has very little effect on either the average MPC or the wealth distribution.

3.2.2 Present Bias

Starting with Laibson (1997), the other commonly adopted departure from the consumption-saving problem with standard preferences is to assume some form of present bias, such as quasi-hyperbolic discounting. We adopt the continuous time formulation as in Laibson, Maxted, and

\(^{14}\)With CRRA preferences, the Euler equation is $u_c(c) = \beta\mathbb{E}\left[\left(1 - \frac{\phi}{1+\phi} \left(\frac{c'(x')}{x'}\right)^\gamma\right)u_c(c')\right]$ where $x$ is cash on hand.
Moll (2021), known as instantaneous gratification. Unlike the model of temptation and self-control, these preferences are not time consistent and so one needs to make an assumption about whether consumers are naive, meaning that they are unaware that their future selves will have different preferences, or are sophisticated, meaning that they are aware of the time inconsistency and play a game against their future selves. Following Laibson, Maxted, and Moll (2021), and to give the model its best shot at generating a large average MPC, we assume that households are naive. We describe the setup formally in Appendix C.2.

The instantaneous gratification model features one additional parameter $\zeta \leq 1$, which measures the extent of present bias. In Table E.6 in the Appendix, we report results for values of $\zeta \in \{0.9, 0.8, 0.7\}$, alongside the baseline continuous time one-asset model (corresponding to the special case $\zeta = 1$). The results suggest that once the instantaneous gratification model is recalibrated to match the same level of aggregate wealth, present bias has a negligible effect on the average MPC. In fact with $\zeta = 0.7$, the average MPC is lower than in the model with exponential discounting. The decomposition illustrates that there are two offsetting effects. On the one hand, the instantaneous gratification models has a stationary distribution with more very low wealth households (e.g., 19% of households with less than $1,000, compared with 2.5% in the baseline). On the other hand, in order to match the same level of aggregate wealth, the calibrated value of the effective discount factor is much larger in the model with present bias (0.997 p.a. vs 0.985 p.a.). This means that everywhere above the borrowing constraint the MPC is lower in the model with present bias. Figure 3 illustrates these differences. The decomposition shows that these two effects roughly cancel out.

3.3 Taking Stock

When the canonical one-asset heterogeneous agent model is calibrated to match the amount of wealth held by the poorest 95% of US households, it generates an average quarterly MPC of around 4%. This value is an order of magnitude larger than the corresponding representative agent model, but still much smaller than empirical estimates.

The fundamental tension in the baseline model is that it can only generate an average quarterly MPC of around 20% when it is parameterized to match an amount of aggregate wealth that is 10 to 20 times smaller than its empirical counterpart for the US, for example in calibrations based on liquid wealth, rather than total wealth. However, these calibrations necessarily ignore almost the entire capital stock in the economy and so are of limited use for general equilibrium applications.

When the one-asset model is extended to allow for ex-ante heterogeneity in discount fac-
tors, rates of return, or elasticity of intertemporal substitution across households, it can generate MPCs of 20% or higher in some calibrations. In all these versions of the model, the reason for the larger MPC is that the presence of different household types makes it possible for the stationary distributions to contain a substantial number of hand-to-mouth households, while still being consistent with an average level of wealth as high as in the data. Yet, all these models have far too many households who are not quite poor enough to be hand-to-mouth, but still have very little wealth. For example, the fraction of households with less than $50,000 is typically much higher than in the data, and the wealth of the median household is 5 to 10 times smaller than in the data.

### 3.4 Spender-Saver Models

The challenge for one-asset models is therefore to simultaneously generate a sufficiently large amount of wealth in the aggregate as well as a large enough fraction of hand-to-mouth households, while still generating enough households in the middle of the distribution. There is one form of ex-ante heterogeneity in the one-asset model that succeeds in this respect. Inspired by the spender-saver model of Campbell and Mankiw (1989), these are versions of the model with discount factor heterogeneity, in which there are two groups of households, one with a very low discount factor (the spenders) and one with a high discount factor (the savers). Judiciously chosen calibrations of this class of model can match all of these features of the data.

To illustrate this, Column 8 in Table 3 reports results from a calibration in which 15% of...
households have a discount factor of 0.4, and the remaining 85% of households have a discount factor that is chosen so that the ratio of average wealth to average income is 4.1 as in the data. In this spender-saver model, 14.8% of households are hand-to-mouth and the average quarterly MPC is 17%. Moreover, median wealth is 0.96, which is not too far from its empirical counterpart of 1.54, and around 47% of households have less than $50,000 of wealth, compared with 39% in the data. The missing middle problem is therefore nowhere near as extreme as in other versions of the one-asset model with heterogeneity.

Nonetheless, despite its success at generating a large average MPC and matching the wealth distribution, the spender-saver model has some important drawbacks that limit its usefulness for counterfactual policy analysis. Most importantly, because the large MPC is driven entirely by a small group of very impatient households, this model features a similar sized MPC out of much larger windfalls (i.e., one order of magnitude larger), and an intertemporal MPC function that drops off very sharply after the first quarter. We return to these comparisons in Section 5. In addition, the spender-saver model implies a weaker connection between low income and low wealth than the observed one, because most of the hand-to-mouth households have low wealth as a result of their strong preference for spending rather than persistent low income realizations.

4 Two-Asset Models

In this section, we extend the precautionary savings model to include two assets: a liquid asset with low return and an illiquid asset with higher return but which is subject to adjustment frictions. We demonstrate that the two-asset model can go a long way toward resolving the intrinsic tension in the one-asset model even in the absence of ex-ante heterogeneity.

In two-asset heterogenous agent models, households can separate their different savings motives into distinct assets. Precautionary and smoothing motives against small, regular income fluctuations induce households to accumulate a buffer of liquid assets, but since the return on this asset is low, a negative intertemporal motive ($\beta R \ll 1$) prevents households from accumulating large amounts of liquid wealth. The bulk of household savings is done in the high return illiquid asset, motivated both by a positive intertemporal motive and precautionary and smoothing motives against large, infrequent income fluctuations. At endogenous intervals, households move funds between their liquid and illiquid accounts as desired. For example, in response to a large negative income shock, a household who has exhausted their buffer of liquid wealth can pay a fee or exert effort to withdraw funds from their illiquid account. Similarly, a household who has experienced a long stream of positive income growth and has accumulated excess liquid wealth can transfer funds to their illiquid account, which pays a higher return and is therefore a
better vehicle for long-run saving.

