

# Household Risk Management\*

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## Abstract

Households' insurance against adverse shocks to income and the value of assets (that is, household risk management) is limited and at times completely absent, in particular for poor households. We explain this basic pattern in household insurance in an infinite horizon model in which households have access to complete markets subject to collateral constraints resulting in a trade-off between risk management concerns and the financing needs for consumption and durable goods purchases. Household risk management is increasing in household net worth and income, under quite general conditions, in economies with income risk and durable goods price risk. Household risk management is precautionary in the sense that an increase in uncertainty increases risk management; remarkably, risk aversion is sufficient for this result and no assumptions on prudence are required.

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# 1 Introduction

We argue that the absence of household risk management is due to the fact that households' financing needs exceed their hedging concerns. We provide a standard neoclassical model in which households' ability to promise to pay is limited by the need to collateralize such promises. Collateral constraints hence restrict both financing as well as risk management as both require households to issue promises to pay. Given this link, households limit their risk management and may completely abstain from hedging when financing needs are sufficiently strong. Thus, the absence of household risk management and the lack of markets that provide such insurance should not be considered a puzzle.

Households' primary financing needs are two: purchases of durable goods and the accumulation of human capital. First, households consume the services of durable goods, most importantly housing, and the purchase of such goods needs to be financed. Second, investment in education requires financing, and education and learning-by-doing imply an age-income profile which is upward sloping on average. The bulk of financing actually extended to households is for purchases of durable goods. Indeed, more than 90% of household liabilities are attributable to durable goods purchases, mainly real estate (around 80%) and vehicles (around 6%), and less than 4% of household liabilities are attributable to education purposes.<sup>1</sup> We study a model in which all household borrowing needs to be collateralized by households' stocks of durable goods. Since most household financing is comprised of such loans, our model is plausible empirically. While households are able to borrow for education only to a very limited extent, consistent with our model, education and learning-by-doing are nevertheless important as they result in age-income profiles that are upward sloping on average which means that households have an incentive to borrow against the future using other means, namely, by financing durable goods.

Shiller (1993) has argued that markets that allow households to manage their risks would significantly improve welfare and that the absence of such markets hence presents an important puzzle. For example, Shiller (2008) writes that “[t]he near absence of derivatives markets for real estate ... is a striking anomaly that cries out for explanation

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<sup>1</sup>In the first quarter of 2009, data from the *Flow of Funds Accounts of the U.S.* suggests that home mortgages are 78% of household liabilities and consumer credit is about 19% and, according to the *Federal Reserve Statistical Release G.19*, 12% is non-revolving consumer credit (which includes automobile loans as well as non-revolving loans for mobile homes, boats, trailers, education, or vacations). Data from the *2007 Survey of Consumer Finances* on the purpose of debt suggests that in 2007, about 83% of household debt is due to the purchase or improvement of a primary residence or other residential property, about 6% is due to vehicle purchases, less than 4% is due to education, and about 6% is due to the purchase of goods or services which is not further broken out.

and for actions to change the situation.” We provide a rationale why households may not use such markets even if they exist. And given this lack of demand from households, the absence of such markets may not be so puzzling after all. The explanation we provide is simple: households’ primary concern is financing, that is, shifting funds from the future to today, not risk management, that is, not transferring funds across states in the future. Risk management would require households to make promises to pay in high income states in the future, but this would reduce households’ ability to promise to pay in high income states to finance durable goods purchases today, because households’ total promises are limited by collateral constraints. Our dynamic model of complete markets subject to collateral constraints allows an explicit analysis of the connection between financing and risk management, and shows that the cost of risk management may be too high.

Indeed, we show that household risk management is increasing in household net worth and income, under quite general conditions. We first show that optimal household risk management of risk averse households whose income follows a stationary Markov chain with a notion of positive persistence is increasing and incomplete, even in the long run, that is, under the stationary distribution of household net worth. We extend these results to an economy with durable goods that the households can borrow against, and show that the increasing risk management result generalizes. Finally, we consider durable goods price risk, in addition to income risk, and provide conditions for increasing risk management. Under some assumptions, households may partially hedge income risk but do not hedge durable goods price risk at all. When households can choose to rent durables as well as buy them, we show that households with low net worth rent and that renters hedge high durable goods prices.

Our economy with income risk only is similar to the classic model of buffer stock savings of Bewley (1977) and Aiyagari (1994), among others. The main difference is that this class of models typically assumes that households have access only to risk-free assets subject to short-sale (or borrowing) constraints, whereas households in our model have access to state-contingent claims, albeit subject to similar short-sale constraints. We explicitly compare the behavior of state-contingent savings in our model to the savings behavior in the standard model with incomplete markets. Most notably, risk aversion is sufficient for state-contingent savings to be precautionary, that is, for an increase in uncertainty to lead to an increase in state-contingent savings. In contrast, with incomplete markets guaranteeing that an increase in uncertainty increases savings requires assumptions about prudence, that is, the third derivative of the utility function. Moreover, in our model net worth next period is monotone increasing in current income given current net worth, whereas this is not the case in the standard incomplete markets model. Finally,

when households' rate of time preference equals the interest rate, households' net worth remains finite in our model even in the long run, while households accumulate infinite buffer stocks in the incomplete markets model.

Consistent with the view that financing needs may override risk management concerns, we discuss evidence on U.S. households which suggests that poor (and financially constrained) households are less well insured against many types of risks, such as health risks or flood risks, than richer (and less financially constrained) households. Most pertinently, Fang and Kung (2012) study panel data on life insurance coverage and find that income shocks are a key determinant of individuals' decisions to maintain or lapse insurance coverage; specifically, "individuals who experience negative income shocks are more likely to lapse all coverage." This within-household variation in insurance coverage is consistent with the predictions of our model. Furthermore, a similar positive relation between income and risk management has recently been documented for farmers in developing economies. In addition, there is evidence that firms' financial constraints affect corporate risk management. One important consequence of the absence of risk management by constrained households and firms is that such households and firms are then more susceptible to shocks.

Section 2 analyzes household income risk management in an endowment economy with income risk only, derives the basic increasing household risk management result, and shows that households' state-contingent savings are precautionary. It also provides a comparison to the standard buffer stock savings model with incomplete markets à la Bewley (1977) and Aiyagari (1994). Section 3 extends the model to an economy with durable goods and shows how the increasing risk management result generalizes and that financing needs for durable goods and education may override hedging concerns. Durable goods price risk management is analyzed in Section 4. This section also considers households' ability to rent durable goods and the interaction between the rent vs. buy decision and risk management.<sup>2</sup> Section 5 reviews the evidence on household insurance and corporate risk management. Section 6 concludes. All proofs are in Appendix A except when noted otherwise.

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<sup>2</sup>The asset pricing implications of housing have recently been considered by Lustig and Van Nieuwerburgh (2005) and Piazzesi, Schneider, and Tuzel (2007) in economies with similar preferences over two goods, (nondurable) consumption and housing services. Both studies consider a frictionless rental market for housing unlike us, which reduces households' financing needs substantially. Lustig and Van Nieuwerburgh (2005) consider the role of solvency constraints similar to ours and Piazzesi, Schneider, and Tuzel (2007) study the frictionless benchmark.

## 2 Household Income Risk Management

In this section we consider household income risk management in an endowment economy. We show that optimal household income risk management is incomplete and monotone increasing in the households' net worth, that is, richer households are better insured. Moreover, we show that household risk management is precautionary, that is, increases when uncertainty is higher, and that there is a sense in which "the poor cannot afford insurance." Finally, we characterize household risk management in the long run and in an economy in which households are eventually unconstrained. A comparison to the classic Bewley (1977) and Aiyagari (1994) type economies is also provided.

### 2.1 Household Finance in an Endowment Economy

Consider household income risk management in an endowment economy. Time is discrete and the horizon is infinite. Households have preferences  $E[\sum_{t=0}^{\infty} \beta^t u(c_t)]$  where we assume that  $\beta \in (0, 1)$  and  $u(c)$  is strictly increasing, strictly concave, continuously differentiable, and satisfies  $\lim_{c \rightarrow 0} u(c) = \infty$  and  $\lim_{c \rightarrow \infty} u(c) = 0$ . Households' income  $y(s)$  follows a Markov chain on state space  $s \in S$  with transition matrix  $\Pi(s, s') > 0$  describing the transition probability from state  $s$  to state  $s'$ , and  $\forall s, s_+, s_+ > s, y(s_+) > y(s) > 0$ . We use the shorthand  $y' \equiv y(s')$  for income in state  $s'$  next period wherever convenient and analogously for other variables. Moreover, let  $\underline{s} = \min\{s : s \in S\}$  and  $\bar{s} = \max\{s : s \in S\}$  and analogously for  $\underline{y}$  and  $\bar{y}$  and let  $S$  also denote the cardinality of  $S$  in a slight abuse of notation.

Lenders are risk neutral and discount the future at rate  $R^{-1} > \beta$ , that is, are patient relative to the households, and have deep pockets and abundant collateral in all dates and states; lenders are thus willing to provide any state-contingent claim at an expected return  $R$ .<sup>3</sup>

Enforcement is limited as follows: households can abscond with their income and cannot be excluded from markets for state-contingent claims in the future. Extending the results in Rampini and Viswanathan (2010, 2013) to this environment, we show in Appendix B that the optimal dynamic contract with limited enforcement can be implemented with complete markets in one-period ahead Arrow securities subject to short-sale constraints (which are a special case of collateral constraints).<sup>4</sup>

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<sup>3</sup>We discuss the case in which  $\beta = R^{-1}$  below. In models of buffer stock savings with idiosyncratic risk and incomplete markets, Bewley (1977), Huggett (1993), Aiyagari (1994), and others show that aggregate asset holdings are finite only if  $R^{-1} > \beta$  in equilibrium.

<sup>4</sup>These one-period ahead Arrow securities are akin to the cash-in-advance contracts in Bulow and Rogoff (1989); see also Krueger and Uhlig (2006). Alvarez and Jermann (2000) provide a decentralization

In some parts of the analysis, we consider Markov chains which exhibit the following notion of positive persistence:

**Definition 1 (Markov process with FOSD)** *A Markov chain  $\Pi(s, s')$  displays first order stochastic dominance (FOSD) if  $\forall s, s_+, \hat{s}', s_+ > s, \sum_{s' \leq \hat{s}'} \Pi(s_+, s') \leq \sum_{s' \leq \hat{s}'} \Pi(s, s')$ .*

This definition requires that the distribution of states next period conditional on current state  $s_+$  first order stochastically dominates the distribution conditional on current state  $s$ , for all  $s_+ > s$ . A Markov chain which is independent over time, that is, satisfies  $\Pi(s, s') = \Pi(s')$ ,  $\forall s \in S$ , exhibits FOSD.<sup>5</sup> Arguably, such positive persistence in household income is plausible empirically.

## 2.2 Household's Income Risk Management Problem

The household solves the following recursive problem by choosing (non-negative) consumption  $c$  and a portfolio of Arrow securities  $h'$  for each state  $s'$  (and associated net worth  $w'$ ) given the exogenous state  $s$  and the net worth  $w$  (cum current income),

$$v(w, s) \equiv \max_{c, h', w' \in \mathbb{R}_+ \times \mathbb{R}^{2S}} u(c) + \beta E[v(w', s') | s] \quad (1)$$

subject to the budget constraints for the current and next period,  $\forall s' \in S$ ,

$$w \geq c + E[R^{-1}h' | s], \quad (2)$$

$$y' + h' \geq w', \quad (3)$$

and the short-sale constraints,  $\forall s' \in S$ ,

$$h' \geq 0. \quad (4)$$

Since the return function is concave, the constraint set convex, and the operator defined by the program in (1) to (4) satisfies Blackwell's sufficient conditions, there exists a unique value function  $v$  which solves the Bellman equation. The value function  $v$  is strictly

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with complete markets and endogenous solvency constraints for economies with limited enforcement as in Kehoe and Levine (1993) and Kocherlakota (1996). The outside option in their model is exclusion from intertemporal markets and implies solvency constraints that are agent and state specific, whereas our outside option without exclusion results in simple short-sale and collateral constraints with a straightforward decentralization.

<sup>5</sup>For a symmetric two-state Markov chain, FOSD is equivalent to assuming that  $\Pi(\bar{s}, \bar{s}) = \Pi(\underline{s}, \underline{s}) \equiv p \geq 1/2$ , that is, that the autocorrelation  $\rho$  is positive, as  $\rho = 2p - 1 \geq 0$ .

increasing, strictly concave, and differentiable everywhere.<sup>6</sup> Denoting the multipliers on the budget constraints (2) and (3) by  $\mu$  and  $\beta\Pi(s, s')\mu'$ , respectively, and the multipliers on the short-sale constraints (4) by  $\beta\Pi(s, s')\lambda'$ , the first order conditions are

$$\mu = u_c(c), \quad (5)$$

$$\mu' = v_w(w', s'), \quad (6)$$

$$\mu = \beta R\mu' + \beta R\lambda'. \quad (7)$$

We have ignored the non-negativity constraint on consumption since it is not binding. The envelope condition is  $v_w(w, s) = \mu$ .

## 2.3 Household Income Risk Management is Increasing

We now show that household risk management is increasing in household net worth. In particular, the set of states that the households hedge is increasing in net worth and richer households' net worth and consumption distribution next period dominate those of poorer households. Richer households moreover spend more on hedging.

**Proposition 1 (Increasing household risk management)** *Let  $w_+ > w$  and denote variables associated with  $w_+$  with a subscript  $+$ . Given the current state  $s$ ,  $\forall s \in S$ , we have: (i) The set of states that the household hedges  $S_h \equiv \{s' \in S : h(s') > 0\}$  is increasing in net worth  $w$ , that is,  $S_{h+} \supseteq S_h$ . (ii) Net worth and consumption next period  $w'_+ \geq w'$  and  $c'_+ \geq c'$ ,  $\forall s' \in S$ , that is,  $w'_+$  and  $c'_+$  statewise dominate and hence FOSD  $w'$  and  $c'$ , respectively; moreover,  $h'_+ \geq h'$ ,  $\forall s' \in S$ , and  $E[h'_+|s] \geq E[h'|s]$ . Finally, consumption across the states the household hedges  $S_h$  is constant, that is,  $c' = c_h$ ,  $\forall s' \in S_h$ , and  $c_h$  is strictly increasing in  $w$ .*

Note that Proposition 1 does not impose any additional structure on the Markov process for income and hence does not determine which states are hedged. If we further assume that the Markov chain displays FOSD, then we can show that households hedge a lower interval of income realizations. Moreover, with this assumption household risk management is increasing in both net worth  $w$  and the current state  $s$ , that is, income.

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<sup>6</sup>See Theorem 9.6 and 9.8 in Stokey and Lucas with Prescott (1989). To see the differentiability, following Lemma 1 in Benveniste and Scheinkman (1979) define  $\hat{v}(\hat{w}, s) \equiv u(\hat{w} - E[R^{-1}h'(w, s)|s]) + \beta E[v(w'(w, s), s')|s]$  where  $h'(w, s)$  and  $w'(w, s)$  are optimal at  $(w, s)$ . Note that  $c(w, s) > 0$  and hence there exists a neighborhood  $N$  of  $w$  such that  $\hat{v}$  is a strictly concave differentiable function with the property that  $\hat{v}(w, s) = v(w, s)$  and  $\hat{v}(\hat{w}, s) \leq v(w, s)$  for all  $\hat{w}$  in  $N$ . Therefore,  $v$  is differentiable at  $w$  with derivative  $u_c(c(w, s))$ ; indeed, by the Theorem of the Maximum,  $c$  is continuous in  $w$  and hence  $v(w, s)$  is continuously differentiable.

**Proposition 2 (Increasing household risk management with FOSD)** *Assume that  $\Pi(s, s')$  displays FOSD. (i) The marginal value of net worth  $v_w(w, s)$  is decreasing in the state  $s$ . (ii) The household hedges a lower interval of states, if at all, given net worth  $w$  and state  $s$ , that is,  $S_h \equiv \{s' \in S : h(s') > 0\} = \{\underline{s}', \dots, s'_h\}$ ; net worth next period  $w'$ , hedging  $h'$ , the interval of states hedged  $S_h$ , and hedged consumption next period  $c_h$  are all increasing in  $w$  and  $s$ ,  $\forall s, s' \in S$ . If moreover  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ , then  $w(s') = w_h$ ,  $\forall s' \in S_h$ , and  $w_h$  is increasing in  $w$ . (iii) If  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ , then the variance of net worth  $w'$  and consumption  $c'$  next period is decreasing in current net worth  $w$ .*

The key to the result is the fact that the marginal value of net worth  $v_w(w, s)$  is decreasing not just in  $w$ , as before, but also in the state  $s$ .<sup>7</sup> First order stochastic dominance means that if the household is in a higher state today, holding current net worth  $w$  constant, then the household's income next period is higher in a FOSD sense. This reduces the cost of hedging to a given level for each state tomorrow, as hedging decreases with the state, and hedging the same amount becomes less costly. The household partially consumes the resources that are thus freed up and partially uses them to buy additional Arrow securities, that is, purchase more insurance, allowing the household to consume more in the hedged states next period. Thus, parts (ii) and (iii) give a sense in which richer households are better insured.

Positive persistence in the income process means that a high income realization reduces the marginal value of net worth for two reasons: first, high current income raises current net worth, which lowers the marginal value of net worth due to concavity; and second, a high current income implies higher expected future income, further reducing the marginal value of net worth by the mechanism described above.<sup>8</sup>

Under the additional assumption of independent income shocks, the household ensures a minimum level of net worth next period, which is increasing in current net worth. Moreover, the variance of both net worth and consumption next period is decreasing in

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<sup>7</sup>The proof is of technical interest as we prove that the marginal value of net worth is (weakly) decreasing in  $s$  by showing that the Bellman operator maps functions which satisfy this property into functions which satisfy the property as well, and that the unique fixed point must satisfy the property, too.

<sup>8</sup>In contrast, in a production economy with technology shocks, positive persistence has two effects which go in opposite directions: on the one hand, high current productivity implies high cash flow and thus raises current net worth, which lowers the marginal value of net worth due to the concavity of the value function; on the other hand, high current productivity increases the expected productivity which means firms would like to invest more, and this effect in turn raises the marginal value of net worth. Thus there are two competing effects when productivity shocks have positive persistence and if the second effect is sufficiently strong, firms hedge states with high productivity.

current net worth, that is, there is a strong sense in which richer households are better insured.<sup>9</sup>

## 2.4 Precautionary Nature of Household Risk Management

We now show that household risk management is precautionary in the sense that a mean preserving spread in income leads the household to increase the expenditure on risk management when income shocks are independent over time. Remarkably, risk aversion alone is sufficient for this result.

**Proposition 3 (Precautionary state-contingent saving)** *Assume that  $\Pi(s, s') = \pi(s')$ ,  $\forall s' \in S$ , and suppose  $\tilde{\pi}(s')$  is a mean-preserving spread of  $\pi(s')$ . Then  $\tilde{E}[\tilde{h}] \geq E[h]$ , where  $\tilde{E}$  is the expectation operator and  $\tilde{h}'$  is optimal risk management given  $\tilde{\pi}(s')$ .*

Thus, state-contingent saving is precautionary without additional assumptions about preferences, whereas saving in the Bewley (1977) economy with incomplete markets is guaranteed to be precautionary only if preferences display prudence, that is, the marginal utility of consumption is convex in consumption. We provide a more explicit comparison to the standard buffer stock savings problem in Section 2.6.

Since the household increases the expenditure on risk management when risk increases, the household must consume less today. In fact, one can show that the household ends up consuming less in each date and state going forward:

**Corollary 1 (Consumption implications of precautionary saving)** *Given the assumptions of Proposition 3 and given net worth  $w$ , precautionary state-contingent saving implies for consumption that  $\tilde{c} \leq c$ ,  $\tilde{c}' \leq c'$ , and indeed  $\tilde{c}(s^t) \leq c(s^t)$  for any subsequent history  $s^t$  and time  $t$ .*

## 2.5 Incomplete Household Risk Management

We have a more explicit characterization of optimal income risk management when the Markov chain displays FOSD:

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<sup>9</sup>If income is lower in downturns and risk management consequently declines, then the cross sectional variation of consumption can be countercyclical, a property documented by Storesletten, Telmer, and Yaron (2004) that is of interest due to its asset pricing implications (see, for example, Mankiw (1986) and Constantinides and Duffie (1996)). Guvenen, Ozkan, and Song (2012) find that the left-skewness of idiosyncratic income shocks is countercyclical, rather than the variance itself, in earnings data from the U.S. Social Security Administration. Rampini (2004) provides a real business cycle model with entrepreneurs subject to moral hazard in which the cross sectional variation of the optimal incentive compatible allocation is similarly countercyclical.

