

# How Much Insurance in Bewley Models?

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## **Abstract**

We assess the degree of consumption insurance implicit in a plausibly calibrated life-cycle version of the standard incomplete-markets model (“Bewley model”), and we compare it to the empirical estimates of Blundell, Pistaferri & Preston (2008) (BPP thereafter). We find that households in Bewley models have access to less consumption smoothing against permanent shocks than what is measured in the data. BPP estimate that 36% of permanent earnings shocks are insurable (i.e., do not translate into consumption growth), while the model’s counterpart of the BPP estimator varies between 7% and 22%, depending on the tightness of debt limits. The BPP estimator of the true insurance coefficient has, in general, a downward bias which grows as borrowing limits become tighter. In the model, the life-cycle profile of the insurance coefficient is sharply increasing, while BPP document that in the data it is roughly flat. Allowing for a plausible degree of “advance information” about future earnings does not reconcile the model-data gap. If earnings shocks display mean reversion, even with very high autocorrelation, then the average degree of consumption smoothing in the model agrees with the BPP empirical estimate, but its life-cycle profile remains steeply increasing and therefore at odds with the data.

# 1 Introduction

Macroeconomists need reliable empirical estimates of the extent to which household consumption is insulated from income fluctuations, for at least two reasons. First, imperfect risk-sharing is at the heart of heterogeneous-agents, incomplete-markets models. Thus, the availability of a simple empirical measure of consumption insurance would allow comparing, parsimoniously, the predictions of different incomplete-markets models along their most salient dimension. Second, macroeconomic models are routinely used for policy evaluation and design. For example, a reform from a progressive to a flat tax system is judged on the basis of the gains from reduced distortions and the losses from lower redistribution. But the size of the latter margin depends on how much smoothing agents can do on their own, through private risk-sharing. Getting this magnitude right in the model is a key requisite if the model is to deliver reliable predictions for policy experiments.

Today, the measurement of consumption insurance against earnings shocks acquires particular salience in the U.S. economy because of the recent sharp increase in cross-sectional wage dispersion. Understanding the macroeconomic and welfare implications of this dramatic change in the wage structure requires macroeconomic models with the correct degree of risk-sharing.<sup>1</sup>

The empirical assessment of the transmission of income shocks into consumption is undermined by two difficulties. First, one needs both longitudinal data on income and on a comprehensive measure of consumption. In the US such a dataset is not available. As a result, authors have either opted for using PSID/CEX data alone (Hall & Mishkin 1982, Altonji & Siow 1987, Cochrane 1991, Mace 1991, Dynarski & Gruber 1997) or for constructing synthetic cohorts to merge high quality cross-sectional income and consumption data (Attanasio & Davis 1996). Second, one needs to identify individual income shocks in the data. From the shape of the empirical autocovariance function of individual income, it is well known that income changes are best described by a combination of very persistent and very transitory shocks (MaCurdy 1982, Abowd & Card 1989, Blundell & Preston 1998). However, in panel data one observes only the total income change, and cannot disentangle the realization of the shocks of different persistence. As a consequence, some authors have opted to simply measure the response of consumption to total income changes (Altonji & Siow 1987, Krueger

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<sup>1</sup>Krueger & Perri (2006), Heathcote, Storesletten & Violante (2008), and Guvenen & Kuruscu (2008) offer alternative views in this debate.

& Perri 2005, Krueger & Perri 2008), while others have used proxies for permanent and transitory income changes (e.g., disability and short unemployment spells, respectively) in an attempt to separately identify the two shocks (Cochrane 1991, Dynarski & Gruber 1997). Finally, a large literature tries to estimate the consumption response of households to tax rebates (Souleles 1999, Shapiro & Slemrod 2003). It is often unclear whether such tax rebates are perceived as a permanent or transitory change in income by households. Moreover, consumers' response to the rebate depends on whether they expect a simultaneous change in government purchases.

In a pair of recent papers, Blundell, Pistaferri & Preston (2004, 2008) (BPP, thereafter) make some important progress in overcoming these two difficulties. In BPP (2004), the authors construct a new panel data set for the US with household information on income and nondurable consumption.<sup>2</sup> In BPP (2008), they use this new data set to estimate consumption insurance coefficients for permanent (random walk) and transitory (i.i.d.) idiosyncratic income shocks, i.e. the fraction of the shocks that does not translate into movements in consumption. We return to the details of their methodology later. They find that 36% of permanent shocks, and 95% of transitory shocks to disposable (i.e., post taxes and transfers) labor income are insurable. These findings are qualitatively consistent with a large literature that rejects full insurance in the US economy (Cochrane 1991, Attanasio & Davis 1996, Fisher & Johnson 2006), and with the “excess smoothness” finding (i.e., consumption reacts to permanent shocks less than what is predicted by the permanent income hypothesis) in the context of aggregate and individual consumption (Campbell & Deaton 1989, Attanasio & Pavoni 2007).

In light of the above discussion, we argue that the BPP insurance coefficients should become central in quantitative macroeconomics. They provide a yardstick to investigate whether current incomplete-markets macroeconomic models used for quantitative analysis admit the right amount of household insurance. In this paper, we begin this investigation within what is, arguably, the standard heterogeneous-agents, incomplete-markets framework,

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<sup>2</sup>The key step in BPP (2004) is, following Skinner (1987), the imputation of a measure for nondurable consumption for each individual/year observation in the Panel Study of Income Dynamics (PSID) by exploiting the fact that food consumption is available in both PSID and the Consumer Expenditure Survey (CEX). From CEX, one can estimate a relationship between food and nondurable consumption expenditures—a food demand function—and then invert the demand function and implement the imputation procedure at the household level, based on the reported value for food consumption in PSID records. Fisher and Johnson (2006) contains a recent implementation of this strategy applied to the study of consumption mobility.

the so-called “Bewley model”.

Bewley models aggregate, through the notion of competitive equilibrium, the behavior of a continuum of independent consumers facing an “income fluctuation problem”.<sup>3</sup> In the last decade, this model has become a common tool for quantitative analysis in macroeconomics.<sup>4</sup> We choose a life-cycle version of the model with capital in positive net supply where households have CRRA utility, are subject to permanent and transitory shocks to earnings while they work, and during retirement receive social security benefits through a scheme that closely mimics the US system. Households smooth shocks by borrowing, as long as their accumulated debt is below a pre-specified limit. They also save for life-cycle, and precautionary reasons, and their wealth helps in absorbing income shocks. The calibration of the model uses standard parameter values in this literature.

By simulating an artificial panel from the model, we address two questions: (i) How much consumption smoothing is there in Bewley models? And, is this number high or low relative to that measured in the data by BPP? (ii) Does the BPP methodology yield reliable estimates of insurance coefficients? Answering this last question is possible because in the model we can compute both the true insurance coefficient and the value for the BPP estimator.