Since most households end up holding the vast majority of their wealth as illiquid assets, which cannot be used for short-term consumption smoothing, they expose themselves to potentially larger consumption fluctuations than if they saved only in liquid assets. However, the welfare cost of these fluctuations is second-order, relative to the first-order gain from earning a higher return on illiquid savings. Because of this trade-off, the model generates wealthy hand-to-mouth households, who have positive, and sometimes substantial, holdings of illiquid wealth, but very little liquid wealth. Wealthy hand-to-mouth households co-exist alongside the traditional poor hand-to-mouth households, who hold very little wealth, either liquid or illiquid. Adopting the same definition of a hand-to-mouth household as in previous sections (less than half of monthly income), 27% of households were wealthy hand-to-mouth in the 2019 SCF, in addition to the 14% of poor hand-to-mouth households. Therefore, in total 41% of US households are hand-to-mouth. Since wealthy hand-to-mouth households also have a large MPC out of small one-time windfalls in the two-asset model, it is the presence of this additional group of hand-to-mouth households that enables the two-asset model to generate a large average MPC while remaining consistent with the distributions of liquid and illiquid wealth in the data.

4.1 Baseline Two Asset Model

Environment We write the two-asset model in continuous time. The economy is populated by a continuum of households who discount the future at the effective rate $\rho = \tilde{\rho} + \delta < 1$ where $\tilde{\rho}$ is the rate of time preference and $\delta$ is the death rate. Flow utility is given by $u(c_t)$, where $u$ is strictly increasing and concave, and $c_t$ denotes consumption expenditures. At each date $t$, households are endowed with log labor income $y_t \in Y$, which follows an exogenous stochastic process described in Appendix B.3. Households can save but not borrow in two assets: (i) a liquid asset $b$ with return $r^b$; and (ii) an illiquid asset $a$ with return $r^a > r^b$. At rate $\chi$, households receive an opportunity to rebalance their financial portfolio which they can take by paying a fixed transaction cost $\kappa$. Between rebalance dates, the illiquid asset accumulates in the background and the household solves a standard consumption-savings problem out of their liquid assets.
The HJB for the household problem is:

\[ \rho v(a, b, y) = \max_c u(c) + v_b(a, b, y) \dot{b} + v_a(a, b, y) \dot{a} + \mathcal{A} v(a, b, y) \]

\[ + \chi [v^*(a, b, y) - v(a, b, y)] \]

subject to

\[ \dot{b} = r^b b + y - c, \quad b \geq 0 \]
\[ \dot{a} = r^a a, \quad a \geq 0 \]

where \( \mathcal{A} \) is the infinitesimal generator of the stochastic process for income. The last term in the HJB equation describes the gain from rebalancing the asset portfolio. The value function after rebalancing, \( v^*(a, b, y) \), is defined by

\[ v^*(a, b, y) = \max \{ \omega(a + b, y), v(a, b, y) \} \]

where

\[ \omega(a + b, y) = \max_{a', b'} v(a', b', y) \]

subject to

\[ a' + b' \leq a + b - \kappa, \quad a', b' \geq 0 \]

Upon receipt of an adjustment opportunity, a household will choose not to rebalance their portfolio if the transaction cost \( \kappa \) exceeds the gains from rebalancing. If the household chooses to rebalance, it can choose any feasible combination of liquid and illiquid assets \((b', a')\).

The solution to this problem yields decision rules for consumption \( c(a, b, y) \), and for the optimal rebalanced portfolio \( a'(a, b, y) \) and \( b'(a, b, y) \), as well as the stationary distribution of households \( \mu(a, b, y) \).

**Parameterization** Relative to the continuous time one-asset model, there are three additional parameters: (i) the arrival rate for rebalancing opportunities \( \chi \); (ii) illiquid asset return \( r^a \); and (iii) the transaction cost \( \kappa \). In our baseline model we set \( \chi = 3 \) so that households get an opportunity to rebalance on average once per month (the model period is one quarter). We also set the (annualized) liquid return \( r^b = -2\% \) (roughly corresponding to a zero nominal return). We then choose the the discount rate \( \rho \), the illiquid rate \( r^a \) and the transaction cost \( \kappa \) to match three targets: (i) a ratio of mean total wealth to mean earnings of 4.1, as in the one-asset model; (ii) a total share hand-to-mouth households (both wealth and poor) of 41%; and (iii) a share of poor hand-to-mouth households of 14%.
Table 5: Baseline two-asset model and sensitivity with respect to the liquid and illiquid rates of return. $b$ denotes liquid wealth and $w = a + b$ total wealth (or net worth).
Table 5 reports the calibrated parameters and wealth statistics in our baseline two asset model. The model matches well the targets for total wealth and the shares of poor and wealthy hand-to-mouth are also closely matched. To achieve this, the calibration requires a sizable gap between the liquid and illiquid returns. We return to this feature of the calibration in the Conclusions. The calibrated transaction cost is around $1,500. Although the model stops generate less aggregate liquid wealth than in the data (0.23 vs 0.56), median liquid wealth is very close to its empirical value, around 5% of average annual labor income. The empirical liquid wealth distribution is extremely right-skewed and there is no force in the model that can deliver this feature of the data.

Marginal Propensities to Consume in the Two Asset Model  The average quarterly MPC in the baseline two-asset model model is 16.1%, around 5 times larger than the corresponding average MPC in the continuous time one-asset model (Table 5, Column 1). A simple back-of-the-envelope calculation confirms that if we multiply the average MPC for poor hand-to-mouth households (24%) by their share (13%), the average MPC for wealthy hand-to-mouth households (30%) by their share (27%) and the average MPC for non hand-to-mouth households (7%) by their share (60%), and then add up, we obtain an average MPC of nearly 16%. Figure 4 (left-panel) illustrates the average MPCs as a function of liquid wealth holdings.

To better understand the source of the higher average MPC in the two-asset model compared to the one-asset model, we apply the decomposition in (4) by computing the average MPC as a function of net worth $w$ in the two asset model, $m_0(w, y) = \int_{a+b=w} m_0(a, b, y) d\mu(a, b, y)$. While both the shape of the consumption function and the distribution of households play a role, the gap in the MPC function is quantitatively more important: the reason is that even at moderate

\footnote{On average, 9% of households rebalance their portfolios each quarter.}

\footnote{However, this feature is not crucial in determining the aggregate MPC because once households have a certain level of liquid assets, they are able to almost perfectly smooth their consumption expenditures.}
levels of net worth there are some low liquid wealth households, which generates an MPC function that declines more slowly with net worth than in the one asset model. This feature of the two-asset model is illustrated in Figure 4 (right panel).

The statistics on the wealth distribution in Table 5 also reveal that the two-asset model does not feature the missing middle problem that was a feature of the one-asset models with ex-ante heterogeneity. Median net worth is above 1, which is much closer to the empirical target of 1.56. The reason is that in the two-asset models the bulk of the wealth of households in the middle of the distribution is held in illiquid assets, which has only a small effect on their MPCs.