**Proposition 4 (Incomplete risk management)** *Assume that  $\Pi(s, s')$  displays FOSD.*

(i) *At net worth  $w = \underline{y}$  in state  $\underline{s}$ , the household does not hedge at all, i.e.,  $\lambda' > 0, \forall s' \in S$ , and  $S_h = \emptyset$ . (ii) At net worth  $w = \bar{y}$ , the household does not hedge the highest state next period, that is,  $\lambda(\bar{s}') > 0$  and  $S_h \subsetneq S, \forall s \in S$ .*

At net worth  $\underline{y}$  (and in state  $\underline{s}$ ) the household does not hedge at all, which can be interpreted as saying that “the poor can’t afford insurance.” Moreover, even at net worth  $\bar{y}$ , the household does not engage in complete risk management, and since hedging is increasing, the household does not hedge the highest state for any level of wealth  $w \leq \bar{y}$ .

Figure 1 illustrates Propositions 2 and 4 for an economy with an independent, symmetric two state Markov chain. The top right panel illustrates that household risk management is increasing, with the top left panel showing that consumption is concave in wealth and hence richer households actually spend a larger fraction of their budget on Arrow securities to hedge future income shocks.

In our model of income risk management without durable goods, household insurance can be interpreted as state-contingent savings. The properties of such state-contingent savings are similar to the properties of savings noted by Friedman (1957) in his famous treatise *A Theory of the Consumption Function* (page 39):

“These regressions show savings to be negative at low measured income levels, and to be a successively larger fraction of income, the higher the measured income. If low measured income is identified with ‘poor’ and high measured income with ‘rich,’ it follows that the ‘poor’ are getting poorer and the ‘rich’ are getting richer. The identification of low measured income with ‘poor’ and high measured income with ‘rich’ is justified only if measured income can be regarded as an estimate of expected income over a lifetime or a large fraction thereof.”

In our model, all households have the same expected income in the long run, and therefore households that are currently poor hedge less, that is, have lower state-contingent savings, than households that are currently rich, and thus our model yields a “theory of the insurance function” akin to Friedman’s (1957) theory of the consumption function.

## 2.6 Comparison to Buffer Stock Savings Models

We briefly compare our results to the savings behavior in the standard incomplete markets model of Bewley (1977), Aiyagari (1994), and others.<sup>10</sup> The household solves the following

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<sup>10</sup>See Ljungqvist and Sargent (2012) for an authoritative treatise of savings behavior in incomplete markets models.

recursive problem by choosing (non-negative) consumption  $c$  and savings  $h$  which do not vary with the state  $s'$  next period (and associated net worth  $w'$ ) given the exogenous state  $s$  and the net worth  $w$  (cum current income),

$$v(w, s) \equiv \max_{c, h, w' \in \mathbb{R}_+ \times \mathbb{R}^{S+1}} u(c) + \beta E[v(w', s')|s] \quad (8)$$

subject to the budget constraints for the current and next period,  $\forall s' \in S$ ,

$$w \geq c + R^{-1}h, \quad (9)$$

$$y' + h \geq w', \quad (10)$$

and the short-sale constraint

$$h \geq 0. \quad (11)$$

While this model behaves similarly to ours in many ways, we stress that household risk management is not monotone increasing in the Bewley model, in the sense that savings are decreasing in the current state  $s$ , which means that the household's consumption is lower in some states next period when the current state  $s$  is higher.

**Proposition 5 (Household risk management in Bewley model not increasing)**  
*Assume that  $\Pi(s, s')$  displays FOSD. (i) The marginal value of net worth  $v_w(w, s)$  is decreasing in net worth  $w$  and in the state  $s$ . (ii) The household's savings  $h$  are increasing in  $w$  given  $s$ , but decreasing in  $s$  given  $w$ ; therefore, net worth and consumption next period  $w'$  and  $c'$  are decreasing in the current state  $s$ .*

The parallels between our model and the Bewley economy are that since  $v_w(w, s)$  is decreasing in  $w$  and  $s$  in both cases, the envelope condition implies that current consumption  $c$  is increasing in  $w$  and  $s$  in both economies as well. Therefore, both risk management expenditures  $E[R^{-1}h'|s]$  in our model and savings  $h$  in the Bewley economy increase in  $w$  given  $s$  and decrease in  $s$  given  $w$ . The key distinction however is that household risk management  $h'$  in our model increases in  $s$ , for all  $s' \in S$ , although as stated before the total risk management expenditures  $E[R^{-1}h'|s]$  decrease in  $s$ ; in other words,  $w'$  and  $c'$  increase in  $s$ , and household risk management is increasing in  $s$  in this sense. In contrast, savings  $h$  decrease in  $s$  implying that net worth and consumption next period  $w'$  and  $c'$  decrease in  $s$ ; this is the sense in which household risk management is not increasing in  $s$  in the Bewley economy.

In contrast to the precautionary nature of state-contingent savings in our model (see Proposition 3), in the Bewley model convexity of marginal utility  $u_c(c)$  is required to guarantee precautionary savings.

**Proposition 6 (Precautionary saving in Bewley model)** *Assume that  $\Pi(s, s') = \pi(s')$ ,  $\forall s' \in S$ . (i) If  $u_c(c)$  is (weakly) convex in consumption  $c$ , the marginal value of net worth  $v_w(w)$  is convex in net worth  $w$ . (ii) Suppose  $\tilde{\pi}(s')$  is a mean-preserving spread of  $\pi(s')$ . If  $u_c(c)$  is (weakly) convex in  $c$ , then household's savings  $\tilde{h} \geq h$ .*

While this result is well-understood (see Leland (1968), Sandmo (1970), Sibley (1975), and Kimball (1990)), we provide a simple and to the best of our knowledge novel proof using a similar recursive approach to the one in the proof of Proposition 2. Again, we emphasize that risk aversion is sufficient for state-contingent savings to be precautionary in our model, in contrast to savings in incomplete markets models which require further assumptions about preferences, in particular prudence, to guarantee precautionary behavior. Note that the presence of borrowing constraints strengthens the precautionary demand for saving by inducing local convexity in the marginal utility of net worth (see Deaton (1991)), but additional assumptions about preferences are required to guarantee precautionary behavior globally.

Figure 3 illustrates the effect of an increase in risk (that is, a mean-preserving spread) on hedging in our model and on saving in the incomplete markets model when the marginal utility is convex. The top left panel shows that in our model the expenditure on state-contingent savings is precautionary (see Proposition 3). The bottom left panel shows that, when  $u_c(c)$  is convex, saving is precautionary in the Bewley economy (see Proposition 6). The example has an independent income process with three states. Specifically,  $y(s') \in \{y - \sigma, y, y + \sigma\}$  with probabilities  $\pi(s') = \pi_\sigma, 1 - 2\pi_\sigma$ , and  $\pi_\sigma$  respectively. We study an increase in risk in the sense of a mean-preserving spread by considering values of  $\pi_\sigma$  equal to 0 (in which case the economy is deterministic), 0.2, and 0.5 (which is the example studied in Figure 1).

Notice that the deterministic limit of our economy and the Bewley economy coincide and hence the solid (black) line denoting “hedging” expenditure  $R^{-1}h'$  in our model in the top left panel is identical to the solid (black) line denoting saving  $R^{-1}h$  in the Bewley economy in the bottom left panel. In a deterministic economy, there is no “hedging” or saving in the steady state, but for higher (and transitory) levels of net worth “hedging” or saving is clearly positive as households dissave slowly.

In our model, hedging expenditures are increasing in risk (see the top left panel), but the behavior of hedging for each state  $h(s')$  is not monotone in risk. Indeed, one can prove that  $\inf_w \{h(\underline{s}') > 0\}$  is the same for all values of  $\pi_\sigma$  and that in a neighborhood above that threshold  $h(\underline{s}')$  is decreasing in  $\pi_\sigma$ . But the top right panel shows that this pattern reverses for higher levels of net worth. In contrast, in the example  $h(\bar{s}')$  is monotone increasing in  $\pi_\sigma$ .

In the Bewley economy with convex marginal utility, an increase in risk increases saving (as the bottom left panel shows), that is, households save more for a given level of wealth than they would in the deterministic economy.

## 2.7 Household Risk Management in the Long Run

How does household risk management behave in the long run, given that households can accumulate net worth? We show that the model induces a stationary distribution for household net worth. Under the unique stationary distribution, households never hedge completely. Notably, households abstain from risk management completely with positive probability under the stationary distribution. This means that even households whose current net worth is high, that are hit by a sufficiently long sequence of low income realizations, end up so constrained again that they no longer purchase any Arrow securities, that is, stop buying any insurance at all.<sup>11</sup>

### Proposition 7 (Household risk management under the stationary distribution)

*Assume that  $\Pi(s, s')$  displays FOSD. (i) There exists a unique stationary distribution of net worth. (ii) The support of the stationary distribution is a subset of  $[\underline{w}, w_{bnd}]$  where  $\underline{w} = \underline{y}$  and  $w_{bnd} \geq \bar{y}$  with equality if  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ . (iii) Under the stationary distribution, household risk management is increasing, incomplete with probability 1, and completely absent with strictly positive probability.*

Figure 2 illustrates Proposition 7 for an independent two state Markov chain as in the example in Section 2.5 above. The top panel displays the unconditional stationary distribution whose support is between the low income realization ( $\underline{y} = 0.8$  in the example) and the high income realization ( $\bar{y} = 1.2$ ). The household never hedges the high state next period, which means the household's net worth conditional on a high realization is always  $w(\bar{s}') = \bar{y}$  as the bottom panel shows. The household does hedge low realization on income, at least as long as net worth is sufficiently high, so starting from net worth  $\bar{y}$  low income realization decrease the household's net worth gradually over time, as the middle panel illustrates; the probability mass decreases at a rate  $\pi(\underline{s})$  in this range. Eventually, the household stops hedging, and subsequent realizations result in net worth  $\underline{y}$  until a high income realization lifts the household's net worth again.

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<sup>11</sup>In the model with incomplete markets, Schechtman and Escudero (1977) provide conditions under which households run out of buffer stock savings with positive probability.

## 2.8 Risk Management when Households are Eventually Unconstrained

Consider the limit of the above economy where  $\beta R = 1$ , which means that households are eventually unconstrained.<sup>12</sup> We show that the economy displays full insurance under the stationary distribution in the limit and that household net worth is nevertheless bounded in the limit. These results are related to results for the classic class of income fluctuations problems studied among others by Yaari (1976), Schechtman (1976), Schechtman and Escudero (1977), Bewley (1977, 1980), Aiyagari (1994), and especially Chamberlain and Wilson (2000), in which households solve a consumption savings problem with non-contingent debt and borrowing constraints, that is, have access to incomplete markets only.<sup>13</sup> Our results are similar in that there is complete consumption insurance in the limit, but they are rather different in that net worth is bounded in the limit whereas it grows without bound in these related papers.

We emphasize that for net worth levels below the upper bound of net worth under the stationary distribution  $w_{bnd}(s)$ ,  $\forall s \in S$  (see the proof of Proposition 7 for an exact definition), household risk management is incomplete and increasing in current net worth even when  $\beta R = 1$ , although such levels of net worth are transient. The main result of our paper hence obtains even in this case, albeit only in the transition.

When income is independent over time and  $\beta R = 1$ , we know from equation (7) and the envelope condition that  $v_w(w) = v_w(w') + \lambda'$  and therefore  $v_w(w)$  is non-increasing and  $w$  is non-decreasing.<sup>14</sup> Denoting the upper bound of net worth under the stationary distribution by  $\bar{w}$ , we hence have  $v_w(\bar{w}) \geq v_w(w')$ , but by strict concavity  $v_w(\bar{w}) \leq v_w(w')$ , and thus  $\bar{w} = w'$ ,  $\forall s' \in S$ , that is,  $\bar{w}$  is absorbing. Note that for  $w < \bar{y}$ ,  $\lambda(\bar{s}') > 0$  and  $w(\bar{s}') = \bar{y}$ . Moreover, suppose  $\exists s' \in S$ , such that  $w' > \bar{y}$ , then  $v_w(\bar{y}) > v_w(w')$  and  $\lambda' > 0$ , that is,  $w' = y' \leq \bar{y}$ , a contradiction. Therefore,  $w' = \bar{y}$ , for all  $s' \in S$ . Thus, the stationary net worth distribution collapses to unit mass at  $\bar{w} = \bar{y}$ .

Proposition 8 states that the full insurance result is general, that is, does not require independence of the income process. Moreover, as  $\beta R$  goes to 1, the stationary distribution converges to the stationary distribution given  $\beta R = 1$  and, when the income process is independent, the stationary distribution for higher  $\beta$  first-order stochastically dominates the distribution for lower  $\beta$ .

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<sup>12</sup>Aguiar, Amador, and Gopinath (2009) discuss the effect of impatience on the long run behavior of models with limited commitment.

<sup>13</sup>In a calibrated life-cycle model with incomplete markets, Fuster and Willen (2011) study the trade-off between insuring consumption across states and intertemporal smoothing quantitatively.

<sup>14</sup>This result is reminiscent of the downward rigidity of wage contracts in Harris and Holmström (1982).

**Proposition 8 (Full insurance under the stationary distribution in the limit)**

(i) When  $\beta R = 1$ , the household engages in full insurance under the stationary distribution. (ii) Let  $p^*(\beta)$  be the stationary distribution of net worth for given  $\beta$ . As  $\beta \nearrow R^{-1}$ ,  $p^*(\beta) \rightarrow p^*(R^{-1})$ ; moreover, when  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ , if  $\beta_+ > \beta$ , then  $p^*(\beta_+)$  FOSD  $p^*(\beta)$ .

In the case of a symmetric two state Markov chain for income, we can solve for the stationary distribution of net worth in closed form. Specifically, say  $S = \{s_L, s_H\}$  with  $s_L < s_H$ , and  $\Pi(s_H, s_H) = \Pi(s_L, s_L) \equiv p$ . We use subscripts  $L$  and  $H$  where convenient. Using the fact that the stationary distribution of  $y$  is  $(1/2, 1/2)$  and that  $w_H = y_H$  since the household does not hedge the highest state next period given FOSD (see Proposition 4),  $w_L = y_L + h_L$ ,  $c_H = w_H - (1 - p)R^{-1}h_L$ ,  $c_L = w_L - pR^{-1}h_L$ , and  $c_H = c_L$ , that is, full insurance, we obtain

$$h_L = \frac{R}{R - \rho}(y_H - y_L), \quad w_L - w_H = \frac{\rho}{R - \rho}(y_H - y_L), \quad c_H = c_L \equiv c = E[y] + \frac{1}{2} \frac{r}{R - \rho}(y_H - y_L)$$

where  $\rho = 2p - 1 \geq 0$  and  $r \equiv R - 1$ . When income is independent over time,  $p = 1/2$  and  $\rho = 0$ , we have  $h_L = y_H - y_L$ ,  $w_H = w_L = y_H$ , and  $c = E[y] + r/R(y_H - E[y])$ .

Note that  $w_L \geq w_H$  and that the difference  $w_L - w_H$  is increasing in the persistence  $\rho$ . So net worth as we defined it is higher in the low state than in the high state. To see why this is, denote the present value of income (ex current income), that is, human capital, by  $PV_s$ , and note that

$$\begin{aligned} PV_H &= R^{-1}(p(y_H + PV_H) + (1 - p)(y_L + PV_L)) \\ PV_L &= R^{-1}((1 - p)(y_H + PV_H) + p(y_L + PV_L)) \end{aligned}$$

which implies that  $PV_H - PV_L = w_L - w_H$  or  $w_H + PV_H = w_L + PV_L$ , that is, total wealth, (financial) net worth plus human capital, is constant across states. When the household has low current income, his (financial) net worth is high to compensate for the reduction in present value of future labor income. When income is independent over time, the present value of future labor income is constant across states and so is the household's (financial) net worth.

To sum up, when  $\beta R = 1$ , households are eventually unconstrained and fully insured, but their net worth remains finite, in contrast to the models with incomplete markets in which households accumulate infinite buffer stocks to smooth consumption in the limit.

### 3 Household Risk Management with Durable Goods

This section extends our model of household finance to include durable goods. The increasing household risk management results generalize to this environment to a large extent. Moreover, we show that for households with sufficiently low net worth financing needs override hedging concerns, and consider the additional financing needs for education purposes.

#### 3.1 Household Finance with Durable Goods

Consider an extension of the economy of Section 2 with two goods, (non-durable) consumption  $c$  and durable goods  $k$ , which in practice comprise mainly housing. The environment, income process, and lenders are as before, but households have separable preferences  $E[\sum_{t=0}^{\infty} \beta^t \{u(c_t) + g(k_t)\}]$  where  $g(k)$  is strictly increasing, strictly concave, and satisfies  $\lim_{k \rightarrow 0} g_k(k) = +\infty$  and  $\lim_{k \rightarrow \infty} g_k(k) = 0$ .

Durable goods depreciate at rate  $\delta \in (0, 1)$  and the price in terms of consumption goods is assumed to be constant and normalized to 1,  $\forall s \in S$ . Households can adjust their durable goods stock freely, but there is no rental market for durable goods and households have to purchase durable goods to consume their services. Durable goods are also used as collateral as we discuss below. We consider durable goods price risk in Section 4 and analyze the implications of households' ability to rent durables as well as purchase durables and borrow against them in Section 4.2.

Enforcement is limited as follows: households can abscond with their income and a fraction  $1 - \theta$  of durable goods, where  $\theta \in (0, 1)$ , and cannot be excluded from markets for state-contingent claims or durable goods. As before, one can show that the optimal dynamic contract with limited enforcement can be implemented with complete markets in one-period Arrow securities subject to collateral constraints that limit the household's state-contingent promises  $b'$  in state  $s'$  next period as follows:  $\theta k(1 - \delta) \geq Rb'$ ,  $\forall s' \in S$ .<sup>15</sup>

The only friction we add to the standard neoclassical environment is that claims need to be collateralized to enforce repayment. Moreover, we assume that there is no rental market for capital for now. Importantly, our environment is one with full information. Thus, households are able to trade contingent claims on all states of nature, which allows them to engage in risk management.

The simplest and equivalent formulation of the household's problem is to assume that

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<sup>15</sup>These collateral constraints are reminiscent of the ones in Kiyotaki and Moore (1997) but allow state-contingent claims and can be explicitly derived in our model by extending the proof in Appendix B to the case with durable goods.

the household leverages durable assets fully, that is, borrows  $\hat{b}' = R^{-1}\theta k(1 - \delta)$ ,  $\forall s' \in S$ , and purchases Arrow securities in the amount  $h' = \theta k(1 - \delta) - Rb'$ ,  $\forall s \in S$ . Under this equivalent formulation, the collateral constraints on  $b'$  reduce to short-sale constraints on  $h'$ . Moreover, since the household borrows as much as possible against durable assets, the household pays down  $\wp \equiv 1 - R^{-1}\theta(1 - \delta)$  per unit of durable assets purchased only, where  $\wp$  can be interpreted as the minimal down payment required from the household to purchase a unit of the durable asset.

The household solves the following recursive problem by choosing (non-negative) consumption  $c$ , (fully levered) durable goods  $k$ , and a portfolio of Arrow securities  $h'$  for each state  $s'$  (and associated net worth  $w'$ ) given the exogenous state  $s$  and the net worth  $w$  (cum current income and durable goods net of borrowing),

$$v(w, s) \equiv \max_{c, k, h', w' \in \mathbb{R}_+^2 \times \mathbb{R}^{2S}} u(c) + \beta g(k) + \beta E[v(w', s')|s] \quad (12)$$

subject to the budget constraints for the current and next period,  $\forall s' \in S$ ,

$$w \geq c + \wp k + E[R^{-1}h'|s], \quad (13)$$

$$y' + (1 - \theta)k(1 - \delta) + h' \geq w', \quad (14)$$

and the short-sale constraints (4),  $\forall s' \in S$ .