Our findings can be summarized as follows. First, the model counterpart of the BPP insurance coefficient for transitory shocks is 94% in the natural borrowing constraints (NBC) economy, and 82% in the zero borrowing constraint (ZBC) economy, and hence close to the empirical estimate of 95%. The insurance coefficient for permanent shocks is 22% in the

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<sup>3</sup>Schechtman & Escudero (1977), Chamberlain & Wilson (2000), Deaton (1991), and Carroll (1997), among others, proved a number of useful theoretical results about optimal consumption smoothing in a partial-equilibrium context. Existence of stationary competitive equilibria in this class of models was first studied by Laitner (1979) and Bewley (1983). Once the numerical tools to compute recursive equilibria became available, Imrohoroglu (1989), Huggett (1993), Aiyagari (1994) and Rios-Rull (1995), among others, advocated and pioneered quantitative research within this framework. Krusell & Smith (1998) developed computational tools to approximate equilibria in the presence of aggregate shocks, thereby greatly expanding the range of questions the model can address. The term “Bewley models” was first used in the Ljungqvist & Sargent (2004) textbook and, since then, it is becoming a common label for these models.

<sup>4</sup>Bewley models have been used extensively in macroeconomics for a variety of questions: measuring the size of precautionary saving (Aiyagari 1994, Hubbard, Skinner & Zeldes 1995, Gourinchas & Parker 2002), understanding the wealth distribution (Huggett 1996, Quadrini 2000, Castaneda, Diaz-Gimenez & Rios-Rull 2003, De Nardi 2004), explaining the equity premium (Telmer 1993, Heaton & Lucas 1996, Storesletten, Telmer & Yaron 2007), evaluating the distributional effects of fiscal policy (Krusell, Quadrini & Ríos-Rull 1996, Ventura 1999, Domeij & Heathcote 2004), measuring the welfare costs of business cycles (Krusell & Smith 1999), designing optimal fiscal policy (Erosa & Gervais 2002, Nishiyama & Smetters 2005, Conesa, Kitao & Krueger 2007); interpreting the path of life cycle inequality in consumption and hours worked (Storesletten, Telmer & Yaron 2001, Storesletten, Telmer & Yaron 2004), only to cite a few.

NBC economy, and only 7% in the ZBC economy. In both cases the model contains much less insurance with respect to permanent shock relative to the empirical estimate of 36%. Moreover, the life-cycle pattern of insurance coefficients for permanent shocks is sharply increasing and convex. This finding is strikingly at odds with the BPP estimates which imply a roughly flat age profile. The life-cycle discrepancy between model and data suggests that the model generates too much consumption smoothing for older workers nearing retirement, but too little smoothing for workers in the early stages of their life-cycle.

Second, we assess the reliability of the estimator proposed by BPP to identify insurance for each type of shock. We find that it works very well for transitory shocks, but it tends to systematically underestimate the true coefficient for permanent shocks which are 23% in both the NBC and ZBC economy. The reason is that the estimation procedure, analogous to an instrumental variables approach, exploits an orthogonality condition between consumption growth and a particular linear combination of past and future income shocks. The bias results from the fact that this orthogonality condition holds only approximately in the model. When borrowing constraints are loose the bias is negligible, but when they are tight this failure becomes very severe. Correcting for this bias, empirical insurance coefficients could be even larger than those estimated.

In light of these two findings, we explore two alternative ways in which standard Bewley models could generate less sensitivity of consumption to permanent shocks. We first allow agents to have some degree of foresight about future income realizations. We model this advance information in two ways. When we let agents know a fraction of the permanent shock one period ahead of time, we show that the BPP estimator of insurance coefficients is, in essence, invariant to the amount of advanced information. When we assume that earnings have an individual-specific deterministic trend which is known by the agent from “birth”, then the BPP estimator reflects a mix of insurance and foresight, and increases with the amount of advance information. However, we argue that for plausibly calibrated heterogeneity in income profiles, the estimated insurance coefficients remain lower than in the data. Overall, advance information does not bridge the gap between model and data.

Next, we generalize the specification of the statistical process for earnings. Instead of restricting it to an  $I(1)$  as assumed by BPP, we posit that the persistent component of the income process is  $AR(1)$ . We first show that the BPP method performs quite well, even under this misspecification error, for high degrees of persistence ( $\rho$ ). Next, we document

that for  $\rho$  between 0.93 and 0.97, depending on tightness of the constraint, the insurance coefficient for persistent shocks in the Bewley model can, on average, achieve its empirical value. However, its life cycle profile remains quite steep. We discuss some modifications of the model which either (i) shift wealth holdings from old to young, allowing the former to self-insure more effectively, or (ii) introduce explicit insurance against labor market shocks for younger agents.

Finally, we contrast the concept of insurance coefficient as a measure of risk sharing, with another norm for risk-sharing proposed by Deaton & Paxson (1994) and Storesletten et al. (2004) and used extensively in the literature: the steepness of life cycle consumption dispersion. There is no contradiction between our result that the model stops short of replicating the empirical insurance coefficient with their finding that a plausibly parameterized life cycle Bewley model generates the right increase in consumption inequality over the life cycle.

The rest of the paper is organized as follows. Section 2 introduces a general framework for measuring insurance, and describes the BPP methodology as a special case. Section 3 outlines the version of the Bewley model we use for our experiments, and describes its parametrization. Section 4 contains the results from our benchmark economies and from a series of sensitivity analysis. Section 5 introduces advance information into the model. Section 6 analyzes the robustness of our findings to the degree of persistence of income shocks. Section 7 concludes the paper.

## 2 A framework for measuring insurance

### 2.1 Insurance coefficients

**Income process** Suppose that residual (i.e., deviations from a deterministic and predictable experience profile common across all households) log-earnings  $y_{it}$  for household  $i$  of age  $t$  can be represented as a linear combination of current and lagged shocks

$$y_{it} = \sum_{j=0}^t \mathbf{a}'_j \mathbf{x}_{i,t-j} \quad (1)$$

where  $\mathbf{x}_{i,t-j}$  is an  $(m \times 1)$  vector of shocks with generic element  $x_{it}$ , and  $\mathbf{a}_j$  is an  $(m \times 1)$  vector of coefficients. The shocks are i.i.d. in the population and over time. Let  $\boldsymbol{\sigma} = (\sigma_1, \dots, \sigma_m)'$  be the corresponding vector of variances for these shocks. This formulation is

extremely general and incorporates, for example, linear combinations of ARIMA processes with fixed effects.

**Insurance coefficients** Let  $c_{it}$  be log consumption for household  $i$  at age  $t$ . We define the *insurance coefficient* for shock  $x_{it}$  as

$$\phi^x = 1 - \frac{\text{cov}(\Delta c_{it}, x_{it})}{\text{var}(x_{it})}, \quad (2)$$

where the variance and covariance are taken cross-sectionally over the entire population of households. One can similarly define the insurance coefficient at age  $t$  (denoted by  $\phi_t^x$ ) where variance covariance are taken conditionally on all households of age  $t$ . The insurance coefficient in (2) has an intuitive interpretation: it is the share of the variance of the  $x$  shock which does *not* translate into consumption growth.