### 4.2 Alternative Calibrations of the Two Asset Model

We now examine the robustness of our finding for the two-asset model with respect to some of the key parameters of the model. In these experiments, whenever we change parameters, we recalibrate only the discount rate $\rho$ to match the same target for total wealth, unless otherwise noted. The decompositions in this section are relative to the baseline two-asset model.

**Rates of Return.** Changing the rates of return on liquid and illiquid wealth has a significant impact on the MPCs, as illustrated in columns (3)-(6) of Table 5. Raising the liquid rate or reducing the illiquid rate narrows the return gap between the two assets and, as explained, fewer HtM households emerge in equilibrium which pushes down the MPC. The decomposition confirms that the reason why the MPC are lower in these cases is not so much the change in the MPC function, but the fact that there are fewer HtM households with large MPCs.

**Rebalancing Frequency.** Table E.7 in the Appendix illustrates that increasing the frequency of rebalancing opportunities from an average of once per month to an average of once per quarter (Table 5, Column 2) or once per year (Column 3) has only a small effect on the average MPC. However, the calibration with less frequent rebalancing opportunities is successful in matching the mean level of liquid wealth. Households hold a larger buffer of liquid wealth both because opportunities to rebalance arrive less frequently and because households that are accumulating wealth must hold their savings in the liquid account for a longer duration on average before transferring them to their illiquid account. This model also features a slightly larger average MPC, despite having fewer hand-to-mouth households, because the less frequent adjustment opportunities means that the wealthy hand-to-mouth households who are waiting to withdraw resource have a higher MPC than in the baseline calibration (38% vs 30%).
Table 6: Quarterly MPC for positive and negative windfalls of different sizes.

<table>
<thead>
<tr>
<th>(1) One Asset</th>
<th>(2) Low wealth</th>
<th>(3) β Het</th>
<th>(4) IES Het</th>
<th>(5) Spender-Saver</th>
<th>(6) Two-Asset</th>
</tr>
</thead>
<tbody>
<tr>
<td>-$5000</td>
<td>8.3</td>
<td>33.5</td>
<td>28.8</td>
<td>11.5</td>
<td>20.2</td>
</tr>
<tr>
<td>-$500</td>
<td>5.0</td>
<td>23.2</td>
<td>19.8</td>
<td>7.1</td>
<td>17.2</td>
</tr>
<tr>
<td>$500</td>
<td>4.6</td>
<td>22.0</td>
<td>18.8</td>
<td>6.7</td>
<td>16.8</td>
</tr>
<tr>
<td>$5000</td>
<td>3.6</td>
<td>18.2</td>
<td>15.5</td>
<td>5.3</td>
<td>13.2</td>
</tr>
</tbody>
</table>

**Rebalancing Cost.** Varying the transaction cost from $0 to $3,000, while keeping the arrival rate of rebalancing opportunities at its baseline value of 3, has only very small effects on the average MPC because there are offsetting effects on the distribution and the shape of the consumption function. See Columns (4)-(7) in Table E.7.

5 Other Concepts of MPCs

So far, we have focused on the quarterly MPC out of an unexpected $500 windfall. In this section, we extend the analysis to (i) MPCs out of unexpected income shocks of different sizes, both positive and negative, (ii) MPCs at different horizons, including MPCs out of the news of future windfalls, and (ii) MPCs out of unexpected illiquid injections (or capital losses) in the two asset models.

5.1 Sign and Size Asymmetries

To explore sign and size asymmetries, we compute MPC out of +/- $500, $5,000. Table 6 summarizes these results. Because of the concavity in the consumption function, the MPC out of small windfalls is bigger than the MPC out of larger windfalls. Concavity also implies that MPC out of income losses are larger than for income gains of the same absolute magnitude, and that size-asymmetry is reversed for negative windfalls: the MPC out of larger income losses is bigger than for smaller losses.

In one-asset models these effects are not very strong because the asymmetries are significant only in regions where the consumption function is very concave, which is near the borrowing limit, where there is only a small share of households in the stationary distribution. The two asset models features much stronger size and sign asymmetry, which reflects the fact that there are more households in regions of the liquid wealth distribution where the consumption function is concave.
5.2 Intertemporal MPCs

We compute the time profile of MPCs from horizon $t = -4$ (one year before the shock) to $t = +4$ (one year after the shock). The quarterly MPC out of of $500 at a horizons $t = -\tau$ should be interpreted as the fraction of the windfall consumed by households upon receiving the news that a windfall will be received in $\tau$ quarters time. The MPC at horizon $t = +\tau$ is the fraction consumed $\tau$ quarters after receipt of an unexpected windfall. Appendix D contains how to compute MPCs at different horizons.

Figure 5 reports the time profile of MPCs across several models. In the baseline one-asset model the profile is flat because of the low share of hand-to-mouth households. In one-asset models with discount factor heterogeneity (as well as IES heterogeneity, not reported here), the profile is more cusp-shaped: MPCs out of news are much smaller than actual MPCs, as are lagged MPCs. It is the impatient households who are responsible for these dynamics. As pointed out by Auclert, Rognlie, and Straub (2018), this tent-shape is particularly extreme in the spender-saver model,

The two-asset model sits in between the spender-saver and the one-asset model with ex-ante heterogeneity because of the large share of hand-to-mouth households who do not respond to news and quickly spend the windfall upon receipt.

5.3 MPC out of Illiquid Wealth

In the two-asset model, we can also compute the MPC out of a small injection of illiquid wealth. Conceptually, the closest empirical counterpart of this MPC would be an estimated MPC out
of changes in housing wealth or out of unrealized capital gains/losses on stocks. To put our analysis in the context of recent empirical contributions, we note that Carroll, Otsuka, and Slacalek (2011) estimate an average quarterly MPC out of housing wealth around 2% percent. Mian, Rao, and Sufi (2013) estimate it at 1.5% percent, and uncover a great deal of heterogeneity with respect to income and leverage. Di Maggio, Kermani, and Majlesi (2020) analyze unrealized capital gains in stock market wealth and conclude that the literature, including their own research, finds values between 0 and 2.5% for the average quarterly MPC.

In our model, the average quarterly MPC out of an illiquid windfall of $500 is 1.4% and the one out of a windfall of $5,000 is 2.4%. These numbers line up with the data quite well: as in the data, this MPC is an order of magnitude smaller compared to the one out of their liquid counterparts. In the model, the higher MPCs out of larger capital gains is due to the fact that many more households with a rebalancing opportunity find worthy paying the fixed transaction cost and consuming part of it when the unexpected windfall is bigger.

6 Conclusions

Marginal propensities to consume (MPCs) are the most important feature of household spending behavior for macroeconomics. They play an essential role in determining the effects of changes in aggregate demand, the strength of the fiscal multiplier and the transmission mechanism of monetary policy. But canonical representative agent models fail in accounting for the empirical evidence on MPCs: in response to an unexpected windfall, the average MPC is large with a wide degree of heterogeneity in MPCs across households.