Note that the value function is written excluding the service flow of the current stock of durable goods. The return function  $u(c) + \beta g(k)$  includes the service flow of durables purchased this period for use next period, which is deterministic given purchases of durables this period. This definition of the value function and net worth allows us to formulate the problem with one endogenous state variable, net worth  $w$ , only. Arguing analogously to before, there exists a unique value function which is strictly increasing, strictly concave, and everywhere differentiable. Note that there is no need to impose non-negativity constraints on consumption and durable goods as these are slack given our preference assumptions. Defining the multipliers as before, the first order conditions are (5) through (7) and

$$\wp \mu = \beta g_k(k) + E[\beta \mu' (1 - \theta)(1 - \delta)|s], \quad (15)$$

or written as an investment Euler equation for durable goods

$$1 = \beta \frac{g_k(k)}{\mu} \frac{1}{\wp} + E \left[ \beta \frac{\mu' (1 - \theta)(1 - \delta)}{\mu \wp} \middle| s \right]. \quad (16)$$

The first term on the right hand side is the service flow of the durable goods purchased this period and consumed next period, that is, the “dividend yield” of durables, and the second term on the right hand side is the return from the resale value of durables net of

borrowing. Since durables are fully levered,  $k(1 - \delta) - R\hat{b}' = (1 - \theta)k(1 - \delta)$ . The down payment requirement  $\wp = 1 - R^{-1}\theta(1 - \delta)$  is in the denominator as this is the amount of net worth the household has to invest per unit of durable assets.

### 3.2 Increasing Household Risk Management with Durable Goods

With durable goods, household risk management is increasing in net worth in the sense that the household's net worth  $w'$  next period is strictly increasing in current net worth. Unlike in the economy with income risk only in Section 2, we can no longer conclude that the household's purchases of Arrow securities necessarily increase in wealth, as the household also buys more durables which increases its net worth next period.

When the Markov process displays FOSD, we can again show that the marginal value of net worth  $v_w(w, s)$  decreases in state  $s$ . Therefore, households hedge a lower set of income realizations and, among the states they hedge, hedge worse income realizations strictly more. With independence of the income process, household risk management is incomplete under the stationary distribution.

#### Proposition 9 (Household risk management with durable goods under FOSD)

Assume that  $\Pi(s, s')$  displays FOSD. (i) The marginal value of net worth  $v_w(w, s)$  is decreasing in the state  $s$ . (ii) The household hedges a lower interval of states, if at all, given net worth  $w$  and state  $s$ , that is,  $S_h \equiv \{s' \in S : h(s') > 0\} = \{\underline{s}', \dots, s'_h\}$ , and  $h'$  is strictly decreasing in  $s'$  on  $S_h$ . Consumption  $c$ , durable goods holdings  $k$ , and net worth next period  $w'$  are strictly increasing in net worth  $w$ , given state  $s$ ; consumption  $c$  is also increasing in  $s$ , given  $w$ . (iii) If moreover  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ , then  $w(s') = w_h$ ,  $\forall s' \in S_h$ , and  $w_h$  is strictly increasing in  $w$ . For  $w \leq \bar{w}$ , the household never hedges the highest state next period,  $h(\bar{s}') = 0$ , where  $\bar{w}$  is the highest wealth level attained under the stationary distribution.

Corollary 2 in Section 4 provides sufficient conditions under which Propositions 1 to 4, 7, and 8 obtain even with durable goods.

### 3.3 Financing Needs Override Risk Management Concerns

We now show that if a household's financing needs are sufficiently strong, then financing needs override hedging concerns. Noting that the budget constraint next period (3) binds in all states and that purchases of Arrow securities are limited by short-sale constraints (4), we know that net worth  $w'$  in state  $s'$  next period is bounded below, namely,

$$w' \geq y' + (1 - \theta)k(1 - \delta) > y'.$$

Households' limited ability to promise implies that their net worth  $w'$  next period in all states is bounded below. But this means that the household must be collateral constrained against all states  $s'$  next period if the household's current net worth  $w$  is sufficiently low, since the marginal value of net worth next period must be bounded above.

**Proposition 10 (Financing needs override risk management concerns)** *If a household's current net worth  $w$  is sufficiently low, the household is constrained against all states next period, and hence does not engage in risk management.*

Households' limited ability to credibly promise repayment means that households cannot pledge future income and households' net worth has to be at least future labor income. Moreover durable goods purchases require some down payment per unit of capital from the household and hence implicitly force households to shift additional net worth to the next period. Both these aspects imply that if current household net worth is relatively low, the household shifts resources to the present to the extent possible, that is, borrows as much as possible against durable goods.

Panel A of Figure 4 illustrates Propositions 9 and 10 in the case of an independent symmetric two state Markov process for income. The consumption of both non-durables and durables are concave in household net worth, consistent with one of the basic stylized facts of the empirical consumption literature. Hedging is increasing in net worth; indeed, for low net worth the household does not hedge at all. The household hedges the low state only once net worth reaches a relatively high level, about the level of the high income in the example. This is due to the financing needs for the purchases of durable goods, which force the household to save. At the bottom of the stationary distribution (where  $w(\underline{s}')$  intersects the 45-degree line), the household does not hedge at all. This level of net worth is also considerably above the low income. The financing needs for durable goods reduce household risk management.

### 3.4 Effect of Persistence and Collateralizability on Hedging

Panel B of Figure 4 illustrates the effect of persistence on household risk management by considering the example from Section 3.3 except with a Markov process for income with autocorrelation 0.5 instead of 0. When income is persistent, the household consumes more non-durables and durables in the high state than in the low state, holding net worth constant. Moreover, the household hedges the low state more, in particular when the current state is high. Thus an increase in persistence increases household risk

management. That said, the household saves less for the high state, in particular when the current state is low.

Figure 5 illustrates the effect of collateralizability by considering the example from Section 3.3 except with collateralizability  $\theta = 0.6$  instead of 0.8. The effects are striking. The household reduces consumption of non-durables and durables for given net worth, which is intuitive as a given durable goods purchase now requires more net worth. Moreover, the household drastically reduces risk management and does not hedge at all until a much higher level of net worth is reached and even then, hedges much less. Essentially, the household is forced to save so much to finance its durable goods purchases that it chooses not to hedge. At the same time, the households' stationary distribution of net worth shifts to the right. This comparative statics result provides an interesting perspective on the effects of financial development, which we interpret as an increase in collateralizability. Financial development that allows households to lever durable goods more, results in lower household net worth accumulation, which all else equal would leave them more susceptible to shocks. Thus, financial development increases household risk management. By enabling higher leverage, financial development renders households' risk management concerns more pertinent.

### 3.5 Financing Education

Age-income profiles are upward sloping on average partly because of economic growth and partly presumably because of learning by doing, that is, skill accumulation with experience. These properties of the labor income process give households further incentives to borrow as much as they can against their durable goods, such as housing, and thus exhaust their debt capacity and abstain from risk management.<sup>16</sup>

Suppose moreover that households are able to invest in education or human capital  $e$ . An amount of education  $e$  invested in the current period, which includes both foregone labor income and direct costs, results in income  $A'f(e)$  in state  $s'$  next period, where  $f$  is strictly increasing and strictly concave,  $\lim_{e \rightarrow 0} f_e(e) = +\infty$ , and  $\lim_{e \rightarrow \infty} f_e(e) = 0$ , and the productivity of human capital  $A' > 0$ , for all  $s' \in S$ , is described by a Markov process also summarized by state  $s$ . Human capital depreciates at a rate  $\delta_e \in (0, 1)$ . Note that households in our model can borrow against neither future labor income nor human capital, as education capital is inalienable, and can only borrow against durable goods. The household's problem is to choose (non-negative) consumption  $c$ , (fully levered)

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<sup>16</sup>One way to capture such age-income profiles would be to specify the exogenous Markov chain for income as having an initial transient set of states with relatively low income and eventually reaching an ergodic set of higher income states.

durable goods  $k$ , education  $e$ , and a portfolio of Arrow securities  $h'$  (with associated net worth  $w'$ ) for each state  $s'$  given the exogenous state  $s$  and net worth  $w$  (cum current income, durable goods net of borrowing, and human capital) to maximize (12) subject to the budget constraints for the current and next period,  $\forall s' \in S$ ,

$$w \geq c + \wp k + e + E[R^{-1}h'|s], \quad (17)$$

$$A'f(e) + e(1 - \delta_e) + (1 - \theta)k(1 - \delta) + h' \geq w', \quad (18)$$

and the short-sale constraints (4),  $\forall s' \in S$ . Note that the household's problem is still well behaved, that is, the constraint set is convex.

**Proposition 11** *In the problem with education, that is, investment in human capital, if a household's current net worth  $w$  is sufficiently low, the household is constrained against all states next period and hence does not engage in risk management.*

Since the proof emphasizes the basic trade-off between financing investment and risk management, we discuss it explicitly here. The household's Euler equation for education, that is, investment in human capital, can be written as

$$\begin{aligned} 1 &= E \left[ \beta \frac{v_w(w', s')}{v_w(w, s)} (A'f_e(e) + (1 - \delta_e)) \middle| s \right] \\ &\geq \Pi(s, s') \beta \frac{v_w(w', s')}{v_w(w, s)} (A(s')f_e(e) + (1 - \delta_e)), \quad \forall s, s' \in S. \end{aligned} \quad (19)$$

The budget constraint (17) implies that  $w \geq e$  and hence as  $w$  goes to zero, so does  $e$  implying that  $f_e(e)$  goes to  $+\infty$ . But then  $\beta v_w(w', s')/v_w(w, s)$  must go to zero,  $\forall s' \in S$ , using the Euler equation for investment in education, and, using equation (7),  $\beta\lambda'/\mu$  must go to  $R^{-1}$  implying that the multipliers on the short-sale constraints  $\lambda' > 0$ ,  $\forall s' \in S$ . The intuition is that if the household's net worth is sufficiently low, then the household's education decreases so much that the marginal rate of transformation on investment in human capital eventually exceeds the return on saving net worth for state  $s'$ , for all states.

Investment in education is an additional reason why households are likely to have higher net worth later in life, giving them further incentives to finance as much of their durable goods purchases as they can, rather than using their limited ability to pledge to shift funds across states later on.

## 4 Durable Goods Price Risk Management

In this section we consider households' hedging of durable goods price risk in addition to income risk. Moreover, we study households' choice between owning and renting durable

goods and its interaction with the hedging of price risk. We show that financially constrained households choose not to hedge durable goods price risk. Moreover, households' ability to rent durables leads them to hedge due to the high implied leverage and indeed can affect the sign of the hedging demand.

## 4.1 Risk Management and Durable Goods Price Risk

We now consider an economy with durable goods price risk. Suppose the price of durable goods  $q(s)$  is stochastic, where the state  $s$  describes the joint evolution of income  $y(s)$  and  $q(s)$ , and the economy is otherwise the same as in Section 3.<sup>17</sup> As in that section, we assume without loss of generality that the household leverages durable assets fully, that is, borrows  $\hat{b}' = R^{-1}\theta q'k(1 - \delta)$  against state  $s'$ ,  $\forall s' \in S$ , and purchases Arrow securities in the amount  $h'$ ,  $\forall s' \in S$ . The collateral constraints again reduce to short-sale constraints. Moreover, since the household borrows as much as possible against durable assets, the household pays down  $\wp(s) \equiv q(s) - R^{-1}\theta E[q'|s](1 - \delta)$  per unit of durable assets purchased only. We assume that  $q(s)$  and  $\wp(s)$  are increasing in  $s$ , although some of our results obtain more generally.

The household's problem, formulated recursively, is to choose (non-negative) consumption  $c$ , (fully levered) durable goods  $k$ , and a portfolio of Arrow securities  $h'$  for each state  $s'$  (and associated net worth  $w'$ ) given the exogenous state  $s$  and the net worth  $w$  (cum current income and durable goods net of borrowing), to maximize (12) subject to the budget constraints for the current and next period,  $\forall s' \in S$ ,

$$w \geq c + \wp(s)k + E[R^{-1}h'|s], \quad (20)$$

$$y' + (1 - \theta)q'k(1 - \delta) + h' \geq w', \quad (21)$$

and the short-sale constraints (4),  $\forall s' \in S$ .

Defining the multipliers as before, the first order conditions are (5) through (7) and

$$\wp(s)\mu = \beta g_k(k) + E[\beta\mu'(1 - \theta)q'(1 - \delta)|s]. \quad (22)$$

The durable goods price affects the down payment  $\wp(s)$  in the current period and the resale value of durable goods next period. If the household cannot pledge the full resale value of durables, that is, if  $\theta < 1$ , then durable goods purchases force the household to implicitly save. Moreover, the household is then exposed to the price risk of durables in two ways: first, the resale value of durable goods affects the household's net worth next period, and second, the durable goods price affects the down payment which in turn

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<sup>17</sup>In Section 3, the price of durable goods is constant and normalized to 1.

affects the marginal value of net worth. If the household can pledge the full resale value of durables, that is, if  $\theta = 1$ , the second term on the right hand side of (22) is zero, and the first order condition simplifies to  $\wp(s)\mu = \beta g_k(k)$ . In this case, the durable goods price only affects the household's problem through the down payment. We are able to characterize the solution explicitly in the case of isoelastic preferences with coefficient of relative risk aversion  $\gamma \leq 1$ : household risk management is increasing. Specifically, we show that the economy is equivalent to an economy with income risk and preference shocks. Remarkably, with logarithmic preferences, households do not hedge the durable goods price risk at all, but may partially hedge income risk. With  $\gamma < 1$ , higher durable goods prices, and hence higher down payments, reduce the marginal value of net worth as the substitution effect dominates the income effect. And vice versa, lower house prices amount to investment opportunities and raise the marginal value of net worth.

**Proposition 12** *Suppose  $\theta = 1$  and preferences satisfy  $u(c) = c^{1-\gamma}/(1-\gamma)$  and  $g(k) = gk^{1-\gamma}/(1-\gamma)$  where  $\gamma > 0$  and  $g > 0$ . (i) If  $\gamma = 1$  (logarithmic preferences), then  $v(w, s) = (1 + \beta g)\hat{v}(w, s) + v_\varphi(s)$ , where  $\hat{v}(w, s)$  solves the income risk management problem (without durable goods) in equations (1) through (4) and  $v_\varphi(s)$  is an exogenous function defined in the proof. Household risk management is increasing in the sense of Propositions 1 and 2 and the household does not hedge durable goods price risk at all. (ii) For  $\gamma \neq 1$ , the problem is equivalent to an income risk management problem in an economy with preference shocks where  $\hat{u}(\hat{c}, s) = \phi(s)u(\hat{c})$  with  $\hat{c}$  and  $\phi(s)$  defined in the proof. Household risk management is increasing in the sense of Proposition 1. Moreover, if  $\Pi(s, s')$  displays FOSD,  $\wp(s)$  is increasing in  $s$ , and  $\gamma < 1$ , then the marginal value of net worth  $v_w(w, s)$  is decreasing in  $s$ , the household hedges a lower set of states, and  $w'$ ,  $h'$ , and  $S_h$  are all increasing in  $w$  and  $s$ ,  $\forall s, s' \in S$ .*

More generally, when  $\theta < 1$ , a drop in the durable goods price lowers the household's net worth and hence raises the marginal utility of net worth, and, when  $\gamma < 1$ , the low durable goods price may further raise the marginal utility of net worth. Thus, households likely hedge low durable goods prices in this case. In contrast, when  $\gamma > 1$ , a drop in the durable goods price has two opposing effects, on the one hand lowering net worth and on the other hand raising the marginal utility of net worth due to the price effect. This additional effect reduces the household's hedging demand. Under plausible parameterizations, the direct effect on net worth arguably dominates nonetheless, but this is of course a quantitative question.<sup>18</sup>

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<sup>18</sup>This result is reminiscent of the results in the consumption based asset pricing literature that show that investors' hedging demand in the presence of expected return variation depends in a similar way

It is worth noting that in the absence of durable goods price risk, when the household can pledge the entire resale value of durables (that is,  $\theta = 1$ ) and given preferences as in Proposition 12, the results from Section 2 extend to the case with durable goods, strengthening Proposition 9.

**Corollary 2** *Suppose  $\theta = 1$  and preferences satisfy  $u(c) = c^{1-\gamma}/(1-\gamma)$  and  $g(k) = gk^{1-\gamma}/(1-\gamma)$  where  $\gamma > 0$  and  $g > 0$ . In the absence of durable goods price risk, Propositions 1 to 4, 7, and 8 hold, that is, household risk management is increasing, precautionary, and incomplete, and is completely absent with positive probability under the stationary distribution.*

Corollary 2 is an immediate consequence of Proposition 12 as  $v_\varphi(s)$  and  $\phi(s)$  are constants in this case.

For the general case with  $\theta < 1$ , Figure 6 illustrates the effect of durable goods price risk on the household's consumption and insurance problem. Panel A considers the case with a process for income and durable goods prices that is independent across time. Note that we consider an example in which income and the price of durables are perfectly correlated, that is, there are two states only, one with high income and a high durable goods price and one with low income and a low durable goods price.<sup>19</sup> For given net worth, when the durable goods price is currently low, the household consumes more non-durables and durables and hedges less. The household hedges less because the higher durable goods purchases force the household to save more resulting in a higher level of net worth next period. At the bottom of the stationary distribution, and for levels of net worth below that, the household does not hedge at all. This implies that the household chooses not to hedge the price risk of durable goods when the household is sufficiently constrained.

Panel B of Figure 6 illustrates the effect of persistence of income and durable goods prices. Persistence reduces the effect of the current price of durables on consumption and increases risk management for the low state, in particular when the current price of durables is high and the household hence purchases less durable goods. Importantly, as before, households with low net worth do not hedge the house price risk even under the stationary distribution.

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on the coefficient of relative risk aversion; investors hedge states with low expected returns when the coefficient of relative risk aversion exceeds 1 and otherwise hedge high expected returns (see, for example, Campbell (1996)).

<sup>19</sup>We analyze the case where income and durable goods price processes are independent of each other in the next subsection.

## 4.2 Risk Management and the Rent vs. Buy Decision

In the analysis so far we have not considered households' ability to rent durable goods. If there were a frictionless rental market, ownership of a durable good and the use of its services would be separable. The need to collateralize claims might still limit risk sharing,<sup>20</sup> but tenure choice would not affect households' portfolio choice. Moreover, households' demand for housing services would not induce a substantial financing need in that case.

We consider a rental market that is not frictionless. Renting durable goods is possible, albeit costly, but relaxes collateral constraints as landlords or lessors can more easily repossess rented durables. A similar market for rented capital has been analyzed in a corporate finance context by Eisfeldt and Rampini (2009) and Rampini and Viswanathan (2013). Sufficiently constrained households choose to rent, which affects their risk management or portfolio choice. Because renting housing is costly, households will continue to have a strong incentive to own housing and hence face considerable financing needs for housing. We are able to characterize the interaction between risk management and home ownership since in our model markets are complete, although subject to collateral constraints. In contrast the literature typically studies the interaction of the risk of home ownership and portfolio choice under the assumption that markets are incomplete. Sinai and Souleles (2005) argue that both home ownership and renting are risky when households do not have access to complete markets.<sup>21</sup>

The household can purchase durable goods as before as well as rent them. We denote the total amount of durable goods of the household by  $k$ , owned durables by  $k_o$  and rented durables by  $k_l$ , where  $k = k_o + k_l$ . Given the current price of durables  $q(s)$  in state  $s$ , the user cost of rented capital is  $u_l(s) \equiv rq(s) - (E[q'|s] - q(s)) + E[q'|s](\delta + m)$  where  $m$  is the landlord's or lessor's monitoring cost per unit of durable asset, which we assume is paid in terms of durable goods at the end of the period.<sup>22</sup> Because of limited enforcement, the household has to pay the rental fee up front, in present value terms, that is,  $R^{-1}u_l(s)$ .

The household's problem with renting, formulated recursively, is to choose (non-negative) consumption  $c$ , (fully levered) owned and rented durable goods  $k_o$  and  $k_l$  and a portfolio of Arrow securities  $h'$  for each state  $s'$  (and associated net worth  $w'$ ) given the

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<sup>20</sup>See, for example, Lustig and Van Nieuwerburgh (2005).