**Identification and estimation** In any given model, it is straightforward to calculate (2) by simulation, since the shocks are observable in the model. However, identifying and estimating (2) from the data poses a crucial difficulty: the individual shocks are not directly observed and cannot be identified from a finite panel of income data.<sup>5</sup>

Suppose panel data on households' income and consumption are available. Let  $\mathbf{y}_i$  be the vector of income realizations for individual  $i$  at all ages  $t = 0, \dots, T$ , and let  $g_t^x(\mathbf{y}_i)$  index measurable functions of this income history, one for each  $t$  and for each shock  $x$ . Identification and estimation of insurance coefficients for shock  $x$  can be achieved by finding functions  $g_t^x$  such that

$$\begin{aligned} \text{var}(x_{it}) &= \text{cov}(\Delta y_{it}, g_t^x(\mathbf{y}_i)), \\ \text{cov}(\Delta c_{it}, x_{it}) &= \text{cov}(\Delta c_{it}, g_t^x(\mathbf{y}_i)), \end{aligned} \quad (3)$$

and then constructing  $\phi^x$  as

$$\phi^x = 1 - \frac{\text{cov}(\Delta c_{it}, g_t^x(\mathbf{y}_i))}{\text{cov}(\Delta y_{it}, g_t^x(\mathbf{y}_i))}. \quad (4)$$

Verifying the first condition in (3) only requires knowledge of the true income process, while verifying the second condition also requires knowledge of how the consumption allocation in

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<sup>5</sup>Note that it is not sufficient to identify the variances of the different shocks, i.e the vector  $\sigma$ . Rather, the realizations of the shocks must be identified, household by household. With a very long sequence of observations, realizations may be identified using filtering techniques. However the pervasive heterogeneity and the short time dimension of commonly available panel data sets is likely to make filtering techniques unreliable in this context.

the data depends on the entire income vector (past and future realizations of the shocks). Thus, it requires knowledge of the true data generating process (i.e. the model) for consumption.

This approach is best thought of in terms of instrumental variables regressions. If  $g_t^x(\mathbf{y}_i)$  satisfies the conditions in (3), then the resulting expression for  $1 - \phi^x$  is equivalent to the coefficient from an instrumental variables regression of consumption changes on income changes, using  $g_t^x(\mathbf{y}_i)$  as an instrument. In general, the correct choice of instrument depends on the particular specification of the income process, and the underlying true model for consumption. To progress further, one has to make assumptions about both.

## 2.2 BPP methodology

One can view the BPP methodology precisely as a choice of a particular income process and consumption allocation.

**BPP income process** BPP choose a particular specification of the income process in (1), where  $m = 2$ ,  $\mathbf{x}_{it} = (\eta_{it}, \varepsilon_{it})'$ ,  $\mathbf{a}_0 = (1, 1)'$  and  $\mathbf{a}_j = (1, 0)'$  for  $j \geq 1$ . This corresponds to the sum of a random walk (permanent) and an i.i.d. component:

$$y_{it} = z_{it} + \varepsilon_{it}, \quad (5)$$

where  $z_{it}$  follows a unit root process with shock  $\eta_{it}$ , and  $\varepsilon_{it}$  is an i.i.d. income shock with variances  $\sigma_\eta$  and  $\sigma_\varepsilon$ , respectively.<sup>6</sup> It follows that income growth can be written as

$$\Delta y_{it} = \eta_{it} + \Delta \varepsilon_{it}. \quad (6)$$

This is a very common income process in the empirical labor literature, at least since MaCurdy (1982), and Abowd & Card (1989), who showed that this specification is parsimonious and yet fits income data well. In Section 6, we verify the robustness of our results to more general specifications of the income process.

**BPP consumption model** BPP assume that the following pair of orthogonality con-

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<sup>6</sup>One can easily generalize this process by allowing a different distribution for the initial draw of the permanent shock. For example, let  $\eta_{i0} = z_0$  with variance  $\sigma_{z_0}$ . This generalization has no bearing on the methodology used to measure insurance coefficients, since the latter is based on growth rates, and hence the initial fixed effect is differenced out.



ditions hold for the true consumption allocation:

$$\text{cov}(\Delta c_{it}, \eta_{i,t+1}) = \text{cov}(\Delta c_{it}, \varepsilon_{i,t+1}) = 0, \quad (\text{NF})$$

$$\text{cov}(\Delta c_{it}, \eta_{i,t-1}) = \text{cov}(\Delta c_{it}, \varepsilon_{i,t-2}) = 0. \quad (\text{SM})$$

The first assumption means that the agent has “No Foresight” (or no advanced information) about future shocks. The second assumption translates into “Short Memory” (or short history dependence) of the consumption allocation with respect to shocks.<sup>7</sup>

Under these assumptions, BPP propose a strategy to identify and estimate the insurance coefficients. For the transitory shock  $\varepsilon$ , they set  $g_t^\varepsilon(\mathbf{y}_i) = \Delta y_{i,t+1}$  and note that

$$\text{cov}(\Delta y_{it}, \Delta y_{i,t+1}) = -\text{var}(\varepsilon_{it}), \quad (7)$$

$$\text{cov}(\Delta c_{it}, \Delta y_{i,t+1}) = -\text{cov}(\Delta c_{it}, \varepsilon_{it}),$$

while for the permanent shocks  $\eta$ , they set  $g_t^\eta(\mathbf{y}_i) = \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1}$  and note that

$$\text{cov}(\Delta y_{it}, \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1}) = \text{var}(\eta_{it}), \quad (8)$$

$$\text{cov}(\Delta c_{it}, \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1}) = \text{cov}(\Delta c_{it}, \eta_{it}).$$

Combining (4) with (7) and (8) confirms that these instruments do in fact correctly identify the insurance coefficients  $(\phi^\eta, \phi^\varepsilon)$ . It is easy to verify that only the orthogonality condition in (NF) is required for the identification of the insurance coefficients for transitory shocks, while both (NF) and (SM) are needed for permanent shocks.

In what follows, we call  $\phi_{BPP}^x$  the insurance coefficient estimator based on the BPP methodology. When the orthogonality conditions hold,  $\phi_{BPP}^x = \phi^x$ , but when they do not there will be a bias in  $\phi_{BPP}^x$ .