One-asset heterogeneous agent models with idiosyncratic income risk and incomplete markets generate an average MPC that is an order of magnitude bigger than in representative agent models, but is still significantly smaller than the data. Allowing for ex-ante heterogeneity across households or behavioral biases in preferences raises the average MPC to be in line with the data, but at the cost of misrepresenting key features of the wealth distribution - these models vastly overstate the fraction of households with low wealth.

Two-asset heterogeneous agent models with a liquid and illiquid asset can resolve this tension. However, baseline versions of the two-asset model require a fairly large gap in the returns on the two assets. Future work can improve on this dimension in at least four ways: (i) allowing for preference heterogeneity (e.g., Aguiar, Bils, and Boar, 2020); (ii) recognizing that many illiquid assets (e.g., durable goods and housing) generate utility flows beyond in addition to financial returns (e.g., Kaplan and Violante, 2014); (iii) introducing a commitment value to illiquid assets, through preferences that feature temptation and self control or sophisticated present bias (e.g.,
Laibson, 1997; Attanasio, Kovacs, and Moran, 2020); and (iv) allowing for imperfect information, which is an area that we have not analyzed in this study, as a potential avenue to improve the model (e.g., Wang, 2004; Guvenen, 2007; Kaplan and Violante, 2010).
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ONLINE APPENDIX

The Marginal Propensities to Consume in Heterogeneous Agent Models

Greg Kaplan and Giovanni L. Violante

This Appendix is organized as follows. Section A describes the estimation of the income process and how we computed some key statistics of the wealth distribution. Section B describes the annual calibration of the baseline model, lays out its continuous time version and derives the MPC under certainty and no borrowing constraints. Section C lays out the household problem under temptation-self control and under present bias. Section E contains additional Tables.

A Data

A.1 Panel Study of Income Dynamics and Estimated Income Processes

We model the discrete-time quarterly income process \( y_t \) as follows:

\[
\log y_t = \begin{cases} 
  z_t + \varepsilon_t & \text{with probability } \lambda_\varepsilon, \quad \varepsilon_t \sim \mathcal{N} \left( -\frac{\sigma_\varepsilon^2}{2}, \sigma_\varepsilon^2 \right) \\
  z_t & \text{with probability } 1 - \lambda_\varepsilon.
\end{cases}
\]

\[
z_t = \begin{cases} 
  \phi z_{t-1} + \eta_t & \text{with probability } \lambda_\eta, \quad \eta_t \sim \mathcal{N} \left( -\frac{\sigma_\eta^2}{2}, \sigma_\eta^2 \right) \\
  \phi z_{t-1} & \text{with probability } 1 - \lambda_\eta
\end{cases}
\]  

(A.1)

We define annual income as the sum of quarterly income within the year

\[ y_t^{\text{ann}} = \sum_{t=1}^{4} y_t \]

and we define annual income growth at lag \( d \) as

\[
\Delta_d \log y_t^{\text{ann}} = \begin{cases} 
  \log y_t^{\text{ann}} & \text{if } d = 0 \\
  \log y_{t+d}^{\text{ann}} - \log y_t^{\text{ann}} & \text{if } d > 0
\end{cases}
\]
Lag ($d$) | $m_{2,d}$ | $m_{4,d}$ | $\kappa_d$
--- | --- | --- | ---
0 | 0.504 | 0.930 | 3.65
1 | 0.142 | 0.220 | 10.90
2 | 0.207 | 0.369 | 8.57
3 | 0.235 | 0.410 | 7.42
4 | 0.280 | 0.544 | 6.96
5 | 0.295 | 0.557 | 6.39
6 | 0.335 | 0.694 | 6.19
7 | 0.352 | 0.729 | 5.87
8 | 0.383 | 0.838 | 5.72
9 | 0.398 | 0.885 | 5.59
10 | 0.422 | 0.967 | 5.43

Table A.1: Empirical moments of annual income growth at different lags. Source: PSID 1968-2008

and the corresponding cross-sectional moments as

$$m_{j,d} = \mathbb{E} \left[ (\Delta_d \log y_{i}^{ann})^j \right]$$

With $\lambda_\epsilon, \lambda_\eta$ fixed exogenously, we require three moments to estimate the three parameters $(\phi_\epsilon, \sigma_\eta^2, \lambda_\eta)$. Note that the set of moments $\{m_{2,d}\}$ for $d = 1 \ldots D$ contains the identical information to the auto-covariance function out to $D$ lags. We express the data in this way since it is more convenient for extending the estimation strategy to the case where $\lambda_\epsilon$ and $\lambda_\eta$ are also estimated.

We use data from the Panel Study of Income Dynamics (PSID) on total annual household labor income for households with heads aged 25 to 65 from 1968 to 2008. We drop households with annual labor income less than $7,250 in 2016 dollars, which correspond to 1,000 hours per year at $7.25 per hour (or part-time employment at the ongoing minimum wage). We remove age and year effects in a first stage by regressing household labor income on a full set of year and age dummies and we construct the empirical counterparts to $m_{2,d}$ using the residuals from this regression. The resulting moments are shown in the first column of Table A.1.

In our baseline specification, we choose $(m_{2,0}, m_{2,1}, m_{2,5})$ as our moments to match. The first row of Table A.2 shows our baseline estimates in which we assume that income shocks arrive on average once per year, $\lambda_\epsilon = \lambda_\eta = 0.25$. In the second row, we shows corresponding estimates when the income shocks arrive every quarter, $\lambda_\epsilon = \lambda_\eta = 1$. In the third row of Table A.2 we estimate the shock arrival rates $\lambda_\epsilon, \lambda_\eta$ alongside the other parameters of the income process. This requires two additional moments. To find moments that identify these parameters, we note that the main effect of lowering the arrival rates below 1 is that it induces excess kurtosis into the
The second and third columns of Table A.1 report $m_{4,d}$ and $\kappa_d$ out to ten lags. Note that log income itself does not display much excess kurtosis, but annual income growth is very leptokurtic, with the degree of leptokurtosis declining as the lag length increases. We add $\kappa_1$ and $\kappa_5$ as the additional moments to identify $\lambda_\epsilon, \lambda_\eta$. The estimates are reported in the third row of Table A.2. They suggest that persistent shocks arrive on average close to once per year, but that transitory shocks are much less frequent and much larger on average than implied by the more restrictive model.