<sup>21</sup>Our model may also provide a useful framework to study household interest rate risk management, which Campbell and Cocco (2003) model as the choice of mortgage type, specifically the choice between adjustable rate mortgages (ARMs) and fixed rate mortgages.

<sup>22</sup>Note that if the price of durable goods were constant and normalized to 1, then  $u_l = r + \delta + m$  which is the sum of Jorgenson's (1963) frictionless user cost  $r + \delta$  plus the monitoring cost  $m$ . The additional term adjusts the user cost for the expected capital gain or loss  $E[q'|s] - q(s)$ .

exogenous state  $s$  and the net worth  $w$  (cum current income and owned durable goods net of borrowing), to maximize (12) subject to the budget constraints for the current and next period,  $\forall s' \in S$ ,

$$w \geq c + \wp(s)k_o + R^{-1}u_l(s)k_l + E[R^{-1}h'|s], \quad (23)$$

$$y' + (1 - \theta)q'k_o(1 - \delta) + h' \geq w', \quad (24)$$

the non-negativity constraints on owned and rented durables,

$$k_o, k_l \geq 0, \quad (25)$$

and the short-sale constraints (4),  $\forall s' \in S$ .

Defining the multipliers as before, the first order conditions are (5) through (7) and

$$\wp(s)\mu \geq \beta g_k(k) + E[\beta\mu'(1 - \theta)q'(1 - \delta)|s], \quad (26)$$

$$R^{-1}u_l(s)\mu \geq \beta g_k(k). \quad (27)$$

Using (26) and (27) one can show that a necessary condition for the household to rent some durables is that the down payment required to purchase durables exceeds the rental cost, that is,  $\wp(s) - R^{-1}u_l > 0$ , as renting is otherwise dominated. Moreover, when the household is severely constrained, the household rents all its durable assets; the intuition is that renting durables allows the household to borrow more. Such households also typically do not hedge as noted throughout. There is an interesting interaction between the rent vs. buy decision and hedging. Since renting allows higher leverage, renters' net worth becomes rather volatile, and hence renters with sufficient net worth may partially hedge until they reach net worth levels where they start to own their durables. Households with higher net worth on the other hand own some or all of their durables, and may hedge income and durable goods price risk. This implies that household risk management may no longer be monotone in household net worth.

Interestingly, renters' hedging demand for durable goods price risk may have the opposite sign from that of households who own most of their durables. That said, since renting is endogenous and more constrained households rent, the demand from renters for hedging claims which pay off in high durable goods price states may be low.

Figure 7 illustrates risk management when households can rent and buy durables, say housing. Panel A considers the case, as in Figure 6, in which income and durable goods prices are perfectly positively correlated and the process is independent across time. The bottom left panel shows that households rent when their net worth is low but substitute to owning houses as net worth increases. Rented houses are smaller than owned houses because renters are low net worth households. Households rent and buy smaller houses,

and consume fewer non-durables, when the price of housing is high. Moreover, households start to own housing at higher levels of net worth, so rent longer, when the price of housing is high, as high house prices imply larger downpayments and hence households are more constrained all else equal, that is, for given net worth.

The top right panel shows households' risk management which displays the by now familiar properties with one noteworthy change: since renting allows higher leverage, households are more inclined to hedge when they rent; indeed, for moderate levels of net worth households are hedging but switch back to not hedging at all at higher levels of net worth. Thus, hedging is no longer monotone increasing in net worth. Moreover, the housing price affects the level of hedging as households purchase larger houses when the price is low forcing them to save more and in turn reducing their incentives to save, and hedge, using financial assets.

Panel B displays the case in which the income and price processes are independent of each other. This allows us to separate hedging of income and price risk. The main additional insight regards the sign of the hedging demand: households, in particular renters, hedge the high house price state (see the top right panel). Note that when income and the price of housing are independent, there are four states next period that households could hedge. As before, households primarily hedge the low income state, except for households with very high net worth. More interestingly, households hedge the high price state, that is, buy more claims for the state with low income and high house prices than for the state with low income and low house prices; to see this in the figure, note that the dashed lines (associated with high house prices) are above the corresponding solid lines (associated with low house prices). Here it is important to keep in mind that the example features isoelastic preferences with  $\gamma = 2$ . Renting has implied collateralization one and hence the fact that renters hedge the high house price state is related to the results in Proposition 12 for  $\gamma > 1$ ; high house prices increase the marginal value of net worth, all else equal. For owners there is an additional effect, that is, all else is not equal: owners' home equity  $(1 - \theta)q'k(1 - \delta)$  is worth more when house prices are high. This effect reduces the marginal utility of net worth when prices are high, but in the example the first effect dominates and even home owners hedge the high price state somewhat more.

Our results on durable goods price risk management lead to two important conclusions. First, financial constraints may be at the heart of the absence of hedging of house prices. Second, the sign of the hedging demand depends on households' preferences, their ability to borrow, and on whether households rent or buy.

## 5 Stylized Facts on Household Risk Management

In this section we briefly survey evidence of what we consider a stylized fact, namely that poor (and more financially constrained) households are less well insured than richer (and less financially constrained) households. Indeed, we think this is part of a much broader pattern applying to entrepreneurial households and firms as well, and we briefly discuss evidence on risk management by Indian farmers and U.S. corporations suggesting that financial constraints reduce risk management substantially.

### 5.1 Evidence on Household Insurance

Among U.S. households, health insurance coverage varies considerably with income and age according to data from the U.S. Census Bureau.<sup>23</sup> The percentage of people without health insurance in the U.S. decreases from 25% of people with income less than \$25,000 to 21% for people with income between \$25,000 and \$50,000, and further decreases to 15% of people with income between \$50,000 and \$75,000 and finally decreases to 8% of people with income exceeding \$75,000. Similarly, by age, the fraction of adults without health insurance decreases from 28% and 26% for age groups 18-24 and 25-34, respectively, to 18% and 14% for age groups 35-44 and 45-64, respectively, and to less than 2% for age group 65 and up. Brown and Finkelstein (2007) report that participation in long-term care insurance by individuals aged 60 and over also varies substantially by wealth in U.S. data, increasing from about 3% for the bottom wealth quartile to about 6%, 11%, and 20% for the second, third, and top quartile, respectively.<sup>24</sup> Inkmann, Lopes, and Michaelides (2011) find that annuity market participation among U.K. households with at least one retired person increases substantially with financial wealth, from less than 1% in the bottom 5% to almost 20% in the top 5% of the wealth distribution. Browne and Hoyt (2000) find that flood insurance coverage, both in terms of the number of policies per capita and the amount of coverage per capita, is positively correlated with disposable personal income per capita using U.S. state level data. Clearly, the extent to which households are insured hence varies substantially with households' income. And, assuming that individuals in age group 18-24 and age group 25-34 are more financially constrained, households' insurance level also seems to vary with financial constraints. This cross-sectional evidence is consistent with the view that there is an important connection

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<sup>23</sup>Table 6 of the U.S. Census Bureau's Report on *Income, Poverty, and Health Insurance Coverage in the United States: 2007* provides data on people without health insurance coverage by income and age.

<sup>24</sup>See their Table 1 which provides data on private long-term care insurance ownership rates among individuals aged 60 and over from the *2000 Health and Retirement Survey*.

between household risk management and households' financial constraints. That said, there are certainly other reasons why insurance participation varies with income, such as crowding out of private insurance by public programs, as stressed, for example, by Brown and Finkelstein (2008), financial literacy that varies with income, or fixed costs of obtaining insurance. We now turn to data documenting the relation between insurance coverage and income using within-household variation, which is consistent with our theory and challenges explanations based on financial literacy or fixed costs.

Fang and Kung (2012) use panel data for males from the *Health and Retirement Survey*, a representative longitudinal survey of older Americans conducted every two years. They find that income shocks are one of the important determinants of whether individuals maintain or lapse life insurance coverage, along with changes in health and marital status. The probability of buying life insurance increases with income and importantly the probability of lapsing coverage decreases with income; "individuals who experience negative income shocks are more likely to lapse all coverage." Therefore, the within-household variation in insurance coverage seems consistent with the predictions of our model.

Among farmers in rural India, Giné, Townsend, and Vickery (2008) find that participation in rainfall insurance programs increases in wealth and decreases with measures of borrowing constraints. Cole, Giné, Tobacman, Topalova, Townsend, and Vickery (2013) provide evidence on the importance of credit constraints for the adoption of rainfall insurance using randomized field experiments in rural India. Farmers who are randomly surprised with a positive liquidity shock are much more likely to buy insurance. Moreover, the authors report that the most frequently stated reason for not purchasing insurance is "insufficient funds to buy insurance." Farmers might of course use other risk sharing mechanisms, including informal ones. To overcome the limitation of analyzing specific risk sharing mechanisms in isolation, Townsend (1994) studies data on Indian farmers' household consumption directly in a seminal paper. Townsend finds that, while the full insurance model provides a remarkably good benchmark, "[t]here is evidence that the landless are less well insured than their village neighbors in one of the three villages." That is, there is "a hint of a pattern by land class. Specifically, the landless and small farmers in Aurepalle and the small and medium farmers in Shirapur seem more vulnerable."

In the spirit of the Townsend (1994) critique, Blundell, Pistaferri, and Preston (2008) study the extent of insurance by analyzing the income and consumption distribution for U.S. households jointly. They find "some partial insurance of permanent shocks, especially for the college educated and those near retirement. [They] find full insurance

of transitory shocks except among poor households.” Overall, we conclude that there is a basic pattern in household insurance: richer households are better insured than poorer households.

## 5.2 Related Evidence on Corporate Risk Management

For firms, Rampini, Sufi, and Viswanathan (2014) find a strong positive correlation between net worth and risk management both in the cross section and within firms over time in data on fuel price risk management by U.S. airlines. Moreover, they document a remarkable drop in fuel price hedging as airlines approach distress which reverses only slowly after distress. Relatedly, the corporate finance literature documents a strong size pattern in risk management, when measured by participation of firms in derivatives markets, among U.S. corporations overall. For example, Nance, Smith, and Smithson (1993) find that firms which do not hedge are smaller, and pay lower dividends, in survey data for large industrial firms. Similarly, Géczy, Minton, and Schrand (1997) find a strong positive relation between derivatives use and firm size among large U.S. firms.<sup>25</sup> The evidence on the relation between corporate risk management and other financial variables in these studies is more mixed (see, for example, Tufano (1996) as well as the aforementioned studies). Nevertheless, the basic pattern for corporate insurance seems to be the same as for households: better financed firms engage in more risk management and poorly financed firms engage at best in limited and typically in no risk management at all.

Many observers find this relation between financing and corporate risk management puzzling. For example, the *Wall Street Journal* writes<sup>26</sup>

“Forward contracts are convenient for small businesses because they generally don’t have any upfront cost, and business owners can lock in a forward contract up to a year ahead. ... Certainly many small companies are still uncomfortable with hedging. Startups, which are generally strapped for resources, typically can’t afford it.”

The statements that hedging does not have any upfront cost, but cash strapped firms cannot afford hedging appear to be inconsistent. In an environment similar to the household finance context analyzed in this paper, Rampini and Viswanathan (2010, 2013)

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<sup>25</sup>Approximately 41% of the firms with exposure to foreign currency risk in their data use currency derivatives and 59% use any type of derivative. Across firm size quartiles, currency derivative use increases from 17% for the smallest quartile to 75% for the largest quartile and the use of any derivatives increases from 33% to 90%; see their table 2.

<sup>26</sup>See the article on “Small Firms Embrace Hedging” on page B5 of the U.S. edition of *The Wall Street Journal* on December 6, 2012.

resolve this apparent inconsistency and argue that firms' financing needs may override their hedging concerns and thus severely constrained firms may abstain from risk management. This is in contrast to received theory, formalized by Froot, Scharfstein, and Stein (1993), which suggests that constrained firms should hedge. The extant results in the literature do not take into account firms' financing needs and the link between financing and risk management induced by collateral constraints, and this literature hence reaches a rather different conclusion.

## 6 Conclusion

An explicit analysis of household risk management is provided in which households have access to complete markets subject to collateral constraints. We show the optimality of increasing household risk management, that is, risk management that increases in household net worth and income, under quite general conditions. Moreover, household risk management is precautionary in the sense that an increase in uncertainty increases risk management. Remarkably, risk aversion alone is sufficient for this result and assumptions on prudence, that is, the third derivative of the utility function, are not required to guarantee this result, in contrast to the classic results on precautionary savings using risk-free assets. Our model also features substantially less asset accumulation than the canonical consumption-savings model with incomplete markets.

Durable goods, most importantly housing, are used as collateral. In the absence of a frictionless rental market, households' demand for the services of consumer durables results in substantial financing needs. We show that if these financing needs are sufficiently strong, they override hedging concerns, which explains the at times complete absence of household risk management. In our view, proposals to introduce new markets providing household risk management tools are hence unlikely to be successful, as households may not use such markets even if they exist.

The fact that household risk management may require collateral in the form of margins has been recognized in the literature, but not explicitly analyzed. For example, Athanasoulis and Shiller (2000) write that “[m]argin requirements might deal with this [collection] problem, but only for people who have sufficient assets as margin. We will disregard these kinds of ... problems.” Our work, in contrast, suggests that collateral constraints, together with households' other financing needs, are at the heart of the explanation why household risk management is limited and key to understanding the basic patterns in household insurance.

## Appendix A: Proofs

**Proof of Proposition 1. Part (i):** Suppose  $\exists \hat{s}' \in S_h$  such that  $\hat{s}' \notin S_{h+}$ . Using (7), (6), the envelope condition, and strict concavity of the value function we have

$$\beta Rv_w(w(\hat{s}'), \hat{s}') = v_w(w, s) > v_w(w_+, s) \geq \beta Rv_w(w_+(\hat{s}'), \hat{s}'),$$

implying, again by strict concavity of the value function, that  $w(\hat{s}') < w_+(\hat{s}')$ . But  $w(\hat{s}') = y(\hat{s}') + h(\hat{s}') > y(\hat{s}') = w_+(\hat{s}')$ , a contradiction.

**Part (ii):** Note that  $w'_+ \geq w'$ ,  $\forall s' \in S$ , implies that  $y' + h'_+ = w'_+ \geq w' = y' + h'$ , that is,  $h'_+ \geq h'$ ,  $\forall s' \in S$ , and hence  $E[h'_+|s] \geq E[h'|s]$ , and, using the envelope condition,  $u_c(c'_+) = v_w(w'_+, s') \leq v_w(w', s') = u_c(c')$ , implying that  $c'_+ \geq c'$ . To see that  $w'_+ \geq w'$ ,  $\forall s' \in S$ , suppose not, that is, suppose  $\exists \hat{s}' \in S$ , such that  $w_+(\hat{s}') < w(\hat{s}')$ , i.e.,  $h_+(\hat{s}') < h(\hat{s}')$ . Proceeding as in part (i), since  $h(\hat{s}') > 0$ ,  $\beta Rv_w(w(\hat{s}'), \hat{s}') = v_w(w, s) > v_w(w_+, s) \geq \beta Rv_w(w_+(\hat{s}'), \hat{s}')$ , implying that  $w_+(\hat{s}') > w(\hat{s}')$ , a contradiction. Finally, for  $s', \hat{s}' \in S_h$ , using (7), (6), and the envelope condition for next period, we have  $\beta Ru_c(c(s')) = v_w(w, s) = \beta Ru_c(c(\hat{s}'))$ , that is,  $c(s') = c(\hat{s}') \equiv c_h$ . By strict concavity of the value and utility function,  $c_h$  is strictly increasing in  $w$  when  $S_h$  is non-empty.  $\square$

**Proof of Proposition 2. Part (i) & (ii)** Define the operator  $T$  as

$$Tv(w, s) \equiv \max_{c, h', w' \in \mathbb{R}_+ \times \mathbb{R}^{2S}} u(c) + \beta E[v(w', s')|s]$$

subject to equations (2) through (4). We show that if  $v$  is a weakly concave function in  $w$  and has the property that  $\forall s, s_+, s_+ > s$ ,

$$\frac{v(\hat{w}, s_+) - v(w, s_+)}{\hat{w} - w} \leq \frac{v(\hat{w}, s) - v(w, s)}{\hat{w} - w}, \quad \forall \hat{w}, w,$$

then  $Tv$  inherits this property. Since the set  $\mathcal{S}$  of bounded, continuous, and weakly concave functions which satisfy the property is closed under the sup norm, the fixed point has the property, too.

Recall that for any concave function, the left and right derivatives exist and denote these by  $v_w^-(w, s)$  and  $v_w^+(w, s)$ , respectively; by concavity,  $v_w^-(w, s) \geq v_w^+(w, s)$ . For  $v \in \mathcal{S}$ ,  $v_w^-(w, s'_+) \leq v_w^-(w, s')$  and  $v_w^+(w, s'_+) \leq v_w^+(w, s')$ . Let the set  $\mathcal{S}^o$  of bounded, continuous, strictly concave, and differentiable functions which satisfy the property that  $\forall s', s'_+, s'_+ > s'$ ,  $v_w(w, s'_+) \leq v_w(w, s')$ ,  $\forall w$ . The set  $\mathcal{S}^o$  is not a closed set under the sup norm, but  $\mathcal{S}^o \subset \mathcal{S}$ . We show that  $T(\mathcal{S}) \subset \mathcal{S}^o \subset \mathcal{S}$  and use Corollary 1 to Theorem 3.2 of Stokey, Lucas with Prescott (1989) to conclude that  $v = Tv \in \mathcal{S}^o$ .

Using an argument similar to the proof of Theorem 9.8 in Stokey, Lucas with Prescott (1989), one can show that  $Tv(w, s)$  is strictly concave and using Benveniste and Scheinkman (1979)  $Tv(w, s)$  is differentiable (see footnote 6). Suppose  $v \in \mathcal{S}$ . For given  $w$  and  $s$ , suppose  $\exists s'_+ > s'$  such that  $h(s'_+) > h(s')$ . Note that the first order condition with respect to  $h'$  can be written as  $Tv_w(w, s) \geq \beta Rv_w^-(w', s')$  if  $h' = 0$  and  $Tv_w(w, s) \in [\beta Rv_w^+(w', s'), \beta Rv_w^-(w', s')]$  if  $h' > 0$ . Then  $\beta Rv_w^-(w(s'_+), s'_+) \geq v_w(w, s) \geq \beta Rv_w^-(w(s'), s')$ , implying, given the assumed property, that  $w(s'_+) \leq w(s')$ . But  $w(s'_+) = y(s'_+) + h(s'_+) >$

$y(s') + h(s') = w(s')$ , a contradiction. Therefore,  $h(s'_+) \leq h(s')$ ,  $\forall s'_+ > s'$ , that is, the household hedges lower income realizations (weakly) more. Hence, the household hedges a lower set of states, if at all.

Denote the set of states that the household hedges by  $S_h \equiv \{s' \in S : h(s') > 0\}$ . Take  $s_+ > s$  and let  $S_{h+}$  be associated with  $s_+$  (and similarly for other variables). Suppose  $\exists s_+ > s$ , such that  $Tv_w(w, s_+) > Tv_w(w, s)$  and, using the envelope condition,  $c_+ < c$ . Since  $h'$  is decreasing in  $s'$ , FOSD implies that  $E[h'|s] \geq E[h'|s_+]$  and hence (2) implies that the solution at  $s$ ,  $\{c, h', w'\}$ , is feasible at  $s_+$ . Since we assumed that  $c_+ < c$ , there must exist an  $\hat{s}' \in S$  such that  $h_+(\hat{s}') > h(\hat{s}')$  since otherwise the household would not spend all its net worth. Using the first order condition stated above and the envelope condition, we have

$$Tv_w(w, s_+) \leq \beta Rv_w^-(w_+(\hat{s}'), \hat{s}') \leq \beta Rv_w^+(w(\hat{s}'), \hat{s}') \leq \beta Rv_w^+(w(\hat{s}'), s') \leq Tv_w(w, s),$$

a contradiction. Thus  $Tv$  inherits the property that  $\forall s, s_+, s_+ > s, Tv_w(w, s_+) \leq Tv_w(w, s)$ ; moreover,  $Tv(w, s)$  is a strictly concave differentiable function, and hence  $T(\mathcal{S}) \subset \mathcal{S}^o \subset \mathcal{S}$ .