**Generality of the BPP approach** The obvious question, at this point, is: how general are assumptions (NF) and (SM)? In the absence of advance information about

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<sup>7</sup>To be precise, BPP start off their analysis from the consumption growth allocation

$$\Delta c_{it} = \pi_{it}^\eta \eta_{it} + \pi_{it}^\varepsilon \varepsilon_{it} + \xi_{it},$$

where  $\pi_{it}^\eta$  and  $\pi_{it}^\varepsilon$  are marginal propensity to consume out of permanent and transitory shocks, and  $\xi_{it}$  is a residual component. The choice of this specification is motivated by Blundell, Low & Preston (2005) who show that it approximates very well the solution of a life cycle optimization problem where agents have CRRA utility. The assumption implicit in the BPP study is that  $(\pi_{it}^\eta, \pi_{it}^\varepsilon, \xi_{it})$  are all independent of income innovations at every relevant lead and lag.

future earnings realizations,  $(NF)$  holds. But, there are instances where it fails. An example is in the presence of individual-specific predictable age-earnings profiles, a common class of income processes in the empirical labor literature introduced by Lillard & Weiss (1979). We return to this point in Section 5.

With respect to assumption  $(SM)$ , one can verify whether it holds in general only in models where the consumption allocation has a closed form. In the absence of a closed form, as in the standard incomplete-markets economy that we study in this paper, one must rely on model simulations.

The consumption literature offers only few closed-form solutions. It is easy to see that complete-markets and autarkic economies satisfy  $(SM)$ . Under complete markets, idiosyncratic shocks do not affect consumption, hence  $cov(\Delta c_{it}, x_{it}) = 0$  and  $\phi^x = 1$ . In autarky,  $\Delta c_{it} = \Delta y_{it}$ , hence  $cov(\Delta c_{it}, x_{it}) = var(x_{it})$  and  $\phi^x = 0$ . Note that in these two extreme cases, the value of  $\phi^x$  is independent of the durability of the shock.

The strict version of the life-cycle, rational-expectations, permanent income hypothesis (PIH), where agents have quadratic utility, live for  $T$  periods and can borrow and save at a constant risk-free rate  $r$  equal to the discount rate, generates the following rule for changes in consumption, when combined with the income process in (5) specified in levels:

$$\Delta C_{it} = \eta_{it} + \chi_t \varepsilon_{it},$$

where  $\chi_t = \frac{r}{(1+r)} \frac{1}{1-(1+r)^{-(T-t+1)}}$ .<sup>8</sup> Hence the PIH satisfies the BPP assumptions, and the insurance coefficients (defined in terms of *levels* rather than logs) for a PIH economy are  $\phi_t^\eta = 0$ , and  $\phi_t^\varepsilon = 1 - \chi_t$ . These values imply full transmission of permanent shocks to consumption, and a smoothing coefficient for transitory shocks that starts near one and decreases monotonically towards zero as the end of life becomes nearer. In what follows, we call this latter result the “horizon effect”.<sup>9</sup>

Finally, one can verify that the BPP assumptions hold in the partial insurance economy developed by Heathcote, Storesletten & Violante (2007), and in the moral-hazard economy studied by Attanasio & Pavoni (2007), both of which provide closed-forms solutions.

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<sup>8</sup>We use upper-case letters to denote variables in levels, and lower-case letters to denote variables in logs.

<sup>9</sup>In the context of the PIH, this structural identification approach based on closed-forms has a long history. Pioneering work by Sargent (1978), on aggregate data, and Hall & Mishkin (1982), on longitudinal PSID data, exploits restrictions across income and consumption processes implied by the PIH to estimate the model’s parameters. A more recent example is Blundell & Preston (1998).

These examples demonstrate that, in a wide variety of economic environments, it is possible to justify consumption allocations that are consistent with  $(NF)$  and  $(SM)$  and the BPP estimator is unbiased. But, is this true also for Bewley models? We answer this question in detail in the next sections.

**BPP findings** Straightforward application of a minimum distance algorithm allows estimation of the cross-sectional covariances in (7) and (8).<sup>10</sup> BPP reach three main findings. First, when labor income is defined as household earnings after tax and transfers, the insurance coefficient for permanent shocks  $\phi_{BPP}^\eta$  is estimated to be 36%. Second, the insurance coefficient for transitory shocks  $\phi_{BPP}^\varepsilon$  is estimated to be 95%. Third, the life cycle profile of  $\phi_{BPP}^\eta$  as a function of age is roughly flat.

### 3 A Bewley model

In this section, we outline and calibrate a life-cycle Bewley economy. We then simulate an artificial panel of household income and consumption from the model, and calculate the model’s counterpart of the BPP insurance coefficients. By comparing them to the empirical values estimated by BPP we can learn whether the Bewley model has the “right” amount of insurance.

Moreover, since in the model we can compute both the true insurance coefficients and those based on the BPP instruments, we are also in a position to assess the reliability of the BPP methodology. We will find out if and when assumptions  $(NF)$  and  $(SM)$  are violated.<sup>11</sup>

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<sup>10</sup>Note that the model can only be estimated from panel data with at least four consecutive observations on both household income and consumption. None of the currently available US surveys have this feature. As discussed in the Introduction, BPP cleverly merge the CEX and PSID and construct a long panel with nondurable consumption and income observations. See BPP (2004, 2008) for details.

<sup>11</sup>Before outlining the model, a brief note on language. We have defined  $\phi^x$  as *insurance* coefficients. In Bewley models, disposable income shocks do not transmit one for one into consumption because consumers have access to borrowing and saving. And thus, in this context, one may prefer the term “self-insurance” or “smoothing” to the term insurance or, say, risk-sharing. For example, Cochrane (1991) advocates the strict use of the term insurance only to denote inter-personal state-contingent transfers. We have chosen to keep using the term insurance in the rest of the paper for three distinct reasons. First, the definition of  $\phi^x$  is model-independent, and thus it can be used also in the context of models allowing for state-contingent income transfers across agents—indeed BPP refer to their estimates as “partial insurance coefficients”. Second, unlike dissaving, borrowing involves an inter-personal (even though not state-contingent) transfer. Third, even within models featuring only a risk-free financial asset, like ours, there may be important risk-sharing mechanism over and above self-insurance, for example government redistribution, that we will model explicitly through social security, the family, and certain institutions such as consumer’s bankruptcy. The total degree of individual consumption smoothing is also affected by such additional insurance mechanisms, over and above self-insurance.

### 3.1 The Economy

The model economy is the life-cycle version of the standard incomplete-markets model introduced by Imrohoroglu, Imrohoroglu & Joines (1995), Rios-Rull (1995) and Huggett (1996). There is no aggregate uncertainty. The economy is populated with a continuum of households, indexed by  $i$ . Agents work until age  $T^{ret}$ , at which they enter into retirement. The unconditional probability of surviving to age  $t$  is denoted by  $\xi_t$ . We assume that  $\xi_t = 1$  for the first  $T^{ret} - 1$  periods, so that there is no chance of dying before retirement. After retirement,  $\xi_t < 1$  and all agents die by age  $T$  with certainty. Altruism is assumed away. In order to focus solely on income uncertainty, we assume that there exist perfect annuity markets so that households are completely insured against survival risk.