The fourth row of Table A.2, labeled “Krueger, Mitman and Perri (2017) formula” constructs the quarterly estimates by applying the following formulas to annual estimates:

$$\phi_z = (\phi_{zn}^{ann})^{0.25}$$
$$\sigma_\epsilon^2 = (\sigma_{\epsilon}^{ann})^2$$
$$\sigma_\eta^2 = \left( \frac{1 - \phi_z^2}{1 - (\phi_{zn}^{ann})^2} \right) (\sigma_\eta^{ann})^2$$

Table A.2: Parameter estimates of various statistical models for income dynamics
The annual estimates upon which these are based are shown in the bottom panel of Table A.2. These are constructed by reinterpreting $y_t$ as annual income and estimating the parameters by matching the moments $(m_{2,0}, m_{2,1}, m_{2,5})$. Below that we report estimates for a version where we restrict the AR(1) component to have high persistence $\phi_{ann}^\eta = 0.995$ and a version where we include an individual-specific fixed effect. For this latter model we add the moment to $m_{2,10}$ to identify the additional parameter.

We model the continuous time income process $y_t$ as follows:

$$
\log y_t = z_t + u_t \\
dz_t = -\phi z_t + \eta_t dJ_\eta, t \\
du_t = -\phi u_t + \epsilon_t dJ_\epsilon, t
$$

where $dJ_\eta$ is a Poisson process with arrival rate $\lambda_\eta$ and $dJ_\epsilon$ is a Poisson process with arrival rate $\lambda_\epsilon$. The innovations are given by

$$
\eta_{it} \sim N\left(0, \sigma_\eta^2\right) \\
\epsilon_{it} \sim N\left(0, \sigma_\epsilon^2\right)
$$

Note that since income is a flow, there is no natural concept of purely transitory shock in continuous time. For consistency with the discrete time formulation, so that the two versions match the same data moments, in our baseline model we restrict $\phi_u = \frac{1}{2} \log 2$ which implies a half-life of two quarters. This is broadly consistent with a discrete time annual formulation in which a transitory shocks lasts for one year. In our baseline model we restrict $\lambda_\eta = \lambda_\epsilon = 0.25$ as in the discrete time model.

The parameter estimates for the continuous time income process are reported in the bottom panel of Table A.2. We also report estimates for the version where we estimate the shock arrival rates. As in the quarterly discrete time model, when the shock arrival rates are estimated we find them to be larger and less frequent than when restricted to arrive on average once per quarter.

**A.2 Survey of Consumer Finances and Wealth Statistics**

To compute moments of the wealth distribution, we first select all households in the 2019 *Survey of Consumer Finances*, without any age restriction. Then as explained we drop the top 5% of the wealth distribution.

Our definition of household labor income includes wage and salary income plus social security income. It excludes other business income, other government transfers, as well as interests,
dividends and capital gains. Mean household labor income is $67,132 and median income is $54,266.

Our definition of net worth is the baseline definition of the SCF for total net worth (variable NETWORTH). See the document Networth Flow chart.pdf in https://www.federalreserve.gov/econres/scfindex.htm. It includes all financial assets (bank accounts, CDs, mutual funds, retirement accounts, and directly held stocks and bonds), vehicles, housing wealth and private business equity net of all types of unsecured and secured debt. Mean wealth is $275,665 and median wealth is $103,380.


Our definition of net illiquid wealth is residual, i.e. net worth minus net liquid wealth. The biggest items among financial assets are retirement accounts, among non-financial assets are housing and business equity. The biggest components on the liability side are mortgages. In terms of the SCF variables net illiquid wealth is: (CDS + SACVBND + CASHLI + OTHMA + RETLIQ) + NFIN - MRTHEL - RESDBT - INSTALL - ODEBT.

B One-Asset Models

B.1 Annual calibration

As in the baseline quarterly calibration, we set \( \gamma = 1 \), the credit limit to zero, \( \delta = 1/50 \) so that the expected adult life span is 50 years, and the real interest rate \( r = 0.01 \). Table A.2 reports the annual value for variances and correlation coefficient estimated to match the same annual covariances restrictions as for the baseline calibration. The discount factor is calibrated internally to match a ratio of mean net worth to mean annual household labor income ratio of 4.1. We obtain an annualized value of 0.980 for the effective discount factor \( \beta \), i.e. virtually the same value as in the quarterly calibration. This is reassuring, since annual and quarterly calibrations should replicate exactly the same set of moments.
B.2 Continuous-time formulation

The continuous-time version of the household problem (1) is:

\[
\max_{\{c_t\}} \mathbb{E}_0 \int_0^\infty e^{-(\delta + \tilde{\rho})t} u(c_t) \, dt
\]

\[
\text{s.t.} \quad \dot{b}_t = \exp(y_t) + rb_t - c_t \]
\[
\dot{b}_t \geq -b \]
\[
y_t \sim F(y_t, y_{t-1})
\]

In this formulation, \(\delta > 0\) is the instantaneous death rate, \(\tilde{\rho} > 0\) the discount rate, \(\rho = \tilde{\rho} + \delta\), and \(b_t\) represents savings. The corresponding HJB equation is:

\[
\rho v(b, y) = \max_c u(c) + v_b(b, y) \dot{b} + \mathcal{A}(y)v(b, y)
\]

subject to

\[
\dot{b} = rb + y - c \]
\[
b \geq 0
\]

where \(\mathcal{A}\) is the infinitesimal generator of the income process. The continuous time equivalent of the income process in (A.1) is:

\[
y_t = z_t + \epsilon_t dJ_{\epsilon t}, \quad (B.3)
\]
\[
dz_t = -(1 - \phi) z_{t-1} + \eta_t dJ_{\eta t}, \text{ with } \eta_t \sim \mathcal{N}(0, \sigma_{\eta})
\]
\[
\epsilon_t \sim \mathcal{N}(0, \sigma_{\epsilon})
\]

where \(J_{\epsilon t}\) and \(dJ_{\eta t}\) are jump processes with arrival rate \(\lambda_{\epsilon}\) and \(\lambda_{\eta}\) respectively. To estimate the parameters of the income process, we time-aggregate in order to match the same set of annual moments described above. Table A.2 reports the point estimates of the parameters of the income process, expressed quarterly for ease of comparison with the discrete time counterpart.

**MPC in continuous time**  To define and compute the MPC in the continuous time version of the model we follow Achdou, Han, Lasry, Lions, and Moll (2017). In continuous time, the MPC is defined over an interval \(\tau\) as:

\[
m_{\tau}(b, y) = \frac{\partial C_\tau(b, y)}{\partial b} \sim \frac{C_\tau(b + x, y) - C_\tau(b, y)}{x}, \quad (B.4)
\]
where
\[ C_\tau(b, y) = \mathbb{E}_0 \left[ \int_0^\tau c(b_t, y_t) dt | b_0 = b, y_0 = y \right]. \]
The conditional expectation \( C_\tau(b, y) \) can be conveniently computed using the Feynman-Kac formula. This formula establishes a link between conditional expectations of stochastic processes and solutions to partial differential equations. Applying the formula, we have \( C_\tau(b, \log y) = K(b, \log y, 0) \), where \( K(b, y, t) \) satisfies the partial differential equation on \([0, \tau] \)
\[
c(b, y) + K_b(b, y, t)b(b, y) + K_y(b, y, t) \left[-(1 - \phi) z\right] + A(y)K(b, y, t) = 0. \tag{B.5}
\]
with terminal condition \( \Gamma(b, y, \tau) = 0 \), where \( A \) is the infinitesimal generator of the income process.