As a corollary of Proposition 1,  $w', h', S_h$ , and  $c_h$  are increasing in  $w$  given  $s$ ,  $\forall s' \in S$ . To see that  $S_h$  is increasing in  $s$  given  $w$ , take  $s_+ > s$  and suppose instead that  $\exists \hat{s}'$  such that  $h(\hat{s}') > 0$  but  $h_+(\hat{s}') = 0$ . Then  $\beta Rv_w(y(\hat{s}'), \hat{s}') \leq v_w(w, s_+) \leq v_w(w, s) = \beta Rv_w(w(\hat{s}'), \hat{s}')$  which implies  $w(\hat{s}') \leq y(\hat{s}')$ , contradicting  $w(\hat{s}') = y(\hat{s}') + h(\hat{s}') > y(\hat{s}')$ . Thus, any state that the household hedges at  $s$ , the household hedges at  $s_+ > s$ , that is,  $S_h$  is increasing in  $s$ . If the household hedges  $s'$  at  $s_+$  but not at  $s$ , then clearly  $w'_+ > w'$  and  $h'_+ > h'$ . If the household hedges  $s'$  at both  $s_+$  and  $s$ , then  $\beta Rv_w(w'_+, s') = v_w(w, s_+) \leq v_w(w, s) = \beta Rv_w(w', s')$  and hence  $w'_+ \geq w'$  and  $h'_+ \geq h'$ . Thus,  $w'$  and  $h'$  are increasing in  $s$ . Moreover, since  $w'$  is increasing in  $s$ , the envelope condition for next period  $v_w(w', s') = u_c(c')$  implies that  $c'$ , and  $c_h$ , are increasing in  $s$  as well.

**Part (iii):** Take  $w_+ > w$  and denote with a subscript  $+$  the optimal policy associated with  $w_+$ . Let  $\tilde{w}' \equiv w' - E[w']$ ,  $\tilde{w}_h \equiv w_h - E[w']$ , (and  $\tilde{y}' = y' - E[w']$ ), and analogously for  $\tilde{w}'_+$ ,  $\tilde{w}_{h+}$ , and  $\tilde{y}'_+$ . We need to show that  $var(\tilde{w}'_+) \leq var(\tilde{w}')$ . Note that  $\tilde{w}' = \max\{\tilde{w}_h, \tilde{y}'\}$  and analogously for  $\tilde{w}'_+$ . If  $\tilde{w}_{h+} = \tilde{w}_h$ , then  $\tilde{w}'_+ = \tilde{w}'$  and the result is obvious. Assume instead that  $\tilde{w}_{h+} > \tilde{w}_h$ , w.l.o.g., and hence  $E[w'_+] > E[w']$ . Moreover,  $\tilde{w}'_+ < \tilde{w}'$ ,  $\forall s' \in S$  such that  $\tilde{w}' > 0$  and  $E[\tilde{w}'_+|\tilde{w}'_+ > 0] < E[\tilde{w}'|\tilde{w}' > 0]$ . Let  $\hat{\tilde{w}}'_+ \equiv \max\{\tilde{w}'_+, 0\}$ ,  $\forall s' \in S$  such that  $\tilde{w}' > 0$  and  $\hat{\tilde{w}}'_+ \equiv \max\{\hat{\tilde{w}}_h, \tilde{y}'\}$  otherwise, where  $\hat{\tilde{w}}_h$  such that  $E[\hat{\tilde{w}}'_+] = 0$ . Note that  $\exists \hat{\tilde{w}}_h \in (\tilde{w}_h, \tilde{w}_{h+}]$  since  $E[\tilde{w}'|\tilde{w}' > 0] > E[\tilde{w}'_+|\tilde{w}'_+ > 0] = E[\hat{\tilde{w}}'_+|\tilde{w}' > 0]$  and thus  $E[\tilde{w}'_+|\tilde{w}'_+ \leq 0] = E[\hat{\tilde{w}}'_+|\tilde{w}' \leq 0] > E[\tilde{w}'|\tilde{w}' \leq 0]$ . Since  $|\hat{\tilde{w}}'_+| \leq |\tilde{w}'|$ ,  $\forall s' \in S$ , with strict inequality for some  $s' \in S$ ,  $var(\hat{\tilde{w}}'_+) < var(\tilde{w}')$ . Moreover,  $E[\hat{\tilde{w}}'_+ - \tilde{w}'_+] = 0$  and  $\hat{\tilde{w}}'_+$  is a mean preserving spread of  $\tilde{w}'_+$ , that is,  $var(\tilde{w}'_+) < var(\hat{\tilde{w}}'_+) < var(\tilde{w}')$ . Moreover, consumption  $c$  is monotone and strictly increasing in net worth  $w$ .  $\square$

**Proof of Proposition 3.** Let  $\bar{\mathcal{S}}$  be the set of bounded, continuous, and weakly concave functions and  $\bar{\mathcal{S}}^o$  be the set of bounded, continuous, strictly concave, and differentiable functions. Using a proof similar to that in Proposition 2 and defining the operator  $T$

analogously, we conclude that  $T(\bar{S}) \subset \bar{S}^o \subset \bar{S}$  so  $v \in \bar{S}^o$ , and similarly for  $\tilde{v}$  (using  $\tilde{T}$ ), which denotes the value function (and operator, respectively) associated with  $\tilde{\pi}(s')$ .

Consider some  $\hat{v} \in \bar{S}^o$ . We show that if  $\tilde{T}^n \hat{v}_w(w) \geq T^n \hat{v}_w(w)$ , then  $\tilde{T}^{n+1} \hat{v}_w(w) \geq T^{n+1} \hat{v}_w(w)$ , which in turn implies that the value functions  $v$  and  $\tilde{v}$  satisfy  $\tilde{v}_w(w) \geq v_w(w)$ ,  $\forall w$ , too. Suppose that  $\tilde{T}^n \hat{v}_w(w) \geq T^n \hat{v}_w(w)$ , but that  $\tilde{E}[\tilde{h}'] < E[h']$ , which, from the budget constraint, implies that  $\tilde{c} > c$ . Moreover,  $S_h \neq \emptyset$  and using the first order condition with respect to  $h$  and the envelope condition we have

$$\begin{aligned} \beta R u_c(c_h) = \beta R T^n \hat{v}_w(w_h) &= T^{n+1} \hat{v}_w(w) = u_c(c) \\ &> u_c(\tilde{c}) = \tilde{T}^{n+1} \hat{v}_w(\tilde{w}_h) = \beta R \tilde{T}^n \hat{v}_w(\tilde{w}_h) = \beta R u_c(\tilde{c}_h), \end{aligned}$$

and therefore  $\tilde{c}_h > c_h$ . Further,  $\tilde{T}^n \hat{v}_w(\tilde{w}_h) = u_c(\tilde{c}_h) < u_c(c_h) = T^n \hat{v}_w(w_h)$ , which in turns implies that  $\tilde{w}_h > w_h$ . Then, since  $\max\{\cdot, 0\}$  is convex,

$$E[h'] = E[\max\{w_h - y', 0\}] < E[\max\{\tilde{w}_h - y', 0\}] \leq \tilde{E}[\max\{\tilde{w}_h - y', 0\}] = \tilde{E}[\tilde{h}'],$$

a contradiction. Hence,  $\tilde{E}[\tilde{h}'] \geq E[h']$ , which implies that  $\tilde{c} \leq c$  and  $(\tilde{T}^{n+1} \hat{v})_w(w) = u_c(\tilde{c}) \geq u_c(c) = (T^{n+1} \hat{v})_w(w)$ , so the value function  $\tilde{T}^{n+1} \hat{v}$  and  $T^{n+1} \hat{v}$  satisfy the property, too.  $\square$

**Proof of Corollary 1.** The fact that  $\tilde{c} \leq c$  is an immediate consequence of Proposition 3. To see that  $\tilde{c}' \leq c'$ , suppose not, that is, suppose  $\exists \hat{s}'$  such that  $\tilde{c}(\hat{s}') > c(\hat{s}')$ , which can only be true if  $\tilde{w}(\hat{s}') > w(\hat{s}')$  and therefore  $\tilde{h}(\hat{s}') > 0$ . But then

$$\beta R u_c(\tilde{c}(\hat{s}')) = u_c(\tilde{c}) \geq u_c(c) \geq \beta R u_c(c(\hat{s}')),$$

which in turn implies that  $\tilde{c}(\hat{s}') \leq c(\hat{s}')$ , a contradiction.

Proceeding analogously, suppose  $\exists \hat{s}''$  such that  $\tilde{c}(\hat{s}'') > c(\hat{s}'')$ , which can only be true if  $\tilde{w}(\hat{s}'') > w(\hat{s}'')$  and therefore  $\tilde{h}(\hat{s}'') > 0$ . But then

$$\beta R u_c(\tilde{c}(\hat{s}'')) = u_c(\tilde{c}(\hat{s}')) \geq u_c(c(\hat{s}')) \geq \beta R u_c(c(\hat{s}')),$$

where  $s'$  is the state preceeding  $\hat{s}''$  and where we used the fact that  $\tilde{c}' \leq c'$ ,  $\forall s' \in S$ . This in turn implies that  $\tilde{c}(\hat{s}'') \leq c(\hat{s}'')$ , a contradiction. By induction,  $\tilde{c}(s^t) \leq c(s^t)$  for any subsequent history  $s^t$  and time  $t$ .  $\square$

**Proof of Proposition 4. Part (i):** Using (6) and the envelope condition, equation (7) evaluated at  $w = \underline{y}$  and  $s = \underline{s}$  implies that  $\beta R \lambda(\underline{s}') = v_w(\underline{y}, \underline{s}) - \beta R v_w(w(\underline{s}'), \underline{s}') \geq (1 - \beta R) v_w(\underline{y}, \underline{s}) > 0$  where we used the fact that  $w(\underline{s}') \geq \underline{y}$ . But then Part (ii) of Proposition 2 implies that  $S_h = \emptyset$ .

**Part (ii):** At net worth  $w = \bar{y}$ , using (7) and the envelope condition, we have  $v_w(\bar{y}, s) = \beta R v_w(w(\bar{s}'), \bar{s}') + \beta R \lambda(\bar{s}')$  which implies that  $\lambda(\bar{s}') > 0$  since  $w(\bar{s}') \geq \bar{y}$  and hence, by strict concavity of  $v$  and the fact that  $v_w(w, s)$  is decreasing in  $s$  (see Part (i) of Proposition 2),  $\beta R \lambda(\bar{s}') = v_w(\bar{y}, s) - \beta R v_w(w(\bar{s}'), \bar{s}') \geq (1 - \beta R) v_w(\bar{y}, s) > 0$ .  $\square$

**Proof of Proposition 5. Part (i):** The proof proceeds analogously to the proof of Part (i) of Proposition 2.

$$Tv(w, s) \equiv \max_{c, h, w' \in \mathbb{R}_+ \times \mathbb{R}^{S+1}} u(c) + \beta E[v(w', s')|s]$$

subject to equations (9) through (11). Define the sets  $\mathcal{S}$  and  $\mathcal{S}^o$  as before. We show that  $T(\mathcal{S}) \subset \mathcal{S}^o \subset \mathcal{S}$  and hence  $v \in \mathcal{S}^o$  has the required property.

Suppose that  $v \in \mathcal{S}$ , but that  $\exists s_+ > s$ , such that  $Tv_w(w, s_+) > Tv_w(w, s)$ , that is  $Tv \notin \mathcal{S}^o$ . Using the envelope condition,  $c_+ < c$  which implies, using the budget constraint (9), that  $h_+ > h$  and  $w'_+ = y' + h_+ > y' + h = w$ ,  $\forall s' \in S$ . The Euler equation for savings can be written as

$$\begin{aligned} Tv_w(w, s) &\geq \beta RE[v_w^-(w', s')|s] \geq \beta RE[v_w^+(w', s')|s] \quad \text{if } h = 0 \\ Tv_w(w, s) &\in [\beta RE[v_w^+(w', s')|s], \beta RE[v_w^-(w', s')|s]] \quad \text{if } h > 0. \end{aligned} \quad (28)$$

Using (28) and the envelope condition, we have

$$\beta RE[v_w^-(w'_+, s')|s_+] \geq Tv_w(w, s_+) > Tv_w(w, s) \geq \beta RE[v_w^+(w', s')|s].$$

However, since  $w'_+ > w'$ ,  $\forall s' \in S$ , and given FOSD, we also have that

$$E[v_w^+(w', s')|s] \geq E[v_w^+(w', s')|s_+] > E[v_w^-(w'_+, s')|s_+],$$

a contradiction. Therefore,  $Tv \in \mathcal{S}^o$ .

**Part (ii):** Since  $v \in \mathcal{S}^o$  by part (i), it is differentiable and  $v_w(w, s)$  is decreasing in  $s$ . Suppose that, given  $s$ ,  $w_+ > w$  and  $h_+ < h$ , then

$$u_c(c) = v_w(w, s) = \beta RE[v_w(w', s')|s] < \beta RE[v_w(w'_+, s')|s] \leq v_w(w_+, s) = u_c(c_+),$$

whereas  $c_+ > c$  implies that  $u_c(c_+) < u_c(c)$ , a contradiction. Thus,  $h$  is increasing in  $w$  given  $s$ .

Let  $s_+ > s$  and suppose that  $h_+ > h$  for given  $w$ . Then  $c_+ < c$  and  $w'_+ > w'$ ,  $\forall s' \in S$ . Then

$$u_c(c) < u_c(c_+) = v_w(w, s_+) = \beta RE[v_w(w'_+, s')|s_+] < \beta RE[v_w(w', s')|s_+] \leq \beta RE[v_w(w', s')|s]$$

since  $v_w(w, s)$  is decreasing in  $s$  by part (i) and  $w'$  is increasing in  $s'$ , contradicting (28). So for  $s_+ > s$ ,  $h_+ \leq h$  and thus  $w'_+ \leq w'$ . Moreover, using the envelope condition,  $u_c(c') = v_w(w', s') \leq v_w(w'_+, s') = u_c(c'_+)$  and thus  $c'_+ \leq c'$ .  $\square$

**Proof of Proposition 6. Part (i):** Suppose  $u_c(c)$  is (weakly) convex. Take  $w_0, w_1 > w_0$ , and  $\varphi \in (0, 1)$ , and define  $w_\varphi \equiv (1 - \varphi)w_0 + \varphi w_1$  and analogously for other variables. Consider operator  $T$  defined analogously to the one in the proof of Proposition 5. By the same argument,  $\mathcal{S}^o \subset \mathcal{S}$  and we can restrict our attention to functions in  $\mathcal{S}^o$ . Assume that savings are strictly positive at  $w_0$  and note that this implies that they are strictly

positive at  $w_1$  and indeed for any  $w \geq w_0$  as savings are increasing in  $w$  by part (ii) of Proposition 5. From the first order condition for savings we have

$$Tv_w(w_0) = u_c(w_0 - R^{-1}h_0) = \beta RE[v_w(y' + h_0)]$$

and analogously for  $h_1$  at  $w_1$  and  $h(w_\varphi)$  at  $w_\varphi$ . Suppose  $v \in \mathcal{S}^o$  and  $v_w(w)$  is convex,  $\forall w \in \mathbb{R}_+$ , but that  $Tv_w(w)$  is not convex, that is,

$$\begin{aligned} u_c(w_\varphi - R^{-1}h(w_\varphi)) &= Tv_w(w_\varphi) > (1 - \varphi)Tv_w(w_0) + \varphi Tv_w(w_1) \\ &= (1 - \varphi)u_c(w_0 - R^{-1}h_0) + \varphi u_c(w_1 - R^{-1}h_1) \geq u_c(w_\varphi - R^{-1}h_\varphi), \end{aligned}$$

and, thus,  $h(w_\varphi) > h_\varphi$ . But then, using the fact that  $v_w(w)$  is convex, we have

$$(1 - \varphi)E[v_w(y' + h_0)] + \varphi E[v_w(y' + h_1)] \geq E[v_w(y' + h_\varphi)] > E[v_w(y' + h(w_\varphi))]$$

and combining the two results,  $Tv_w(w_\varphi) > \beta RE[v_w(y' + h(w_\varphi))]$ , a contradiction. When savings are zero at  $w_1$ , then  $Tv_w(w) = u_c(w)$  in the relevant range which is convex by assumption. Let  $w^* = \inf_w \{h > 0\}$ . The above shows that  $Tv_w(w)$  is convex on  $[0, w^*]$  and  $[w^*, \infty)$ . Next we consider the case where  $w_0 < w^* < w_1$ .

Note that for  $w \leq w^*$ ,  $Tv_w(w) = u_c(w)$ , and for  $w > w^*$ ,  $c < w$  as  $h > 0$  and hence  $Tv_w(w) = u_c(c) > u_c(w)$ . First, consider  $\varphi \in (0, 1)$  such that  $w_\varphi \equiv (1 - \varphi)w_0 + \varphi w_1 \leq w^*$ ; then

$$(1 - \varphi)Tv_w(w_0) + \varphi Tv_w(w_1) > (1 - \varphi)u_c(w_0) + \varphi u_c(w_1) \geq u_c(w_\varphi) = Tv_w(w_\varphi).$$

If instead  $w_\varphi > w^*$ , then define  $\varphi^*$  and  $\hat{\varphi}$  implicitly by  $w^* = (1 - \varphi^*)w_0 + \varphi^*w_1$  and  $w_\varphi = (1 - \hat{\varphi})w^* + \hat{\varphi}w_1$ , which implies that  $\varphi = (1 - \hat{\varphi})\varphi^* + \hat{\varphi}$ ; then by the previous argument

$$(1 - \varphi^*)Tv_w(w_0) + \varphi^*Tv_w(w_1) > Tv_w(w^*)$$

and hence

$$\begin{aligned} (1 - \varphi)Tv_w(w_0) + \varphi Tv_w(w_1) &= (1 - \hat{\varphi})[(1 - \varphi^*)Tv_w(w_0) + \varphi^*Tv_w(w_1)] + \hat{\varphi}Tv_w(w_1) \\ &> (1 - \hat{\varphi})Tv_w(w^*) + \hat{\varphi}Tv_w(w_1) \geq Tv_w(w_\varphi), \end{aligned}$$

where the last inequality follows from the convexity above  $w^*$ . Therefore,  $Tv_w(w)$  is convex with strict convexity at  $w^*$ .

We already know that  $v \in \mathcal{S}^o$  and for any  $\hat{v} \in \mathcal{S}^o$ ,  $T^n \hat{v} \rightarrow v$ . But by above if we start with  $\hat{v}$  such that  $\hat{v}_w(w, s)$  is convex, then  $T^n \hat{v}$  is convex; moreover,  $T^n \hat{v}_w(w, s) = u_c(\hat{c})$  and the policy function converges, and hence so does the marginal value of net worth. Thus,  $v_w(w, s)$  is convex, too.

**Part (ii):** Define  $\tilde{\mathcal{S}}$  and  $\tilde{\mathcal{S}}^o$  as in the proof of Proposition 3. Define the operator  $T$  as in the proof of Proposition 5 and define the operator  $\tilde{T}$  associated with  $\tilde{\pi}(s')$  analogously. Proceeding along the lines of the proof of part (i) of Proposition 5, one can show that  $T(\tilde{\mathcal{S}}) \subset \tilde{\mathcal{S}}^o \subset \tilde{\mathcal{S}}$  and analogously for  $\tilde{T}$ .

Pick  $\hat{v} \in \bar{\mathcal{S}}^o$  such that  $\hat{v}_w(w)$  is convex. We show that if  $\tilde{T}^n \hat{v}_w(w) \geq T^n \hat{v}_w(w)$ , then  $\tilde{T}^{n+1} \hat{v}_w(w) \geq T^{n+1} \hat{v}_w(w)$ . Suppose that  $\tilde{T}^n \hat{v}_w(w) \geq T^n \hat{v}_w(w)$ , but that  $\tilde{h} < h$ , and hence  $\tilde{c} > c$  and  $\tilde{w}' < w'$ . Using the first order condition for savings, we have

$$u_c(c) = E[\beta R T^n v_w(y' + h)] \leq \tilde{E}[\beta R T^n v_w(\tilde{y}' + h)] < \tilde{E}[\beta R \tilde{T}^n v_w(\tilde{w}')] \leq u_c(\tilde{c}),$$

and thus  $c > \tilde{c}$ , a contradiction. Thus,  $\tilde{h} \geq h$ ,  $\tilde{c} \leq c$ , and  $\tilde{T}^{n+1} \hat{v}_w(w) \geq T^{n+1} \hat{v}_w(w)$ .