Households have time-separable expected utility given by:

$$\mathbb{E}_0 \sum_{t=1}^T \beta^{t-1} \xi_t u(C_{it}).$$

During the working years, households receive labor income  $Y_{it}$  which is comprised of three components in logs:

$$\begin{aligned} \log Y_{it} &= \kappa_t + y_{it} \\ y_{it} &= z_{it} + \varepsilon_{it}, \end{aligned}$$

where  $\kappa_t$  is a deterministic experience profile that is common across all households, and  $y_{it}$  is the stochastic portion of income;  $z_{it}$  is a permanent component and  $\varepsilon_{it}$  is a transitory component. The component  $z_{it}$  follows a random walk

$$z_{it} = z_{i,t-1} + \eta_{it},$$

where  $z_{i0}$  is drawn from an initial Normal distribution with mean zero and variance  $\sigma_{z_0}$ . The shocks  $\varepsilon_{it}$  and  $\eta_{it}$  have mean zero, are Normally distributed with variances  $\sigma_\varepsilon$  and  $\sigma_\eta$ , and are orthogonal to each other, and independent over time and across households in the economy. This is precisely the BPP income process.

The concept of labor income that we adopt in the model for  $Y_{it}$  is households' earnings after taxes and transfers, the same used by BPP in the calculation of the insurance coefficients. However, it is useful to also define gross (or pre-government) labor income as  $\tilde{Y}_{it}$ , with  $\tilde{Y}_{it} = G(Y_{it})$ . For now, it suffices to think of the  $G$  function as the inverse of a tax function. In the calibration section, we explain in detail how we obtain  $G$ .

Retired households receive after-tax social security transfers  $P\left(\tilde{\mathbf{Y}}_i\right)$  from the government which are a function of the entire individual vector of gross earnings realizations  $\tilde{\mathbf{Y}}_i = \left\{\tilde{Y}_{i1}, \dots, \tilde{Y}_{it}, \dots, \tilde{Y}_{i,T^{ret}-1}\right\}$ .

Households can trade a risk-free, one-period bond which pays a constant after-tax rate of return,  $1 + r$ . We denote by  $A_{i,t+1}$  the amount of this asset carried over by individual  $i$  from time  $t$  to  $t + 1$ . As usual in these models, this asset has the twin role of a store of value and of a vehicle of self-insurance. Households begin their life with initial wealth  $A_{i0}$  drawn from the distribution  $H(A_{i0})$ , and face a lower bound  $\underline{A} \leq 0$  on their asset position.

The households budget constraint in this economy is, therefore,

$$\begin{aligned} C_{it} + A_{i,t+1} &= (1 + r) A_{it} + Y_{it}, & \text{if } t < T^{ret} \\ C_{it} + \left(\frac{\zeta_t}{\zeta_{t+1}}\right) A_{i,t+1} &= (1 + r) A_{it} + P\left(\tilde{\mathbf{Y}}_i\right), & \text{if } t \geq T^{ret} \end{aligned} \tag{9}$$

Finally, it is useful to note that in the version of the model with  $\underline{A} = 0$  households behave close to the buffer-stock, no-debt consumers characterized by Carroll (1997)—the only difference being the retirement period and the social security system.

For reasons we explain in the next section, in solving the model we do not impose restrictions which would correspond to a closed-economy general equilibrium of a production economy. However, our allocations of the baseline economy can also be interpreted as equilibrium outcomes.<sup>12</sup>

## 3.2 Calibration

We calibrate the model parameters to reproduce certain key features of the US economy. Our parametrization is standard for this class of economies.

**Demographics** The model period is one year. Households enter the labor market at age 25. We set  $T^{ret} = 35$  and  $T = 70$ . Thus workers retire at age 60 and die with certainty at age 95. The survival rates  $\xi_t$  are obtained from the NCHS (1992).

**Preferences** We choose a CRRA specification for  $u(C_{it})$  with risk aversion parameter  $\gamma = 2$ . We explore the sensitivity of our results to values of  $\gamma$  in the range  $[1, 15]$ .

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<sup>12</sup>In particular, any chosen value for the interest rate can be rationalized as the equilibrium marginal product of capital with the appropriate value of the technology parameters (depreciation and capital share). The government budget constraint can be thought of as holding exactly by assuming that the residual between tax revenues and pension benefits represents non-valued government consumption, and aggregate initial transfers to newborn agents distributed based on the function  $H(A_{i0})$ .

**Discount factor and interest rate** The size of the stock of accumulated assets directly affects the extent to which income shocks are smoothed. Hence it is important to ensure that the wealth to income ratio in the model is similar to that in the US economy. We set  $\beta$  to match an aggregate wealth-income ratio of 2.5. This is, approximately, the average wealth to average income ratio computed from the 1989 and 1992 Survey of Consumers Finances (SCF), when wealth is defined as total net worth, income is pre-tax labor earnings plus capital income, and when the top 5% of households in the wealth distribution are excluded.<sup>13</sup> The reason for this exclusion is comparability with PSID and CEX, the key sources of the BPP estimates. It is well known that both PSID and CEX severely under-sample the top of the wealth distribution.<sup>14</sup> We choose 1989 and 1992 as benchmark years for consistency with the sample period used by BPP. We study the sensitivity of our finding to the choice of the capital-income target.

Since our benchmark model is calibrated to generate only half of the total wealth in the US economy, we do not determine the interest rate in equilibrium. Instead, we set  $r = 3\%$  and we report results for different values of  $r$  in our robustness analysis.

**Income process** We calibrate the common deterministic age profile for log income  $\kappa_t$  using PSID data.<sup>15</sup> For the stochastic components of the income process, three parameters are required. These are the variance of the two shocks,  $\sigma_\varepsilon$  and  $\sigma_\eta$ , and the cross-sectional variance of the initial value of the permanent component  $\sigma_{z_0}$ . In our benchmark calibration we set the variance of permanent shocks to be 0.01 to match the rise in earnings dispersion over the life cycle in PSID from age 25 to age 60. The initial variance of the permanent shocks is set at 0.15 to match the dispersion of household earnings at age 25. We set the variance of transitory shocks to be 0.05, at the BPP point estimate. We also report results from various sensitivity analysis on these values.<sup>16</sup>

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<sup>13</sup>Below we explain how, in the model, we translate after-tax income  $Y_{it}$  into a measure of pre-tax, or gross, income  $\tilde{Y}_{it}$  that is needed to calibrate the wealth-income ratio and to determine social security benefits paid to each household.

<sup>14</sup>Wolff (1999) (Table 6) documents that PSID and SCF agree upon the amount of wealth held by the median household, and by the bottom four quintiles, but there are large discrepancies at the top. As a result, in 1992 average wealth in SCF is 50% higher than in PSID, which is precisely the share of net worth held by the top 5% in the SCF.

<sup>15</sup>The estimated profile peaks after 21 years of labor market experience at roughly twice the initial value, and then it slowly declines to about 80% of the peak value.