**B.3 MPC Under Certainty and No Borrowing Constraints**

The budget constraint of the household problem (1) is:
\[ c_t = Rb_t + y_t - b_{t+1} \]
Iterating forward, we obtain:
\[
c_0 + \frac{1}{R} c_1 + \frac{1}{R^2} c_2 + ... = Rb_0 + \sum_{t=0}^{\infty} \left( \frac{1}{R} \right)^t y_t.
\]
Using the household Euler equation between \( t \) and \( t + 1 \)
\[ c_{t+1} = (\beta R)^{\frac{1}{\gamma}} c_t \]
to substitute \( c_t \) at every \( t \) on the left hand side as a function of \( c_0 \), we arrive at:
\[
c_0 + \frac{1}{R} c_0 (\beta R)^{\frac{1}{\gamma}} + \frac{1}{R^2} c_0 \left[(\beta R)^{\frac{1}{\gamma}}\right]^2 + ... = Rb_0 + \sum_{t=0}^{\infty} \left( \frac{1}{R} \right)^t y_t.
\]
and collecting terms on the left hand side:
\[
c_0 \left[ \frac{1}{1 - R^{-1} (\beta R)^{\frac{1}{\gamma}}} \right] = Rb_0 + \sum_{t=0}^{\infty} \left( \frac{1}{R} \right)^t y_t
\]
which proves that \( m_0^* = 1 - R^{-1} (\beta R)^{\frac{1}{\gamma}} \).
C Models with Behavioral Biases in Preferences

C.1 Temptation and Self-Control

In this Appendix we describe the model of temptation and self-control that we solve in Section 3.2.1. We assume that in each period the agent is tempted to consume their entire wealth and the temptation utility function is the same as for actual consumption. The household problem can then be written in recursive form as:

$$v(b, y) = \max_{b' \geq 0} \left\{ u(c) + \varphi u(c) + \beta \mathbb{E} v(b', y') \right\} - \varphi (Rb + y)$$

subject to

$$c + b' = Rb + y, \quad b' \geq 0$$

The parameter $\varphi \geq 0$ measures the strength of the temptation. When $\varphi = 0$, the model collapses to the model without temptation.

The first-order condition for this problem is

$$u_c(c) = \beta \mathbb{E} \left[ \left( 1 - \frac{\varphi}{1 + \varphi} \frac{u_c(Rb' + y')}{u_c(c')} \right) u_c(c') \right]. \quad (C.6)$$

This first-order condition can be interpreted as a modified Euler equation, with an endogenous discount factor. With log preferences $u(c) = \log(c)$ the endogenous discount factor becomes

$$\beta \left( 1 - \frac{\varphi}{1 + \varphi} \left( \frac{c'}{Rb' + y'} \right) \right)$$

which makes it clear that households who consume a higher fraction of their wealth act as if they are more impatient. These are typically poorer households and so with this preference formulation, the effective discount factor tends to be lower for household with lower wealth. In the limit, as households become hand-to-mouth, $c' = Rb' + y'$ and the discount factor becomes $\beta \frac{1}{1 + \varphi}$.
C.2 Present-Bias

In this Appendix we describe the model of naive present bias that we solve in Section 3.2.2. First consider the problem of a household that does not suffer from present bias:

\[
\rho \tilde{v}(b, y) = \max_c \left[ u(c) + \tilde{\sigma}_b(b, y) \dot{b} + A(y) \tilde{v}(b, y) \right]
\]
subject to
\[
\dot{b} = rb + y - c, \quad b \geq 0
\]

where \( A \) is the infinitesimal generator of the income process. The first order condition to this optimization problem for \( b > 0 \) is

\[
u_c(c) = \tilde{\sigma}(b, y)
\]
The solution to this problem defines a consumption function given by

\[
\tilde{c}(b, y) = \min \left\{ u^{-1}_c(\tilde{\sigma}_b(b, y)), y \right\}
\]

A household with naive present bias has a continuation value given by

\[
v(b, y) = \zeta \tilde{v}(b, y) \quad \text{for} \quad \zeta < 1.
\]

So for \( b > 0 \), consumption solves the first order condition condition

\[
u_c(c) = v_b(b, y) = \zeta \tilde{v}(b, y).
\]

With CRRA utility, this gives the consumption function

\[
c(b, y) = \min \{ \zeta^{-\frac{1}{\gamma}} \tilde{c}(b, y), y \}.
\]

D MPCs at Different Horizons

To compute the MPC at different horizons, we proceed as follows. Let, for example, \( t = 1 \) be the horizon of interest. Then, the MPC at horizon 1 out of a windfall income \( x \) is:

\[
m_1(x; b, y) = \int_F \left[ c \left( b' (b + x, y), y' \right) - c \left( b' (b, y), y' \right) \right] dF (y', y) \]

Iterating this procedure forward, one obtains \( m_t(x; b, y) \), for all \( t > 0 \). The cumulative MPC until horizon \( T \) is simply the sum of the MPCs at each horizon \( t = 0, 1, ..., T \). The average (or aggregate) MPC at horizon \( t \) is obtained by integrating the function \( m_t(x; b, y) \) under the stationary
distribution, i.e.

\[ \bar{m}_t(x) = \int_{B \times Y} m_t(x; b, y) \, d\mu(b, y). \]  

(D.7)

Finally, we are also interested in the MPC out of the news that a windfall of size \( x \) will be received in the future. For example, the MPC at horizon \(-1\), i.e. out of the announcement that \( x \) will be paid next period, is:

\[ m_{-1}(x; b, y) = \frac{c(x; b, y) - c(b, y)}{x} \]  

(D.8)

where \( c(b, y) \) is the solution to the Bellman equation corresponding to the optimization problem (1):

\[ v(b, y) = \max_{\bar{c}} u(\bar{c}) + \beta \mathbb{E} \left[ v(b', y') \mid y \right] \]

and \( c(x; b, y) \) is the solution to the following Bellman equation, modified to account for the fact that the household expects \( x \) next period:

\[ v(b, y) = \max_{\bar{c}} u(\bar{c}) + \beta \mathbb{E} \left[ v(b' + x, y') \mid y \right] \]  

(D.9)

and subject to the same set of constraints as (1).
### Table E.1: Baseline one-asset model and calibrations for different model frequency (annual and continuous time). Model frequency indicates the frequency at which consumption and saving decisions are made. See Table A.2 for details on the income process at different frequencies.