Since  $T^n \hat{v} \rightarrow v$  and  $T^n \hat{v}_w(w, s) = u_c(c)$  (and analogously for  $\tilde{T} \hat{v}$ ), and the policy functions converge, the value functions  $v$  and  $\tilde{v}$  satisfy the property, too.  $\square$

**Proof of Proposition 7. Part (i):** We first argue that levels of net worth below  $\underline{y}$  and above  $w_{bnd}(s)$ ,  $\forall s \in S$ , defined below, are transient. Using (3) which holds with equality and (4) we have  $w' \geq y' \geq \underline{y}$  and hence levels of net worth below  $\underline{y}$  are transient,  $\forall s \in S$ . Using part (ii) of Proposition 4,  $\forall w \leq \bar{y}$ ,  $\lambda(\bar{s}') > 0$ ,  $\forall s \in S$ . Suppose  $S_h = \emptyset$  at  $(\bar{y}, \bar{s})$ , then since hedging is increasing,  $S_h = \emptyset$ ,  $\forall (w, s)$  with  $w \leq \bar{y}$ . Therefore, once  $w \leq \bar{y}$ , net worth never exceeds  $\bar{y}$  again. Suppose  $S_h \neq \emptyset$  at  $(\bar{w}, \bar{s})$ ; then  $v_w(\bar{y}, \bar{s}) = \beta R v_w(w', s')$ ,  $\forall s' \in S_h$ , and let  $w_{bnd}(s')$  solve this equation  $\forall s' \in S_h$ . Moreover, define  $w_{bnd}(s') = y(s')$ ,  $\forall s' \in S \setminus S_h$ . By part (i) of Proposition 2,  $v_w(w', s')$  is decreasing in  $s'$  and hence  $w_{bnd}(s')$  is decreasing in  $s'$ ,  $\forall s' \in S_h$ , and  $w_{bnd}(\underline{s}') = \max_{s' \in S_h} w_{bnd}(s')$ . Note that for any  $s \in S$ ,  $\forall w \leq w_{bnd}(s)$ ,  $w' \leq w_{bnd}(s')$ ,  $\forall s' \in S$ . To see this, suppose instead that  $\exists \hat{s}'$  such that  $w' > w_{bnd}(\hat{s}')$ . If  $w \leq \bar{y}$ , both  $w$  and  $s$  are smaller than or equal  $\bar{y}$  and  $\bar{s}$ , respectively, and the fact that  $w'$  is increasing in  $w$  and  $s$  (see part (ii) of Proposition 2) implies  $w' \leq w_{bnd}(\hat{s}')$ , a contradiction. Therefore,  $w > \bar{y}$  and  $w_{bnd}(s) > y(s)$ ; moreover,

$$\begin{aligned} v_w(w_{bnd}(s), s) &\leq v_w(w, s) = \beta R v_w(w', s') + \beta R \lambda(\hat{s}') < \beta R v_w(w_{bnd}(\hat{s}'), \hat{s}') \\ &\leq v_w(\bar{y}, \bar{s}) = \beta R v_w(w_{bnd}(s), s) < v_w(w_{bnd}(s), s), \end{aligned}$$

a contradiction. Thus, for any  $s \in S$ , once  $w \leq w_{bnd}(s)$ ,  $w' \leq w_{bnd}(s')$ ,  $\forall s' \in S$ , and let  $w_{bnd} = \max\{\bar{y}, w_{bnd}(\underline{s}')\}$ .

To show that net worth levels above  $w_{bnd}$  are transient, suppose net worth  $w(s_t)$  at time  $t$  in state  $s_t$  is such that  $w(s_t) > w_{bnd}$ . Any path which reaches a state  $s_{t+n}$  against which the household is constrained at time  $t+n$  results in a household net worth  $w(s_{t+n}) = y(s_{t+n}) \leq \bar{y}$  and indeed net worth is bounded above by  $w_{bnd}$  from then onwards. Consider a path along which the household is never constrained; since  $v_w(w, s) = \beta R v_w(w', s')$  along such a path,  $\exists n < \infty$ , such that  $v_w(w_{t+n}, s_{t+n}) = (\beta R)^{-n} v_w(w_t, s_t) > v_w(\bar{y}, s_{t+n})$  and hence again  $w_{t+n} < \bar{y}$  at time  $t+n$  and net worth is less than  $w_{bnd}$  thereafter.

To prove that the existence of a unique stationary distribution, define  $Z^*$  as the set of  $(w, s)$  such that either  $(w, s) = (y(s), s)$ , any  $s \in S$ , or for any  $\hat{s} \in S$ ,  $s \in S$ ,  $(w, s)$  solves  $v_w(y(\hat{s}), \hat{s}) = (\beta R)^n v_w(w, s)$ , for  $n \geq 1$ , and  $w \geq y(s)$ . Let  $Z \equiv \cup_{s \in S} ([\underline{y}, w_{bnd}(s)] \times \{s\})$ . For any  $z = (w, s) \in Z$ ,  $v_w(w, s) \geq \beta R v_w(y(\bar{s}) = \bar{y}, \bar{s})$ , as the household does not hedge the highest state. So  $\forall z \in Z$ ,  $P(z, (\bar{y}, \bar{s})) > 0$ , where  $P(z, z')$  is the induced transition function, and hence  $(\bar{y}, \bar{s})$  is a consequent  $\forall z \in Z$ . Next we show that  $(\bar{y}, \bar{s})$  is recurrent, and indeed that all  $z \in Z^*$  are recurrent, whereas all  $z \in Z \setminus Z^*$  are transient. For  $(\bar{y}, \bar{s})$  pick  $s \in S$  and solve for  $v_w(\bar{y}, \bar{s}) = (\beta R)^n v_w(w, s)$  for each  $n \geq 1$  such that  $w \geq y(s)$ . Each such  $(w, s) \in Z^*$  is a consequent of  $(\bar{y}, \bar{s})$  and so is  $(y(s), s)$ ,  $\forall s \in S$ ,

since the household stops hedging state  $s$  in state  $s$  after a finite  $n$ . Hence for each  $\hat{s}$ ,  $(y(\hat{s}), \hat{s})$ ,  $\forall s \leq \hat{s}$ , solve for  $v_w(\hat{y}, \hat{s}) = (\beta R)^n v_w(w, s)$ , for each  $n \geq 1$ , such that  $w \geq y(s)$ . Each such  $(w, s) \in Z^*$  is a consequent of  $(y(s), s)$  and hence of  $(\bar{y}, \bar{s})$ . Hence,  $\forall z \in Z^*$ ,  $P((\bar{y}, \bar{s}), z) > 0$ , that is, all  $z \in Z^*$  are consequent for  $(\bar{y}, \bar{s})$ . Therefore,  $(\bar{y}, \bar{s})$  is recurrent and so are all  $z \in Z^*$ . In contrast, for any  $z \in Z \setminus Z^*$ ,  $(\bar{y}, \bar{s})$  is a consequent of  $z$  but not vice versa, that is,  $P((\bar{y}, \bar{s}), z) = 0$  for  $z \in Z \setminus Z^*$ , and such  $z$  are transient. Since  $P(z, (\bar{y}, \bar{s})) \geq \min_{s \in S} \Pi(s, \bar{s}) > 0$ , Theorem 11.2 in Stokey and Lucas with Prescott (1989) implies that there exists a unique invariant distribution. For each  $z \in Z^*$ , define  $\varepsilon_z = \min_{\hat{z} \in Z^*} P(\hat{z}, z)$  and note that  $\varepsilon_{(\bar{y}, \bar{s})} = \min_{s \in S} \Pi(s, \bar{s}) > 0$ . Hence, let  $\varepsilon = \sum_{z \in Z^*} \varepsilon_z \geq \varepsilon_{(\bar{y}, \bar{s})} > 0$ . Theorem 11.4 in Stokey and Lucas with Prescott (1989) implies that there exists a unique ergodic set with no cyclically moving subsets and the rate of convergence is geometric.

**Part (ii):** See the proof of part (i) for a proof that net worth levels below  $\underline{y}$  and above  $w_{bnd}$  are transient. When  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ , denote the net worth at the upper bound of the stationary distribution by  $w_{bnd}$  and using (7) and the envelope condition, we have  $v_w(w_{bnd}) = \beta R v_w(w_{bnd}) + \beta R \lambda(\bar{s}')$ , implying that  $\lambda(\bar{s}') > 0$  and hence since  $w'$  is weakly increasing in  $w$  and  $s'$ ,  $w_{bnd} = w(\bar{s}') = \bar{y}$ .

**Part (iii):** Household risk management is increasing by Proposition 1. Household risk management is incomplete with probability 1 since the stationary distribution of net worth is bounded above by  $w_{bnd}$  and at  $w_{bnd}(s)$  for  $s \in S_h$  we have  $w_{bnd}(s) > y(s)$  and

$$\begin{aligned} v_w(w_{bnd}(s), s) &= \beta R v_w(w(\bar{s}'), \bar{s}') + \beta R \lambda(\bar{s}') \\ &\leq \beta R v_w(\bar{y}, \bar{s}') + \beta R \lambda(\bar{s}') = (\beta R)^2 v_w(w_{bnd}(s), s) + \beta R \lambda(\bar{s}') \end{aligned}$$

implying that  $\lambda(\bar{s}') > 0$ , and at  $w_{bnd}(s)$  for  $s \in S \setminus S_h$  we have  $w_{bnd}(s) = y(s)$  and

$$v_w(\bar{y}, \bar{s}) \leq v_w(w_{bnd}(s), s) = \beta R v_w(w(\bar{s}'), \bar{s}') + \beta R \lambda(\bar{s}') \leq \beta R v_w(\bar{y}, \bar{s}') + \beta R \lambda(\bar{s}')$$

and again  $\lambda(\bar{s}') > 0$ . Therefore, since risk management is increasing,  $\lambda(\bar{s}') > 0$  for all  $w \leq w_{bnd}(s)$ ,  $\forall s \in S$ . By Part (i) of Proposition 4, risk management is completely absent at  $\underline{w} = \underline{y}$  and  $\underline{s}$ ; by continuity,  $\exists \varepsilon > 0$  such that for  $w > \underline{w}$  with  $|w - \underline{w}| < \varepsilon$ ,  $v_w(w, \underline{s}) > \beta R v_w(\underline{y}, \underline{s})$ , which means that the household does not hedge at all in this neighborhood. Clearly,  $w = \bar{y}$  has positive probability under the stationary distribution since household income  $\bar{y}$  has positive probability under the stationary distribution of income. If the household does not hedge  $\underline{s}'$  at  $\bar{y}$ , then  $\underline{w}$  has strictly positive probability. Consider instead a path along which the household continues to hedge the lowest income realization the following period, then  $\exists n < \infty$  such that  $v_w(w_{t+n}, s_{t+n}) = (\beta R)^{-n} v_w(\bar{y}, \bar{s}) > v_w(\underline{y}, s_{t+n})$  and hence  $w_{t+n} < \underline{y}$ , which is not possible. So the household must stop hedging the lowest state after a finite sequence of lowest income realizations, that is, the household does not hedge at all with positive probability under the stationary distribution.  $\square$

**Proof of Proposition 8. Part (i):** From equation (7) and the envelope condition that  $v_w(w, s) = v_w(w', s') + \lambda'$  and therefore  $v_w(w, s)$  is non-increasing. Consider the marginal value of net worth at the upper bound of the stationary distribution for some state  $s$ ,  $v_w(\bar{w}(s), s)$ ; suppose there exists some state, say, w.l.o.g., next period, such that

$v_w(\bar{w}(s), s) > v_w(w', s')$ . But  $v_w(w', s') \geq v_w(w'', s'')$ ,  $\forall s'' \in S$ , including  $s'' = s$ . But then, by concavity,  $v_w(\bar{w}(s), s) \leq v_w(w'', s)$ , a contradiction. Thus,  $v_w(w, s) = v_w(w', s')$ ,  $\forall (w, s), (w', s')$  in the support of the stationary distribution.

**Part (ii):** We first prove that as  $\beta \nearrow R^{-1}$ ,  $p^*(\beta) \rightarrow p^*(R^{-1})$ . From the proof of Proposition 7 and Theorem 11.4 in Stokey and Lucas with Prescott (1989), we know that

$$\|p_0 P(\beta)^k - p^*(\beta)\|_\Delta \leq (1 - \varepsilon)^k \|p_0 - p^*(\beta)\|_\Delta \leq (1 - \varepsilon)^k 2,$$

where  $p_0$  and  $p^*(\beta)$  are defined in the proof of Proposition 7 and  $\|\cdot\|_\Delta$  denotes the total variation norm, and we use the fact that the total variation norm is bounded by 2. Note that  $\varepsilon = \varepsilon_{(\bar{y}, \bar{s})}$  does not depend on  $\beta$ .

Let  $\delta_n > 0$ ,  $\delta_n \searrow 0$ . Given  $\delta_n$ , there exists  $k_n$  such that  $\|p_0 P(\beta)^{k_n} - p^*(\beta)\|_\Delta < \delta_n/2$ ,  $\forall \beta$ . Further, pick  $\beta_n$  such that  $\forall \beta > \beta_n$ ,

$$v_w^\beta(\bar{y}, \bar{s}) = (\beta R)^l v_w^\beta(w_l^\beta(s), s), w_l^\beta(s) \geq y(s), \text{ and } |w_l^\beta(s) - w^*(s)| < \delta_n, 1 \leq l \leq k_n, \forall s \neq \bar{s},$$

where  $v_w^{R^{-1}}(\bar{y}, \bar{s}) = v_w^{R^{-1}}(w^*(s), s)$ ,  $\forall s \neq \bar{s}$ . Note that by continuity of the optimal policy in  $\beta$  we can ensure that there is such a  $\beta_n$ . Essentially, for all  $\beta > \beta_n$ , the household hedges all states (except the highest one) for the first  $k_n$  periods.

Define  $H_n(\beta) = \{z \in Z^*(\beta) | p_0 P(\beta)^{k_n}(z) > 0\}$ ,  $R_n(\beta) = \{z \in Z^*(\beta) | p_0 P(\beta)^{k_n}(z) = 0\} = Z^*(\beta) \setminus H_n(\beta)$ , and  $H_n(\beta, s) = \{z \in Z^*(\beta) | z = (w_l^\beta(s), s), 1 \leq l \leq k_n\}$ ,  $\forall s \neq \bar{s}$ , and  $H_n(\beta, \bar{s}) = \{(\bar{y}, \bar{s})\}$ . By construction, we have  $p_0 P(\beta)^{k_n}(H_n(\beta, s)) = p_0 P(R^{-1})^{k_n}(\{(w^*(s), s)\})$  and  $p_0 P(\beta)^{k_n}(H_n(\beta)) = p_0 P(R^{-1})^{k_n}(Z^*(R^{-1})) = 1$ . For  $\beta > \beta_n$ ,

$$\begin{aligned} & |p^*(\beta)(H_n(\beta, s)) - p^*(R^{-1})(\{(w^*(s), s)\})| < |p^*(\beta)(H_n(\beta, s)) - p_0 P(R^{-1})^{k_n}(\{(w^*(s), s)\})| \\ & + |p_0 P(R^{-1})^{k_n}(\{(w^*(s), s)\}) - p^*(R^{-1})(\{(w^*(s), s)\})| \\ & = |p^*(\beta)(H_n(\beta, s)) - p_0 P(\beta)^{k_n}(H_n(\beta, s))| \\ & + |p_0 P(R^{-1})^{k_n}(\{(w^*(s), s)\}) - p^*(R^{-1})(\{(w^*(s), s)\})| < \delta_n/2 + \delta_n/2 = \delta_n, \end{aligned}$$

which follows from the convergence in the total variation norm given any  $\beta$ . Moreover,  $H_n(\beta, s) \rightarrow \{(w^*(s), s)\}$ ,  $\forall s \neq \bar{s}$ , and  $p^*(\beta)(R_n(\beta)) \rightarrow 0$  and  $p^*(\beta)(H_n(\beta)) \rightarrow 1$ .

We now prove that when  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ , if  $\beta_+ > \beta$ , then  $p^*(\beta_+)$  FOSD  $p^*(\beta)$ . We follow a proof strategy similar to the one used in Part (i) of Proposition 3. Define the operator  $T$  as in the proof of Proposition 2. Let  $\beta_+ > \beta$  and denote variables associate with  $\beta_+$  with a subscript  $+$ . As before,  $T(\bar{\mathcal{S}}) \subset \bar{\mathcal{S}}^o \subset \bar{\mathcal{S}}$  and analogously for  $T_+$ .

Pick  $\hat{v} \in \bar{\mathcal{S}}^o$ . We show that if  $T_+^n \hat{v}_w(w, s) \geq T^n \hat{v}_w(w, s)$ , then  $T_+^{n+1} \hat{v}_w(w, s) \geq T^{n+1} \hat{v}_w(w, s)$ . Suppose  $T_+^n \hat{v}_w(w, s) \geq T^n \hat{v}_w(w, s)$ , but that  $T_+^{n+1} \hat{v}_w(w, s) < T^{n+1} \hat{v}_w(w, s)$ , and hence by the envelope condition  $u_c(c_+) < u_c(c)$ , implying that  $c_+ > c$  and  $E[h'_+|s] < E[h'|s]$ . If so, there must exist a state  $s'$  for which  $0 \leq h_+(s') < h(s')$  and  $w_+(s') < w(s')$ , but then

$$u_c(c_+) < u_c(c) = \beta R T^n v_w(w(s'), s') \leq \beta R T^n v_w(w_+(s'), s') < \beta_+ R T_+^n v_w(w_+(s'), s') \leq u_c(c_+),$$

a contradiction. Hence,  $T_+^{n+1} \hat{v}_w(w, s) \geq T^{n+1} \hat{v}_w(w, s)$ ,  $c_+ \leq c$ , and  $E[h'_+|s] \geq E[h'|s]$ .

Since  $T^n \hat{v} \rightarrow v$  and  $T^n \hat{v}_w(w, s) = u_c(c)$  (and analogously for  $T_+ \hat{v}$ ), and the policy functions converge, the value functions  $v$  and  $v_+$  satisfy the property, too.

Note that if  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s' \in S$ , then net worth in the hedged states  $w_h$  is constant and  $E[h'_+] \geq E[h']$  implies  $w_{h+} \geq w_h$ . In this case we can follow the proof of Part (i) of Proposition 7 and start at  $(\bar{y}, \bar{s})$ , a recurrent state, with the distribution

$$p_0 = \begin{cases} 1 & \text{if } z = (\bar{y}, \bar{s}) \\ 0 & \text{if } z \neq (\bar{y}, \bar{s}), z \in Z^*(\beta). \end{cases}$$

Let  $P(\beta)$  denote the transition matrix on the induced state space  $z = (w, s) \in Z^*(\beta)$ . Then  $p_0 P(\beta)_+^k$  FOSD  $p_0 P(\beta)^k$  and hence  $p^*(\beta_+)$  FOSD  $p^*(\beta)$ .  $\square$

**Proof of Proposition 9. Part (i):** The proof is in a similar spirit to the Proof of Part (i) of Proposition 2. We show that if the properties that  $v(w, s)$  is increasing in  $s$  and  $v_w(w, s)$  is decreasing in  $s$  are satisfied by  $v$  next period, then  $Tv$  satisfies these same properties this period, and conclude that the fixed point satisfies these properties as well. Moreover, as before, we observe that if the properties are satisfied next period, then the household hedges a lower set of states and  $h'$  is decreasing in  $s'$ .

Now suppose that  $\exists s_+ > s$ , such that  $Tv_w(w, s_+) > Tv_w(w, s)$ , implying by the envelope condition that  $c_+ < c$ . From the budget constraint(2) we have

$$c_+ + \wp k_+ + \sum_{s' \in S} \Pi(s_+, s') h'_+ = w = c + \wp k + \sum_{s' \in S} \Pi(s, s') h',$$

and given FOSD and the fact that  $h'$  is decreasing in  $s'$  we have  $\sum_{s' \in S} \Pi(s_+, s') h' \leq \sum_{s' \in S} \Pi(s, s') h'$ , which implies that  $x = \{c, k, h'\}$  is feasible at  $s_+$  and, since  $v(w, s)$  is increasing in  $w$  and  $s$ ,  $Tv(w, s_+) \geq Tv(w, s)$ .