<sup>16</sup>In particular, we run a set of simulations with  $\sigma_\eta = 0.02$  which is the BPP estimate for the variance of the permanent component. Such value implies an excessive rise of earnings dispersion over the life cycle. Nevertheless, it is the point estimate which is typically obtained when the permanent-transitory income

**Initial wealth** In the benchmark calibration we assume that all households start their economic life with zero wealth, i.e.  $A_{i0} = 0$ . We also consider an environment in which initial wealth levels are drawn from a distribution calibrated to replicate the empirical distribution of wealth for young households in the data.<sup>17</sup>

**Borrowing limit** We consider two alternative borrowing limits.<sup>18</sup> We allow for borrowing subject only to the restriction that with probability one, households who live up to age  $T$  do not die in debt (i.e., the “natural debt limit”). This assumption represents an upper bound on the amount agents can borrow.<sup>19</sup> We also study the self-insurance possibilities of agents when the other extreme of no borrowing,  $\underline{A} = 0$ , is imposed.<sup>20</sup>

**Social security benefits** Social security benefits are a function of lifetime average individual gross earnings  $\tilde{Y}_i^{SS} = \frac{1}{T^{ret}-1} \sum_{t=1}^{T^{ret}-1} \tilde{Y}_{it}$ . This function is designed to mimic the actual US system. This is achieved by specifying that benefits are equal to 90% of average past earnings up to a given bend point, 32% from this first bend point to a second bend point, and 15% beyond that. The two bend points are set at, respectively, 0.18 and 1.10 times cross-sectional average gross earnings, based on the US legislation and individual earnings data for 1990. Benefits are then scaled proportionately so that a worker earning average labor income each year is entitled to a replacement rate of 45% (Mitchell & Phillips 2006).

To compute social security benefits for each household, we need to translate net earnings  $Y_{it}$ , our primitive earnings concept entering the working households’ budget constraint, into gross earnings  $\tilde{Y}_{it}$ . We do it by inverting the non-linear tax function estimated by Gouveia & Strauss (1994) and used, for example, by Castaneda et al. (2003). The explicit functional form is given by

$$\tau(\tilde{Y}_{it}) = \tau^b \left[ \tilde{Y}_{it} - \left( \tilde{Y}_{it}^{-\tau^p} + \tau^s \right)^{-\frac{1}{\tau^p}} \right]. \quad (10)$$

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process is estimated using moments in first-differences, as in BPP.

<sup>17</sup>Precisely, we target the empirical distribution of financial wealth/earnings ratios in the population of households aged 20-30 in the SCF. We assume that the initial draw of earnings is independent of the initial draw of this ratio, since in the data the empirical correlation is 0.02.

<sup>18</sup>The model displays precautionary saving both because of prudence as defined by Kimball (1990), and because households save to avoid hitting the debt limit (Huggett 1993).

<sup>19</sup>The level of the natural debt limit depends on the discretization of the income process, through the level of the lowest possible income realization. In the benchmark economy, the natural borrowing limit decreases from approximately 5.8 times average annual earnings at age 25 to 2.5 times average earnings at age 50.

<sup>20</sup>In a typical simulation of our economy with  $\underline{A} = 0$ , about 7% of households are at the constraint. These are primarily very young households. The fraction constrained decreases from 44% at age 26 to almost zero around age 45, but it rises again during retirement since the optimal consumption path is downward sloping (at rate  $\beta R$ ) and the pension income path is constant.



The values for  $\tau^b$  and  $\tau^\rho$  are taken from Gouveia & Strauss (1994) and set at  $\tau^b = 0.258$  and  $\tau^\rho = 0.768$ , their estimates for 1989, the latest year available.<sup>21</sup> The value for  $\tau^s$  is then chosen so that the ratio of total personal current tax receipts on labor income (not including social security contributions) to total labor income is the same as for the US economy in 1990, i.e. roughly 25%. Given a realization for after-tax earnings  $Y_{it}$ , we compute the corresponding gross earnings  $\tilde{Y}_{it}$  as the solution to the equation  $\tilde{Y}_{it} - \tau(\tilde{Y}_{it}) = Y_{it}$  which, implicitly, determines the  $G$  function defined above.

As in the US system, in the model the government taxes 85% of benefits through the function  $\tau(\cdot)$ , hence  $P(\tilde{\mathbf{Y}}_i)$  in the retiree's budget constraint (9) represents net benefits.

## 4 Results

All our results are based on simulating, from the invariant distribution of the model economy, an artificial panel of 50,000 households for 70 periods, i.e. a life-cycle. We have verified that increasing the sample size further does not lead to any change in the results.<sup>22</sup> Our two benchmark economies are calibrated as described in Section 3.2, and differ only through the borrowing constraint (and therefore the discount factor). The first economy has the loosest possible debt limit, the second has the tightest (zero). We refer to these two models as the natural borrowing constraint (NBC) economy, and the zero borrowing constraint (ZBC) economy.

### 4.1 Consumption and wealth over the life cycle

It is useful to begin with an examination of the life cycle profile of the first two moments (mean, variance of the log) for income, consumption and wealth in the two baseline models. The life cycle is plotted in Figure 1.

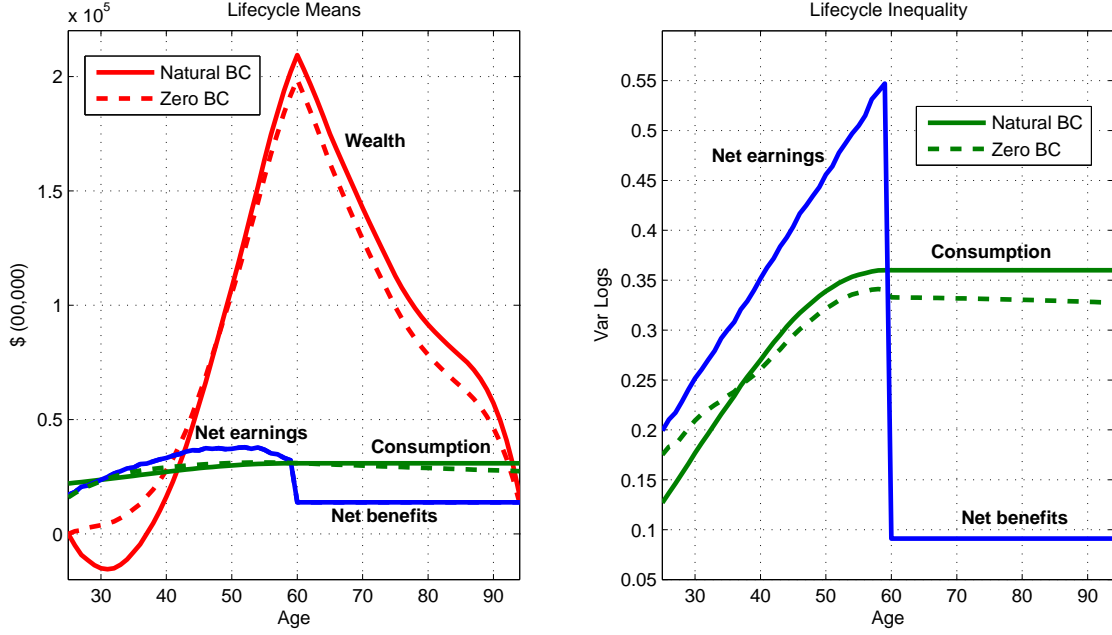
Average net earnings and social security benefits are exogenously fed into the model. Mean consumption grows until retirement because of the precautionary saving motive, which

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<sup>21</sup>We exclude social security tax from the Gouveia-Strauss tax function because they are not subtracted from the net earnings definition of BPP.