<table>
<thead>
<tr>
<th></th>
<th>(1) Quarterly (Discrete)</th>
<th>(2) Annual (Discrete)</th>
<th>(3) Quarterly (Continuous)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarterly MPC (%)</td>
<td>4.6</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Annual MPC (%)</td>
<td>14.6</td>
<td>14.3</td>
<td>11.5</td>
</tr>
<tr>
<td>Quarterly MPC of the HtM (%)</td>
<td>28.7</td>
<td></td>
<td>33.7</td>
</tr>
<tr>
<td>Share of HtM (%)</td>
<td>2.5</td>
<td>8.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Annualized discount factor</td>
<td>0.980</td>
<td>0.980</td>
<td>0.985</td>
</tr>
</tbody>
</table>

#### Panel A: Wealth Statistics

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean wealth</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Median wealth</td>
<td>1.3</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>$a \leq 1000$</td>
<td>2.5</td>
<td>8.6</td>
<td>2.5</td>
</tr>
<tr>
<td>$a \leq 5000$</td>
<td>11.6</td>
<td>15.6</td>
<td>8.0</td>
</tr>
<tr>
<td>$a \leq 10000$</td>
<td>18.5</td>
<td>21.9</td>
<td>13.4</td>
</tr>
<tr>
<td>$a \leq 50000$</td>
<td>40.3</td>
<td>42.7</td>
<td>34.9</td>
</tr>
<tr>
<td>$a \leq 100000$</td>
<td>51.9</td>
<td>54.1</td>
<td>48.0</td>
</tr>
<tr>
<td>Wealth, top 10% share</td>
<td>46.6</td>
<td>53.0</td>
<td>40.3</td>
</tr>
</tbody>
</table>
### Table E.2: Baseline one-asset model and sensitivity analysis with respect to the statistical process for income dynamics. See Table A.2 for details on each income process.
<table>
<thead>
<tr>
<th></th>
<th>(1) Baseline</th>
<th>(2) With Bequests</th>
<th>(3) No Death</th>
<th>(4) Annuities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarterly MPC (%)</td>
<td>4.6</td>
<td>4.6</td>
<td>4.4</td>
<td>4.9</td>
</tr>
<tr>
<td>Annual MPC (%)</td>
<td>14.6</td>
<td>14.6</td>
<td>14.7</td>
<td>15.8</td>
</tr>
<tr>
<td>Quarterly MPC of the HtM (%)</td>
<td>28.7</td>
<td>28.7</td>
<td>30.3</td>
<td>29.1</td>
</tr>
<tr>
<td>Share of HtM (%)</td>
<td>2.5</td>
<td>2.5</td>
<td>1.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Annualized discount factor</td>
<td>0.980</td>
<td>0.980</td>
<td>0.975</td>
<td>0.961</td>
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</table>

**Panel A: Decomposition**

<table>
<thead>
<tr>
<th></th>
<th>(1) Baseline</th>
<th>(2) With Bequests</th>
<th>(3) No Death</th>
<th>(4) Annuities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap with Baseline MPC</td>
<td>0.0</td>
<td>-0.2</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Effect of MPC Function</td>
<td>0.0</td>
<td>0.4</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Effect of Distribution</td>
<td>0.0</td>
<td>-0.6</td>
<td>-0.0</td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td>0.0</td>
<td>-0.0</td>
<td>-0.0</td>
<td></td>
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</table>

**Panel B: Wealth Statistics**

<table>
<thead>
<tr>
<th></th>
<th>(1) Baseline</th>
<th>(2) With Bequests</th>
<th>(3) No Death</th>
<th>(4) Annuities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean wealth</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Median wealth</td>
<td>1.3</td>
<td>1.3</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>$a \leq 1000$</td>
<td>2.5</td>
<td>2.5</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>$a \leq 5000$</td>
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<td>11.6</td>
<td>9.4</td>
<td>11.4</td>
</tr>
<tr>
<td>$a \leq 10000$</td>
<td>18.5</td>
<td>18.5</td>
<td>15.7</td>
<td>18.2</td>
</tr>
<tr>
<td>$a \leq 50000$</td>
<td>40.3</td>
<td>40.3</td>
<td>36.7</td>
<td>40.1</td>
</tr>
<tr>
<td>$a \leq 100000$</td>
<td>51.9</td>
<td>51.9</td>
<td>48.3</td>
<td>51.7</td>
</tr>
<tr>
<td>Wealth, top 10% share</td>
<td>46.6</td>
<td>46.6</td>
<td>42.0</td>
<td>46.5</td>
</tr>
</tbody>
</table>

Table E.3: Baseline one-asset model and sensitivity analysis with respect to survival rates and to assumptions on assets of the deceased are distributed among the living.
Table E.4: One-asset model with heterogeneity in the curvature parameter $\gamma$ of the CRRA utility function.
<table>
<thead>
<tr>
<th></th>
<th>(1) Baseline</th>
<th>(2) RA=1, IES=2</th>
<th>(3) RA=1, IES=0.25</th>
<th>(4) RA=8, IES=1</th>
<th>(5) RA=0.5, IES=1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarterly MPC (%)</td>
<td>4.6</td>
<td>5.3</td>
<td>5.7</td>
<td>3.4</td>
<td>4.6</td>
</tr>
<tr>
<td>Annual MPC (%)</td>
<td>14.6</td>
<td>16.4</td>
<td>17.6</td>
<td>11.9</td>
<td>14.6</td>
</tr>
<tr>
<td>Quarterly MPC of the HtM (%)</td>
<td>28.7</td>
<td>29.0</td>
<td>29.2</td>
<td>23.8</td>
<td>28.7</td>
</tr>
<tr>
<td>Share of HtM (%)</td>
<td>2.5</td>
<td>3.3</td>
<td>3.9</td>
<td>1.2</td>
<td>2.5</td>
</tr>
<tr>
<td>Annualized discount factor</td>
<td>0.980</td>
<td>0.986</td>
<td>0.954</td>
<td>0.951</td>
<td>0.980</td>
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</table>

**Panel A: Decomposition**

<table>
<thead>
<tr>
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<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
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<tbody>
<tr>
<td>Gap with Baseline MPC</td>
<td>0.7</td>
<td>1.1</td>
<td>-1.2</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Effect of MPC Function</td>
<td>0.1</td>
<td>0.2</td>
<td>-0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Effect of Distribution</td>
<td>0.6</td>
<td>0.9</td>
<td>-1.6</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td>0.0</td>
<td>0.0</td>
<td>0.4</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**Panel B: Wealth Statistics**