Suppose  $k_+ \leq k$ . There must exist an  $\hat{s}'$  such that  $w_+(\hat{s}') > w(\hat{s}')$ , since otherwise consumption of goods and durables and the net worth next period are all lower at  $s_+$  than  $s$ , contradicting the optimality of  $x_+$  since  $x$  is feasible. But then  $h(\hat{s}) > 0$  and therefore  $\beta R\mu_+(\hat{s}') = \mu_+ > \mu \geq \beta R\mu(\hat{s}')$  implying  $w_+(\hat{s}') < w(\hat{s}')$ , a contradiction.

Now suppose  $k_+ > k$ . For  $s' \in S_h \cap S_{h+}$ ,  $\beta\mu'/\mu = R^{-1} = \beta\mu'_+/\mu_+$ . For  $s' \in S \setminus S_h \cap S \setminus S_{h+}$ ,  $\beta\mu'/\mu > \beta\mu'_+/\mu_+$ . For  $s' \in S_h \cap S \setminus S_{h+}$ ,  $\beta\mu'/\mu = R^{-1} \geq \beta\mu'_+/\mu_+$ . Finally  $S_h \cap S \setminus S_{h+} = \emptyset$ , since for such  $s'$  we would have  $\beta R\mu'_+ = \mu_+ > \mu \geq \beta R\mu'$ , implying  $w'_+ < w'$ , whereas  $w'_+ = y' + (1 - \theta)k_+(1 - \delta) + h'_+ > y' + (1 - \theta)k(1 - \delta) = w'$ , a contradiction. Recalling that  $R^{-1} \geq \beta\mu'/\mu$  and that the right hand side is decreasing in  $s'$ , the Euler equation for durables (16) implies

$$\begin{aligned} 1 &= \beta \frac{g_k(k_+)}{\mu_+} \frac{1}{\wp} + \left[ \sum_{s' \in S_{h+}} \Pi(s_+, s') R^{-1} + \sum_{s' \in S \setminus S_{h+}} \Pi(s_+, s') \beta \frac{\mu'_+}{\mu_+} \right] \frac{(1 - \theta)(1 - \delta)}{\wp} \\ &< \beta \frac{g_k(k)}{\mu} \frac{1}{\wp} + \left[ \sum_{s' \in S_h} \Pi(s_+, s') R^{-1} + \sum_{s' \in S \setminus S_h} \Pi(s_+, s') \beta \frac{\mu'}{\mu} \right] \frac{(1 - \theta)(1 - \delta)}{\wp} \\ &\leq \beta \frac{g_k(k)}{\mu} \frac{1}{\wp} + \left[ \sum_{s' \in S_h} \Pi(s, s') R^{-1} + \sum_{s' \in S \setminus S_h} \Pi(s, s') \beta \frac{\mu'}{\mu} \right] \frac{(1 - \theta)(1 - \delta)}{\wp} = 1, \end{aligned}$$

a contradiction.

**Part (ii):** Arguing analogously to Part (i) of Proposition 2, since the property in Part (i) above is satisfied, the household hedges a lower set of states and  $w'$  and  $h'$  is decreasing in  $s'$  since for two states  $s'_+ > s'$  which are hedged we have  $v_w(w'_+, s'_+) = v_w(w', s') \geq v_w(w', s'_+)$ , that is,  $w' \geq w'_+$ , and  $h' > h'_+$  as  $y' < y'_+$ .

Using the envelope condition and (5) we have  $v_w(w, s) = u_c(c)$ , and given the strict concavity of the value function, if  $w_+ > w$ ,  $v_w(w_+, s) < v_w(w, s)$  and hence  $c_+ > c$ , that is,  $c$  is strictly increasing in  $w$ , given  $s$ , and since  $v_w(w, s)$  is decreasing in  $s$ ,  $c$  is increasing in  $s$ .

To see that  $k$  is strictly increasing in  $w$  given  $s$ , take  $w_+ > w$  and note that by strict concavity of  $v$ ,  $\mu_+ < \mu$ . Suppose that  $k_+ \leq k$ , then  $g_k(k) \leq g_k(k_+)$ . Rewriting the Euler equation for durable goods purchases (16) we have

$$1 = \beta \frac{g_k(k)}{\mu} \frac{1}{\wp} + \sum_{s' \in S_h} \Pi(s, s') R^{-1} \frac{(1 - \theta)(1 - \delta)}{\wp} + \sum_{s' \in S \setminus S_h} \Pi(s, s') \beta \frac{\mu' (1 - \theta)(1 - \delta)}{\mu \wp}.$$

Assume, without loss of generality, that  $S_h = S_{h+}$ . Since  $g_k(k_+)/\mu_+ > g_k(k)/\mu$ , it must be the case that  $\exists \hat{s}' \in S \setminus S_h$  such that  $\mu_+(\hat{s}')/\mu_+ < \mu(\hat{s}')/\mu$  and hence  $\mu_+(\hat{s}') < \mu(\hat{s}')$ , that is,  $w_+(\hat{s}') > w(\hat{s}')$ . But since  $\hat{s}' \in S \setminus S_h$ ,  $w_+(\hat{s}') = y(\hat{s}') + (1 - \theta)k_+(1 - \delta) \leq y(\hat{s}') + (1 - \theta)k(1 - \delta) = w(\hat{s}')$ , we have a contradiction.

To see that  $w'$  is strictly increasing in  $w$  given  $s$ ,  $\forall s' \in S$ , assume again *w.l.o.g.* that  $S_h = S_{h+}$ . On  $S_h$ ,  $v_w(w, s) = \beta R v_w(w', s')$  and hence  $w'_+ > w'$ . On  $S \setminus S_h$ ,  $w'_+ = y' + (1 - \theta)k_+(1 - \delta) > y' + (1 - \theta)k(1 - \delta) = w'$ .

**Part (iii):** If  $\Pi(s, s') = \pi(s')$ ,  $\forall s, s'$ , then for any two states  $s'_+ > s'$  that are hedged we have  $v_w(w'_+) = v_w(w')$ , that is,  $w' = w'_+ \equiv w_h$ .

Since  $\bar{w}$  is the highest wealth level that is attained under the (unique) stationary distribution, we have at  $\bar{w}$  that  $v_w(\bar{w}) = \beta R v_w(\bar{w}') + \beta R \lambda(\bar{s}')$ , so  $\lambda(\bar{s}') > 0$ . Now suppose  $\exists \hat{w} < \bar{w}$  such that the household hedges all states at  $\hat{w}$  implying that  $v_w(\hat{w}) = \beta R v_w(\hat{w}(s'))$ ,  $\forall s' \in S$ , that is, net worth next period must be lower than net worth this period in all states. But then there would have to exist a  $w_- < \hat{w}$  such that  $w_-(\bar{s}') > \hat{w}(\bar{s}')$  (since otherwise  $\bar{w}$  could not be attained from below  $\hat{w}$ ), which implies that  $\hat{w}(\bar{s}') < w_-(\bar{s}') = y(\bar{s}') + (1 - \theta)k_-(1 - \delta) + h_-(\bar{s}')$ , so  $h_-(\bar{s}') > 0$ . This in turn implies that  $v_w(w_-) = \beta R v_w(w_-(\bar{s}'))$ , that is,  $v_w(w_-) < v_w(\hat{w})$ , a contradiction.  $\square$

**Proof of Proposition 10.** The budget constraint (13) implies that  $w \geq c$ ; thus, as  $w$  goes to 0,  $c$  goes to 0 and using the envelope condition  $v_w(w, s) = u_c(c)$  goes to  $+\infty$ . Since  $w' \geq y' + (1 - \theta)k(1 - \delta) > y' \geq \underline{y}$  and  $v_w(\underline{y}, s')$  is bounded for all  $s'$ ,  $v_w(w', s') < v_w(\underline{y}, s') < +\infty$ , and hence for sufficiently low  $w$ ,  $\lambda' > 0$ ,  $\forall s' \in S$ .  $\square$

**Proof of Proposition 12. Part (i):** When  $\theta = 1$ , the investment Euler equation for durable goods (22) simplifies to

$$\wp(s)\mu = \beta g_k(k), \quad (29)$$

which in the case of logarithmic utility further simplifies to  $k = (\beta g/\wp(s))c$ . Define the total expenditure on consumption and durable goods as  $\hat{c} = c + \wp(s)k = (1 + \beta g)c$ .

Substituting for  $c$  and  $k$  in the return function we have

$$\hat{u}(\hat{c}, s) = u(c) + \beta g(k) = (1 + \beta g)u(\hat{c}) + \varphi(s),$$

where  $\varphi(s) = -(1 + \beta g) \log(1 + \beta g) + \beta g \log(\beta g) - \beta g \log(\wp(s))$ . The problem with durable goods can then be written as an income risk management problem with preference shocks

$$v(w, s) = \max_{\hat{c}, h', w' \in \mathbb{R}_+ \times \mathbb{R}^{2S}} \hat{u}(\hat{c}, s) + \beta E[v(w', s')|s] \quad (30)$$

subject to

$$w \geq \hat{c} + E[R^{-1}h'|s], \quad (31)$$

(3), and (4).

Let  $\hat{v}(w, s)$  solve the following income risk management problem without preference shocks

$$\hat{v}(w, s) = \max_{\hat{c}, h', w' \in \mathbb{R}_+ \times \mathbb{R}^{2S}} u(\hat{c}) + \beta E[\hat{v}(w', s')|s]$$

subject to (31), (3), and (4). This is in fact the problem considered in Section 3. Noting that the preference shock component of utility  $\varphi(s)$  is separable and defining  $v_\varphi(s)$  recursively as

$$v_\varphi(s) \equiv \varphi(s) + \beta E[v_\varphi(s')|s],$$

we have  $v(w, s) = (1 + \beta g)\hat{v}(w, s) + v_\varphi(s)$  as can be verified by substituting into equation (30).

**Part (ii):** With isoelastic preferences, (29) simplifies to  $k = (\beta g/\wp(s))^{1/\gamma}c$ . Define the total expenditure on consumption and durable goods as  $\hat{c} = c + \wp(s)k = (1 + \wp(s)(\beta g/\wp(s))^{1/\gamma})c$ . Substituting for  $c$  and  $k$  in the return function we have

$$\hat{u}(\hat{c}, s) = u(c) + \beta g(k) = \phi(s)u(\hat{c}),$$

where  $\phi(s) = (1 + (\beta g)^{1/\gamma}\wp(s)^{(\gamma-1)/\gamma})^\gamma$ . The proof of Proposition 1 applies without change.

Suppose  $\Pi(s, s')$  satisfies FOSD and  $\wp(s)$  is increasing in  $s$ . To prove that  $v_w(w, s)$  is decreasing in  $s$  when  $\gamma < 1$ , first observe that  $\phi(s)$  is decreasing in  $s$  in that case (whereas it is increasing in  $s$  if  $\gamma > 1$ ). We can now proceed as in the proof of the first part of Part (ii) of Proposition 2, that is, we assume that the property is satisfied by  $v(\cdot)$  next period and then show that it has to be satisfied by  $Tv(\cdot)$  in the current period as well. As before, note that if the property is satisfied next period, the household hedges a lower set of states and  $h'$  decreases in  $s'$ . Suppose the opposite, that is, suppose  $\exists s_+ > s$ , such that  $Tv_w(w, s_+) > Tv_w(w, s)$ , implying by the envelope condition that  $\phi(s_+)u(\hat{c}_+) = \mu_+ > \mu = \phi(s)u(\hat{c})$  and therefore  $u(\hat{c}_+) > \phi(s)/\phi(s_+)u(\hat{c}) \geq u(\hat{c})$ , which further implies that  $\hat{c}_+ < \hat{c}$ . Since  $h'$  is decreasing in  $s'$ ,  $E[R^{-1}h'|s] \leq E[R^{-1}h'|s_+]$  and  $\{\hat{c}, h', w'\}$  is feasible at  $s_+$ . Since  $\hat{c}_+ < \hat{c}$ ,  $\exists \hat{s}'$  such that  $w_+(\hat{s}') > w(\hat{s}')$  since otherwise  $\{\hat{c}_+, h'_+, w'_+\}$  would achieve lower utility than switching to  $\{\hat{c}, h', w'\}$ , contradicting optimality. But then  $y(\hat{s}') + h_+(\hat{s}') = w_+(\hat{s}') > w(\hat{s}') = y(\hat{s}') + h(\hat{s}')$  and  $h_+(\hat{s}') > h(\hat{s}') \geq 0$ , so  $\beta R\mu_+(w_+(\hat{s}'), \hat{s}') = \mu_+ > \mu \geq \beta R(w(\hat{s}'), \hat{s}')$ , implying  $w_+(\hat{s}') < w(\hat{s}')$ , a contradiction. Therefore  $v_w(w, s)$  is decreasing in  $s$ , and the rest of the proposition obtains from the proof of Part (ii) of Proposition 2 without change.  $\square$

## Appendix B: Equivalence of economies with limited enforcement and collateral constraints

This appendix shows the equivalence of the optimal dynamic contract with limited enforcement without exclusion and an economy with one-period state-contingent claims subject to collateral constraints. For simplicity we consider the case without durable goods. The household's problem with limited enforcement at time  $\tau \geq 0$  given net worth  $w(s^\tau)$ , which we denote  $\mathcal{P}_\tau(w(s^\tau))$ , is to choose a sequence of consumption choices and net payments  $\{c(s^t), p(s^t)\}_{t \geq \tau}$  where  $s^t \equiv \{s_0, \dots, s_t\}$ , to maximize

$$E_\tau \left[ \sum_{t=\tau}^{\infty} \beta^{(t-\tau)} u(c_t) \right], \quad (32)$$

subject to

$$w(s^\tau) \geq c(s^\tau) + p(s^\tau), \quad (33)$$

$$y(s^t) \geq c(s^t) + p(s^t), \quad \forall t > \tau, \quad (34)$$

the lender's participation constraint

$$E_\tau \left[ \sum_{t=\tau}^{\infty} R^{-(t-\tau)} p_t \right] \geq 0, \quad (35)$$

the limited enforcement constraint

$$E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} \beta^{(t-\tau')} u(c_t) \right] \geq E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} \beta^{(t-\tau')} u(\hat{c}_t) \right], \quad \forall \tau' \geq \tau, \forall \{\hat{c}(s^t)\}_{t=\tau'}^{\infty}, \quad (36)$$

where  $\{\hat{c}(s^t)\}_{t=\tau'}^{\infty}$  together with  $\{\hat{p}(s^t)\}_{t=\tau'}^{\infty}$  solve  $\mathcal{P}_{\tau'}(\hat{w}(s^{\tau'}))$  with  $\hat{w}(s^{\tau'}) = y(s^{\tau'})$ . We say a sequence of net payments is implementable if it satisfies the lender's participation constraint and the limited enforcement constraints.

### Proposition 13 (Equivalence of limited enforcement and collateral constraints)

(i) Any sequence of net payments  $\{p(s^t)\}_{t=\tau}^{\infty}$  is implementable in problem  $\mathcal{P}_\tau(w(s^\tau))$  iff

$$0 \geq E_{\tau'} \left[ \sum_{t=\tau'}^{\infty} R^{-(t-\tau')} p_t \right], \quad \forall \tau' > \tau, \quad (37)$$

that is, the present value of the remaining payments is never positive. (ii) The set of sequences of net payments satisfying (37) is equivalent to the set of sequences of one-period state-contingent claims  $\{h(s^t)\}_{t=\tau}^{\infty}$  that satisfy the short-sale constraints

$$h(s^t) \geq 0, \quad \forall t > \tau. \quad (38)$$

**Proof of Proposition 13.** Part (i): ( $\Rightarrow$ ) Suppose not, that is, suppose that  $\{p(s^t)\}_{t=\tau}^\infty$  is such that (37) is violated for some  $s^{\tau'}$ ,  $\tau' > \tau$ , that is

$$E_{\tau'} \left[ \sum_{t=\tau'}^\infty R^{-(t-\tau')} p_t \right] > 0.$$

W.l.o.g. let  $\tau' = \tau + 1$ . The household could default in state  $s^{\tau+1}$  at time  $\tau + 1$  and issue new payments  $\{\hat{p}(s^t)\}_{t=\tau+1}^\infty$  such that  $\hat{p}(s^t) = p(s^t)$ ,  $t > \tau + 1$ , and  $\hat{p}(s^{\tau+1}) = -E_{\tau+1} \left[ \sum_{t=\tau+2}^\infty R^{-(t-(\tau+1))} \hat{p}_t \right]$ , and hence by construction  $E_{\tau+1} \left[ \sum_{t=\tau+1}^\infty R^{-(t-(\tau+1))} \hat{p}_t \right] = 0$ . Clearly,  $\hat{p}(s^{\tau+1}) < p(s^{\tau+1})$  and  $\hat{c}(s^t) = c(s^t)$ , for all  $t \geq \tau + 2$ , but

$$\hat{c}(s^{\tau+1}) = c(s^{\tau+1}) + p(s^{\tau+1}) - \hat{p}(s^{\tau+1}) = c(s^{\tau+1}) + E_{\tau+1} \left[ \sum_{t=\tau+1}^\infty R^{-(t-(\tau+1))} p_t \right] > c(s^{\tau+1}),$$

which would be an improvement and hence a contradiction. We prove the other direction after proving part (ii).

Part (ii): Take any sequence of net payments  $\{p(s^t)\}_{t=\tau}^\infty$  that satisfies (37) and define

$$h(s^{\tau'}) \equiv -E_{\tau'} \left[ \sum_{t=\tau'}^\infty R^{-(t-\tau')} p_t \right] \geq 0, \quad \forall \tau' > \tau,$$

then  $h(s^{\tau'}) = -p(s^{\tau'}) + R^{-1} E_{\tau'}[h_{\tau'+1}]$  or  $p(s^{\tau'}) = -h(s^{\tau'}) + R^{-1} E_{\tau'}[h_{\tau'+1}]$ . We can therefore rewrite (34) as

$$y(s^t) + h(s^t) \geq c(s^t) + R^{-1} E_t[h_{t+1}], \quad \forall t \geq \tau + 1, \quad (39)$$

and (33) as

$$w(s^\tau) \geq c(s^\tau) + R^{-1} E_\tau[h_{\tau+1}], \quad (40)$$

where  $h(s^\tau) = 0$  as (35) holds with equality.

Moreover, any sequence  $\{h(s^t)\}_{t=\tau+1}^\infty$  with  $h(s^t) \geq 0$ ,  $\forall t > \tau$ , satisfies (37) as

$$\begin{aligned} E_{\tau'} \left[ \sum_{t=\tau'}^\infty R^{-(t-\tau')} p_t \right] &= E_{\tau'} \left[ \sum_{t=\tau'}^\infty R^{-(t-\tau')} \{-h_t + R^{-1} E_t[h_{t+1}]\} \right] \\ &= -E_{\tau'} \left[ \sum_{t=\tau'}^\infty R^{-(t-\tau')} h_t \right] + E_{\tau'} \left[ \sum_{t=\tau'+1}^\infty R^{-(t-\tau')} h_t \right] = -h(s^{\tau'}) \leq 0. \end{aligned}$$

Finally, to complete part (i), ( $\Leftarrow$ ), the household would never default on a sequence  $\{h(s^t)\}_{t=\tau+1}^\infty$  with  $h(s^t) \geq 0$ ,  $\forall t > \tau$ , establishing that if (37) is satisfied, the sequence  $\{p(s^t)\}_{t=\tau}^\infty$  is implementable.  $\square$

The problem with limited enforcement  $\mathcal{P}_\tau(w(s^\tau))$  in equations (32) to (36) is therefore equivalent to maximizing (32) subject to (40), (39), and (38), which can be written recursively as in equations (1) to (4). Moreover, the proof can be extended to the case with durable goods by adapting the proof in Rampini and Viswanathan (2013).