<sup>22</sup>The model is solved using the method of endogenous grid points developed by Carroll (2006) with 100 exponentially spaced grid points for assets. The grid for lifetime average earnings has 19 points. The decision rule is constrained to be linear between grid points. The permanent component is approximated using a discrete Markov chain with 39 equally-spaced points on an age-varying grid chosen to match the age-specific unconditional variances. The transitory component is approximated with 19 equally-spaced points. We have verified that further increasing the cardinality of the grids does not affect our conclusions.





**Figure 1:** Life cycle profiles for means and variances in the NBC and ZBC economies.

explains why its profile is steeper in the ZBC model. It then declines at a constant rate during retirement since the precautionary motive is absent, annuity markets are perfect, and the intertemporal saving motive is negative, i.e.  $\beta R < 1$ . Mean wealth dynamics follow the typical triangle-shaped path of life cycle models. In the NBC economy, households are indebted, on average, for the first decade, but then they decumulate wealth at a slower rate once retired. The reason is that both economies have the same aggregate capital-income ratio, and agents in the NBC economy optimally hold lower wealth than the ZBC agents during their youth, and more during retirement.

The cross-sectional variance of log net earnings increases linearly over the life cycle because of the cumulation of permanent shocks, and drops to a constant level during retirement since pension benefits are deterministic and much less unequal than labor income.

Consumption inequality rises during work-life, but more slowly than earnings inequality thanks to the self-insurance and the redistributive social security system. The initial level of consumption inequality is lower in the NBC economy since, initially, borrowing allows households to smooth consumption more effectively. Over time, in the NBC economy wealth dispersion grows at a faster rate (as some agents keep saving and others keep borrowing), which translates into faster growth in consumption inequality. In the absence of binding borrowing limits, cross-sectional consumption inequality should remain constant

	Permanent Shock			Transitory Shock		
	Data BPP	Model BPP	Model TRUE	Data BPP	Model BPP	Model TRUE
Natural Borrowing Limit	0.36 (0.09)	0.22	0.23	0.95 (0.04)	0.94	0.94
Zero Borrowing Limit	0.36 (0.09)	0.07	0.23	0.95 (0.04)	0.82	0.82

**Table 1:** Results from the benchmark models with NBC and ZBC

during retirement as consumption growth would be the same for every agent (and equal to  $\beta R$ ). This is essentially the case for the NBC economy, whereas in the ZBC economy the fraction of agents at the constraint gradually rises during retirement, which slowly reduces cross-sectional consumption dispersion.

## 4.2 BPP insurance coefficients in the data and the model

We now turn to the insurance coefficients. To be consistent with the BPP approach, when computing insurance coefficients, log consumption and log after-tax earnings are defined as residuals from a common age profile, and denoted as  $(c_{it}, y_{it})$ .

In all tables and figures below, columns labeled “Data BPP” report the BPP (2008) empirical estimates (with associated standard errors) from the merged PSID/CEX data set (1980-1992). Columns labeled “Model BPP” refer to the estimates of model’s insurance coefficients calculated using the instrumental variables approach described in Section 2.1, i.e.  $\phi_{BPP}^x$ . The difference between Data BPP and Model BPP is informative on the extent of consumption insurance in Bewley model relative to the data, since these are measured in exactly the same way.

**Average insurance coefficients** How much consumption insurance does a reasonably calibrated Bewley model permit? Table 1 shows that applying the BPP methodology to the simulated panel of consumption and income generates insurance coefficients of 0.22 for permanent shocks, and 0.94 for transitory shocks in the economy with natural borrowing limits (NBC). In the economy with zero borrowing (ZBC), these two coefficients are 0.07 and 0.82, respectively. These numbers compare to estimates of insurance coefficients of, respectively, 0.36 and 0.95 in the US data.

Hence, the model generates the right amount of insurance with respect to transitory

shocks in the NBC economy, and 87% of its data counterpart in the ZBC economy. In this respect, the model is successful. However, the amount of insurance against permanent shocks is substantially less than in the US economy: around 60% of its empirical value in the NBC economy, and 20% in the ZBC economy. In this respect, the model admits substantially less insurance than the US economy against permanent earnings shocks.

### 4.3 Accuracy of the BPP methodology

We now assess the accuracy of the BPP methodology for estimating insurance coefficients. This can be done by comparing the columns labeled “Model BPP” and “Model TRUE”. This latter label refers to the model’s insurance coefficients  $\phi^x$  calculated directly from the realizations of the individual shocks instead of the instruments.

Table 1 reveals that whereas the BPP methodology works extremely well for transitory shocks, it tends to systematically underestimate the amount of insurance for permanent shocks. The bias is very small for the NBC economy, just 0.01, but it is large for the ZBC economy, around 0.16. This result suggests that the unbiased empirical estimate of the insurance coefficient for permanent shocks  $\phi_{BPP}^\eta$  may be even higher than 0.36, which is the BPP point estimate for the US economy.<sup>23</sup>

**Failure of orthogonality conditions** This downward bias in the BPP estimator for permanent shocks is exacerbated in the ZBC economy. The reason for the large bias in  $\phi_{BPP}^\eta$  is that the orthogonality conditions in  $(SM)$  may fail when agents are near the liquidity constraint.<sup>24</sup> It turns out that both covariances in  $(SM)$  contribute to the negative bias. However, the quantitatively more important factor is that  $cov(\Delta c_{it}, \varepsilon_{i,t-2}) < 0$ .

To gain intuition for why this covariance may be negative near the borrowing limit, consider a household who receives a negative transitory shock at  $t - 2$  (i.e.,  $\varepsilon_{t-2} < 0$ ). Such a household would like to borrow (or dissave) to smooth the negative shock. However, for a household close to its borrowing limit, even a small reduction in wealth can have a large expected utility cost because of the possibility of becoming constrained in the future. This smoothing entails an optimal drop in consumption at  $t - 2$ . The closer agents are to

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<sup>23</sup>Authors’ calculations suggest that the absolute size of biases is largely independent of the level of the true value. Hence, unbiased point estimates of  $\phi_{BPP}^\eta$  for the US economy, once accounting for the downward bias, could be anywhere between 0.37 and 0.52 depending how constrained US households are.