<table>
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<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean wealth</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Median wealth</td>
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<td>1.1</td>
<td>1.1</td>
<td>2.4</td>
<td>1.3</td>
</tr>
<tr>
<td>$a \leq 1000$</td>
<td>2.5</td>
<td>3.4</td>
<td>4.0</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>$a \leq 5000$</td>
<td>11.6</td>
<td>13.9</td>
<td>15.3</td>
<td>5.7</td>
<td>11.6</td>
</tr>
<tr>
<td>$a \leq 10000$</td>
<td>18.5</td>
<td>21.4</td>
<td>23.0</td>
<td>9.3</td>
<td>18.5</td>
</tr>
<tr>
<td>$a \leq 50000$</td>
<td>40.3</td>
<td>43.3</td>
<td>44.8</td>
<td>25.8</td>
<td>40.4</td>
</tr>
<tr>
<td>$a \leq 100000$</td>
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<td>55.2</td>
<td>38.7</td>
<td>51.9</td>
</tr>
<tr>
<td>Wealth, top 10% share</td>
<td>46.6</td>
<td>48.6</td>
<td>49.5</td>
<td>35.3</td>
<td>46.6</td>
</tr>
</tbody>
</table>

Table E.5: One-asset model with Epstein-Zin preferences.
### Panel A: Decomposition

<table>
<thead>
<tr>
<th></th>
<th>(1) Baseline</th>
<th>(2) $\beta_{IG} = 0.9$</th>
<th>(3) $\beta_{IG} = 0.8$</th>
<th>(4) $\beta_{IG} = 0.7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarterly MPC (%)</td>
<td>3.0</td>
<td>3.6</td>
<td>3.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Annual MPC (%)</td>
<td>11.5</td>
<td>13.1</td>
<td>10.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Quarterly MPC of the HtM (%)</td>
<td>33.7</td>
<td>21.7</td>
<td>14.4</td>
<td>8.1</td>
</tr>
<tr>
<td>Share of HtM (%)</td>
<td>2.0</td>
<td>6.6</td>
<td>17.1</td>
<td>19.6</td>
</tr>
<tr>
<td>Annualized discount factor</td>
<td>0.985</td>
<td>0.989</td>
<td>0.993</td>
<td>0.997</td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap with Baseline MPC</td>
<td>0.6</td>
<td>0.8</td>
<td>-0.5</td>
<td></td>
</tr>
<tr>
<td>Effect of MPC Function</td>
<td>-1.6</td>
<td>-7.6</td>
<td>-10.2</td>
<td></td>
</tr>
<tr>
<td>Effect of Distribution</td>
<td>1.4</td>
<td>2.0</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td>0.8</td>
<td>6.4</td>
<td>8.8</td>
<td></td>
</tr>
</tbody>
</table>

### Panel B: Wealth Statistics

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean wealth</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Median wealth</td>
<td>1.6</td>
<td>1.5</td>
<td>1.6</td>
<td>1.9</td>
</tr>
<tr>
<td>$a \leq $1000</td>
<td>2.5</td>
<td>7.4</td>
<td>16.7</td>
<td>19.1</td>
</tr>
<tr>
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<td>8.0</td>
<td>15.3</td>
<td>21.9</td>
<td>23.1</td>
</tr>
<tr>
<td>$a \leq $10000</td>
<td>13.4</td>
<td>20.5</td>
<td>25.7</td>
<td>26.1</td>
</tr>
<tr>
<td>$a \leq $50000</td>
<td>34.9</td>
<td>38.9</td>
<td>40.3</td>
<td>38.2</td>
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<tr>
<td>$a \leq $100000</td>
<td>48.0</td>
<td>49.6</td>
<td>49.3</td>
<td>46.5</td>
</tr>
<tr>
<td>Wealth, top 10% share</td>
<td>40.3</td>
<td>39.4</td>
<td>37.7</td>
<td>34.8</td>
</tr>
</tbody>
</table>

Table E.6: One-asset model with preferences featuring present bias in consumption choices. The parameter $\zeta < 1$ measures the strength of the present bias.
<table>
<thead>
<tr>
<th>Panel A: Calibrated Variables</th>
<th>(1) Baseline 2-asset</th>
<th>(2) $\chi=1$</th>
<th>(3) $\chi=0.25$</th>
<th>(4) $\kappa=0$</th>
<th>(5) $\kappa=3000$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rebalance arrival rate</td>
<td>3.00</td>
<td>1.00</td>
<td>0.25</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Quarterly MPC (%)</td>
<td>16.1</td>
<td>14.9</td>
<td>16.3</td>
<td>14.4</td>
<td>15.3</td>
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<tr>
<td>Annual MPC (%)</td>
<td>41.2</td>
<td>37.7</td>
<td>42.3</td>
<td>32.7</td>
<td>40.4</td>
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<tr>
<td>Quarterly PHTM MPC (%)</td>
<td>24.3</td>
<td>24.1</td>
<td>23.9</td>
<td>31.0</td>
<td>24.5</td>
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<tr>
<td>Quarterly WHtM MPC (%)</td>
<td>29.8</td>
<td>25.9</td>
<td>37.7</td>
<td>18.7</td>
<td>28.6</td>
</tr>
<tr>
<td>Mean MPC at Mean Wealth (%)</td>
<td>7.0</td>
<td>8.0</td>
<td>9.2</td>
<td>8.8</td>
<td>6.7</td>
</tr>
<tr>
<td>Prob. HtM status at year t and year t+1</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
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<tr>
<th>Panel B: Targeted Statistics</th>
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<tbody>
<tr>
<td>Mean total wealth</td>
</tr>
<tr>
<td>Share hand-to-mouth</td>
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<tr>
<td>Share poor hand-to-mouth</td>
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<thead>
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<th>Panel C: Decomposition</th>
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<tr>
<td>Gap with Baseline MPC</td>
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<tr>
<td>Effect of MPC function</td>
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<tr>
<td>Distributional Effect</td>
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<td>Interaction</td>
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<th>Panel D: Wealth Statistics</th>
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<tr>
<td>Mean liquid wealth</td>
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<tr>
<td>Median total wealth</td>
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<tr>
<td>Median liquid wealth</td>
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<td>$b \leq 1000$</td>
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<tr>
<td>$b \leq 5000$</td>
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<td>$b \leq 10000$</td>
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<tr>
<td>$w \leq 1000$</td>
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<td>$w \leq 5000$</td>
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<td>$w \leq 10000$</td>
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<tr>
<td>$w \leq 500000$</td>
</tr>
<tr>
<td>$w \leq 100000$</td>
</tr>
<tr>
<td>Wealth, Top 10% share</td>
</tr>
<tr>
<td>Wealth, Top 1% share</td>
</tr>
<tr>
<td>Gini coefficient, total wealth</td>
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Table E.7: Two-asset baseline model and sensitivity with respect to the rebalancing frequency and the transaction cost conditional on rebalancing.