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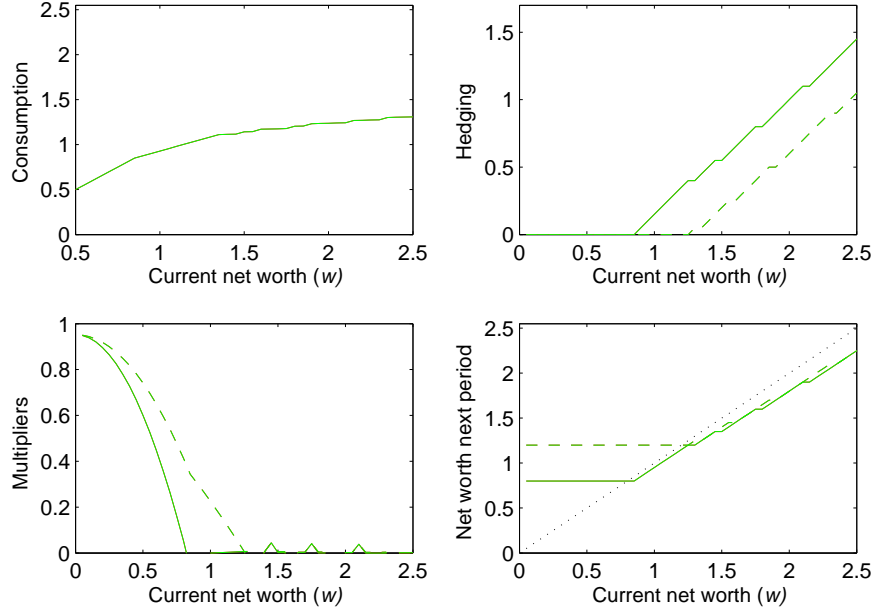
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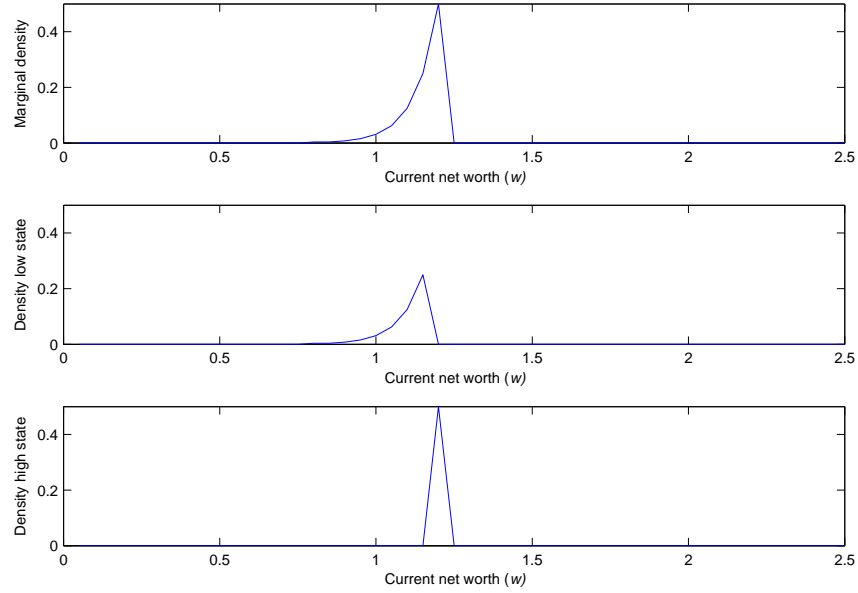
**Figure 1: Increasing Household Risk Management**

This figure displays household income risk management when household income follows an independent two state Markov process. The solid (dashed) lines plot the policies for the low (high) state next period. Top left: consumption  $c$ ; top right: hedging  $h'$ ; bottom left: (scaled) multiplier on the short-sale constraint  $\beta\lambda'/\mu$ ; and bottom right: net worth next period  $w'$  and 45-degree line (dotted). The parameter values are:  $\beta = 0.90$ ,  $R = 1.05$ ,  $\Pi(\underline{s}, \underline{s}) = \Pi(\bar{s}, \bar{s}) = 0.50$ ,  $y(\underline{s}) = 0.80$ ,  $y(\bar{s}) = 1.20$ , and preferences  $u(c) = c^{1-\gamma}/(1-\gamma)$  with  $\gamma = 2$ .



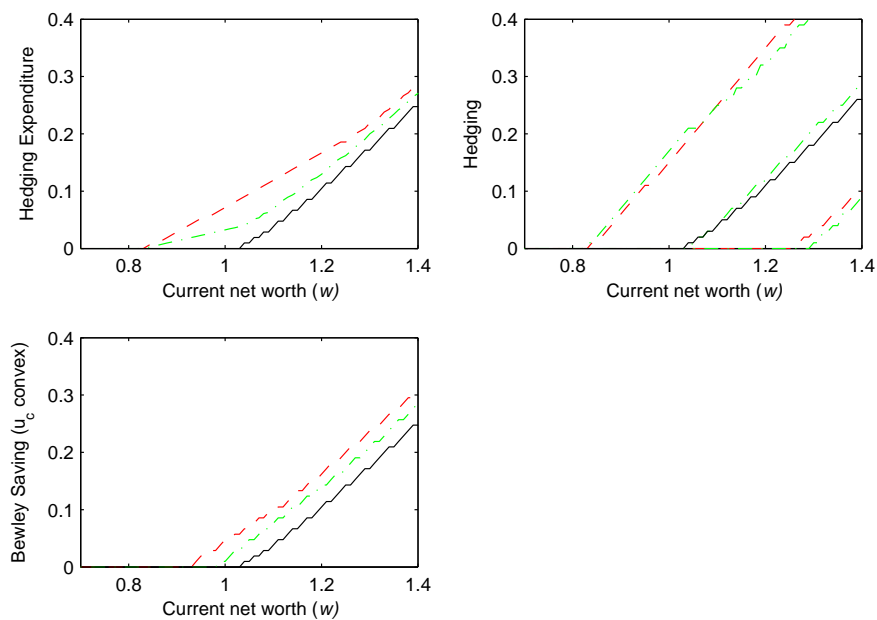
## Figure 2: Stationary Distribution of Household Net Worth

This figure displays the stationary distribution of net worth from Proposition 7 for an endowment economy when household income follows an independent two state Markov process as in Figure 1 (see the caption of that figure for parameter values). Top: unconditional distribution of net worth; middle: distribution conditional on the low state; bottom: distribution conditional on the high state.



**Figure 3: Risk and Precautionary Behavior of Hedging and Saving**

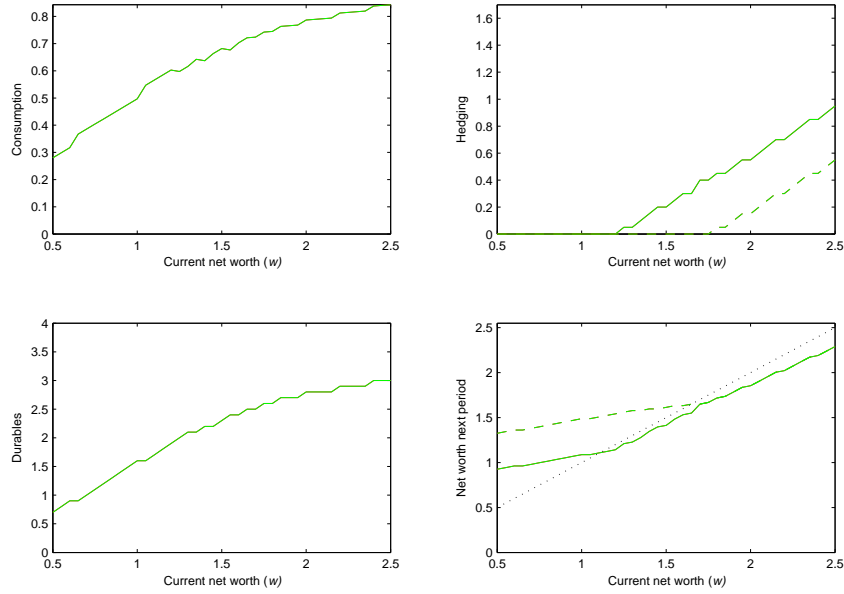
This figure displays the effect of an increase in risk on the precautionary behavior of household income risk management in our model (top two panels) and of saving in a Bewley (1977) economy with convex  $u_c(c)$ . Household income follows an independent three state Markov process with  $y(s') \in \{y - \sigma, y, y + \sigma\}$  and  $\pi(s') = \pi_\sigma, 1 - 2\pi_\sigma$ , and  $\pi_\sigma$ , respectively, with  $y = 1$ ,  $\sigma = 0.2$ , and  $\pi_\sigma$  taking the values 0 (solid (black) – deterministic case), 0.2 (dash-dotted (green)), and 0.5 (dashed (red) – two state case as in Figure 1). For our model, the top left panel displays hedging expenditures  $E[R^{-1}h']$  and the top right panel hedging for each state tomorrow  $h(s')$  as a function of net worth for various values of  $\pi_\sigma$ . For the Bewley (1977) economy, the bottom left panel displays saving  $h$  as a function of net worth for various values of  $\pi_\sigma$ . The other parameter values are as in Figure 1.



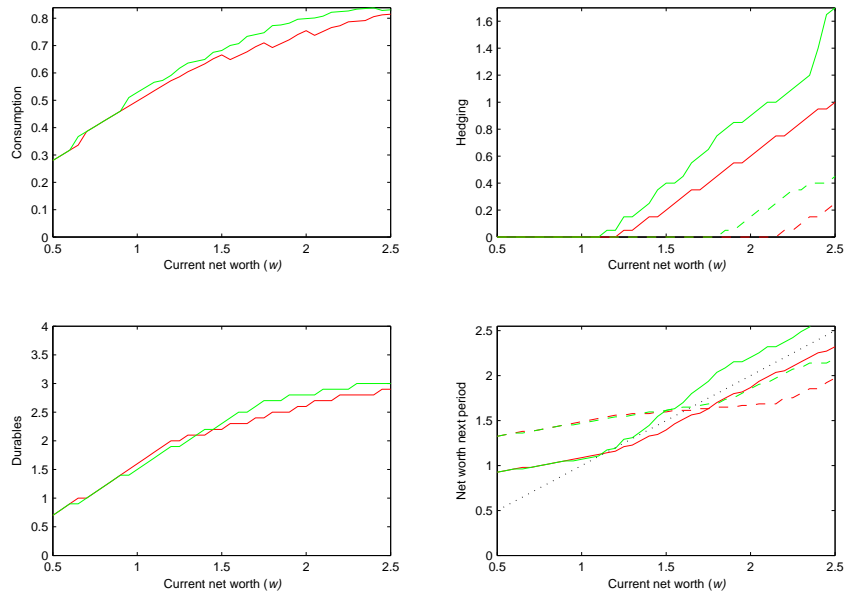
### Figure 4: Household Risk Management with Durable Goods

This figure displays household income risk management with durable goods when income follows a two state Markov process with independence (Panel A) and persistence (Panel B). The solid (dashed) lines plot the policies for the low (high) state next period. In Panel B, the darker (and red) lines are associated with  $\underline{s}$  and the lighter (and green) lines with  $\bar{s}$ . Top left: consumption  $c$ ; top right: hedging  $h'$ ; bottom left: durable goods consumption  $k$ ; and bottom right: net worth next period  $w'$  and 45-degree line (dotted). Parameters are as in Figure 1 except that  $\theta = 0.80$  and utility from durable goods  $g(k) = gk^{1-\gamma}/(1-\gamma)$  with  $\gamma = 2$  and  $g = 2$ . In Panel A (B),  $\Pi(\underline{s}, \underline{s}) = \Pi(\bar{s}, \bar{s}) = 0.50$  (0.75).

#### Panel A: Independent income

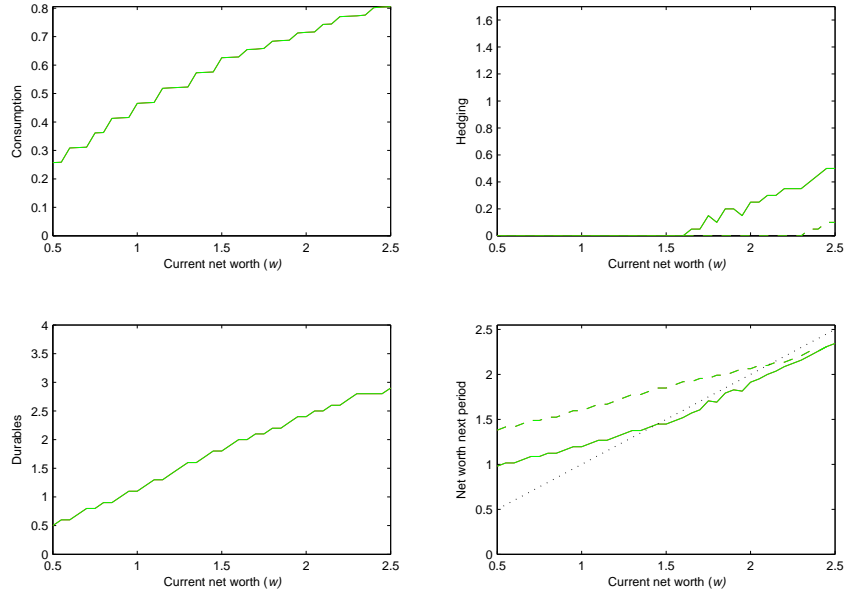


#### Panel B: Persistent income



**Figure 5: Effect of Collateralizability of Durable Goods**

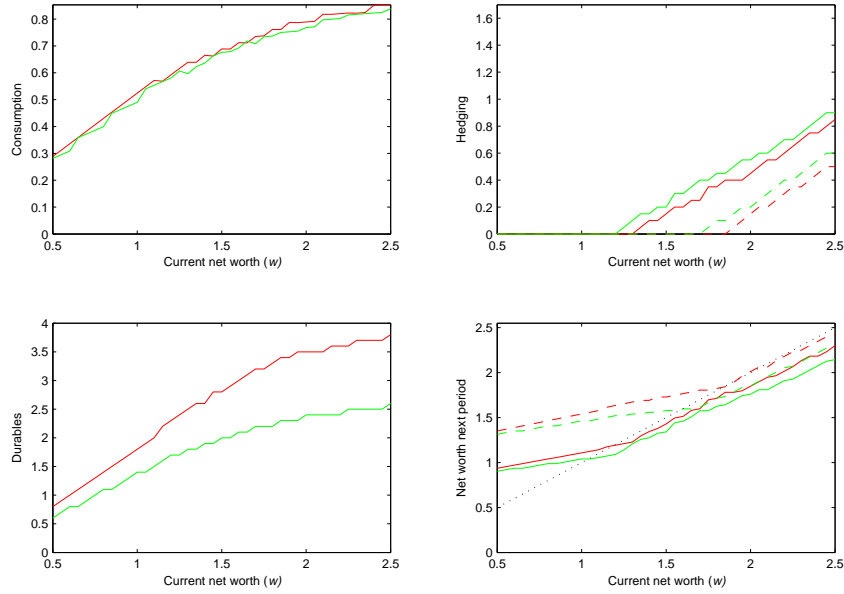
This figure displays household income risk management with durable goods when household income follows a two state Markov process with independence (as in Panel A of Figure 4) when the collateralizability of durable goods is  $\theta = 0.6$  (instead of 0.8 as before). The solid (dashed) lines plot the policies for the low (high) state next period. Top left: consumption  $c$ ; top right: hedging  $h'$ ; bottom left: durable goods consumption  $k$ ; and bottom right: net worth next period  $w'$  and 45-degree line (dotted). All other parameters are as in Figure 4.



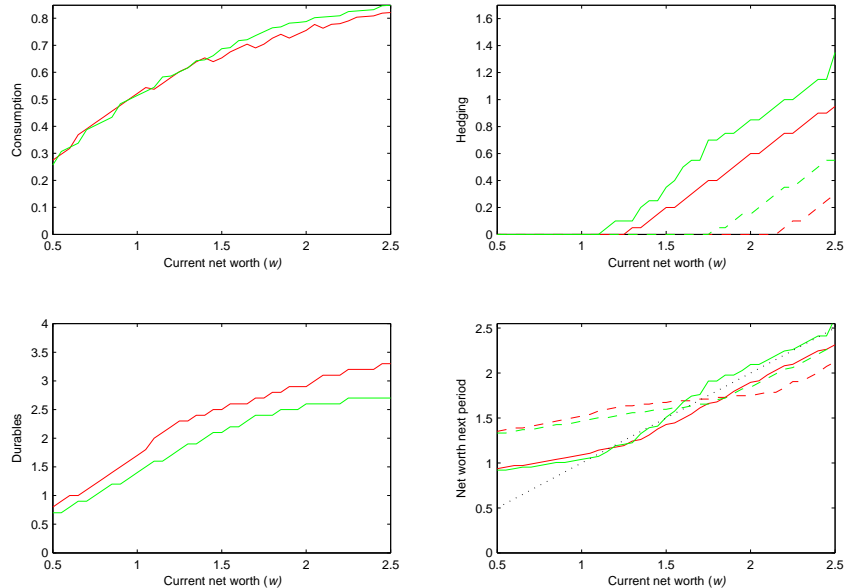
## Figure 6: Household Risk Management with Durable Goods Price Risk

This figure displays household income risk management with durable goods price risk when household income and durable goods prices follow a two state Markov process with independence (Panel A) and persistence (Panel B). The solid (dashed) lines plot the policies for the low (high) state next period. The darker (and red) lines are associated with  $\underline{s}$  and the lighter (and green) lines with  $\bar{s}$ . Top left: consumption  $c$ ; top right: hedging  $h'$ ; bottom left: durable goods consumption  $k$ ; and bottom right: net worth next period  $w'$  and 45-degree line (dotted). Parameters are as in Figure 4 except that  $q(\underline{s}) = 0.95$  and  $q(\bar{s}) = 1.05$ . In Panel A (B),  $\Pi(\underline{s}, \underline{s}) = \Pi(\bar{s}, \bar{s}) = 0.50$  (0.75).

### Panel A: Independent Markov process



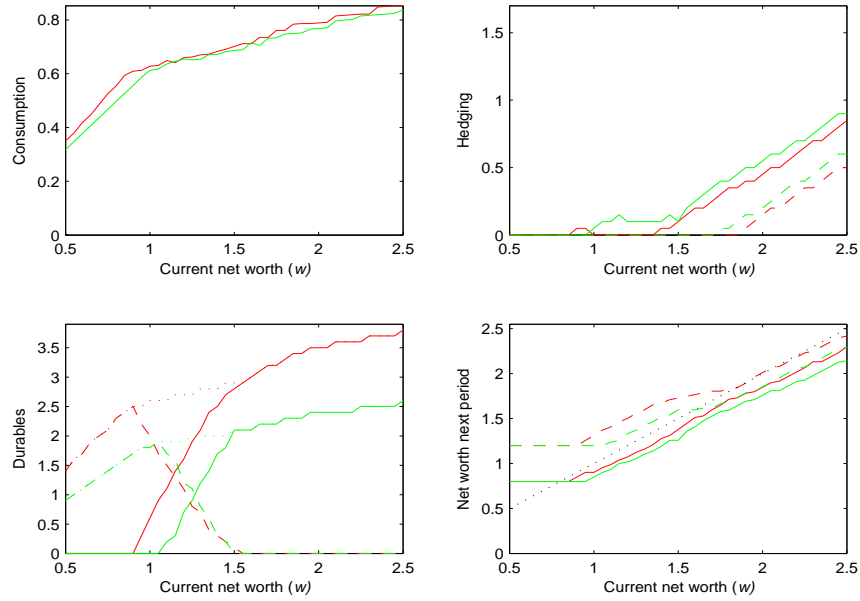
### Panel B: Persistent Markov process



## Figure 7: Risk Management, Rent vs. Buy, and Durable Goods Price Risk

This figure displays household risk management with durable goods price risk when households can choose to rent as well as buy durables and where income and durable goods prices follow an independent two state Markov process. In Panel A, the price and income process are perfectly correlated while in Panel B they are independent. The solid (dashed) lines plot the policies for the low (high) price state next period (except where noted otherwise). The darker (and red) lines are associated with  $\underline{s}$  and the lighter (and green) lines with  $\bar{s}$ . Top left: consumption  $c$ ; top right: hedging  $h'$ ; bottom left: consumption of durable goods, total  $k$  (dotted), owned  $k_o$  (solid), and rented  $k_l$  (dashed); and bottom right: net worth next period  $w'$  and 45-degree line (dotted). Parameters are as in Panel A of Figure 6 except that the monitoring cost  $m = 0.02$ .

### Panel A: Risk Management with Perfect Correlation of Price and Income



### Panel B: Risk Management with Independence of Price and Income