<sup>24</sup>Recall that assumption  $(SM)$  is required for identification of insurance coefficients for permanent shocks, but not for transitory shocks.

the borrowing constraint, the larger this drop. This leads to a *positive* expected change in consumption in the next period, i.e.  $cov(\Delta c_{t-1}, \varepsilon_{t-2}) < 0$  as consumption returns to its baseline level. Since agents prefer smooth paths for consumption, this adjustment takes place gradually, and  $cov(\Delta c_t, \varepsilon_{t-2}) < 0$  as well.<sup>25</sup>

**Small-sample bias** Even though we have mainly interpreted the data-model discrepancy in the BPP coefficients as failure of the orthogonality conditions assumed by BPP, there is an additional source of discrepancy. While in the model's simulations we use a very large sample, the BPP estimates are based on a smaller sample of around 17,000 household/year observations, or roughly 1,300 households per year. To assess the magnitude of the small-sample bias, we have run 50 simulations of samples with 1,300 households each. The means of both the true and the BPP coefficients are virtually unchanged, so we conclude that the small-sample bias is negligible.

## 4.4 Age profiles of insurance coefficients

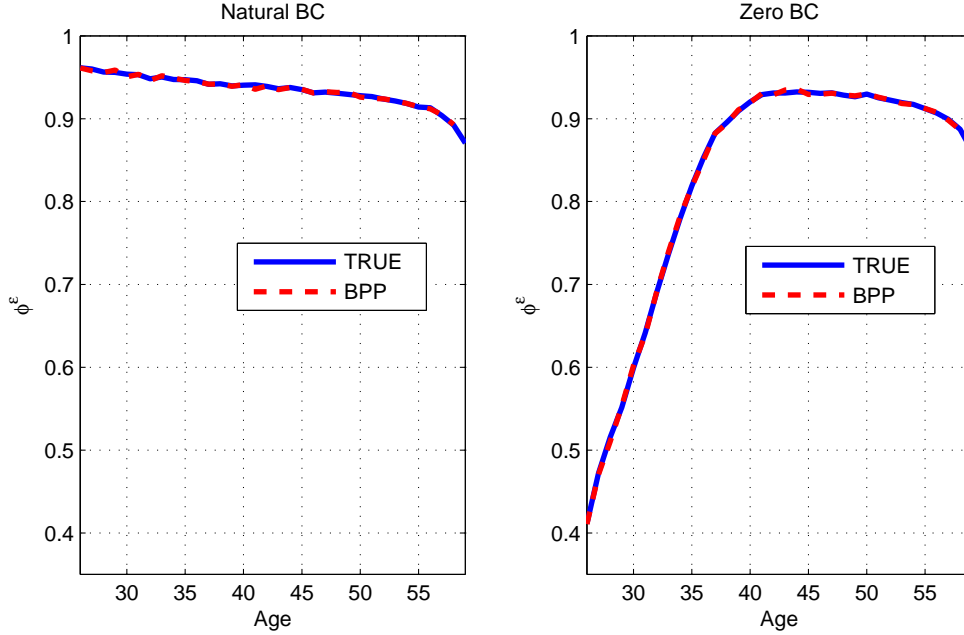
**Transitory shocks** Not only are the overall true insurance coefficients for transitory shocks,  $\phi^\varepsilon$ , different in the ZBC and NBC economies (0.82 versus 0.94), but shape of their respective life cycle profiles are very different. This is evident from Figure 2.

In the NBC economy, the insurance coefficients for transitory shocks are above 0.85 at all ages and decrease slightly with age. The loose debt limits allow young households to smooth the effects of negative transitory shocks even though they have not accumulated much precautionary wealth. The decrease with age is due to the shortening time horizon. A transitory income shock is effectively transitory only insofar as there are remaining future dates in which an offsetting shock may be received. This is the horizon effect that we discussed in Section 2.2 in reference to the PIH. Finally, note that the BPP estimator is extremely accurate at every age.

When we impose a no-borrowing constraint, the age pattern of the transitory insurance coefficients changes dramatically: it starts at around 0.40 at age 25, and increases sharply in a concave fashion to 0.93 by age 45. As explained, young workers have little wealth

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<sup>25</sup>With a longer panel, it may be possible to reduce the downward bias in  $\phi_{BPP}^\eta$  by adding additional lags of income growth to the instrument. For example, using  $g_t^\eta(\mathbf{y}_i) = \Delta y_{i,t-2} + \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1}$  changes the required short memory assumption to  $cov(\Delta c_{it}, \eta_{i,t-2}) = cov(\Delta c_{it}, \eta_{i,t-1}) = cov(\Delta c_{it}, \varepsilon_{i,t-3}) = 0$ . The cost of using this modified instrument is the additional year of income data required, and the associated increase in measurement error.



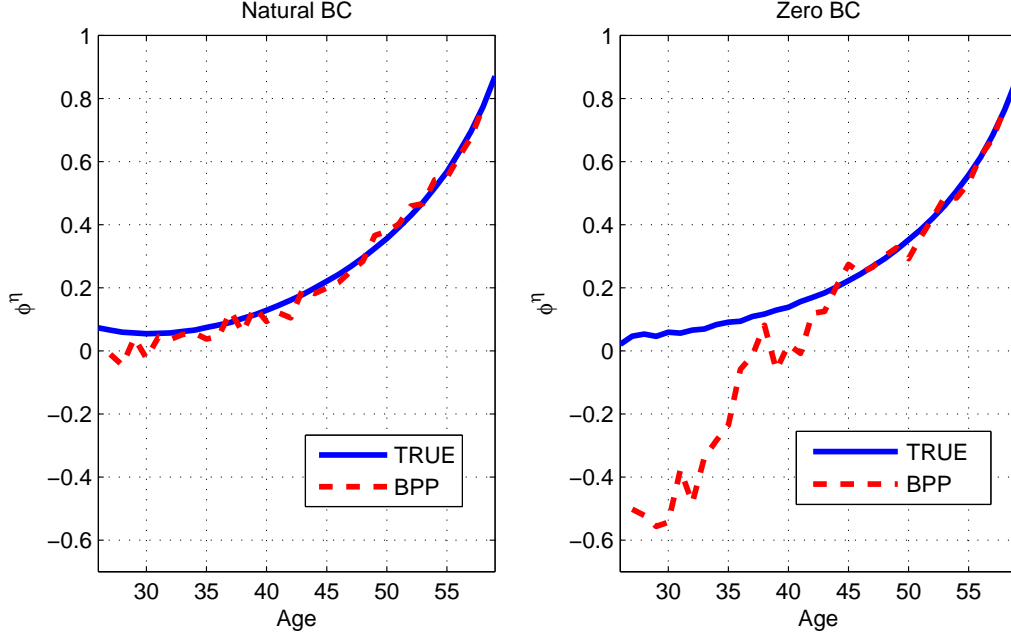
**Figure 2:** Age profiles of insurance coefficients for transitory shocks.

and cannot borrow. As such, they are unable to smooth negative transitory shocks until they have cumulated enough precautionary savings. Once this point is reached, the profile starts declining as the horizon effect kicks in. In the ZBC case too, the BPP estimator is consistently accurate.

**Permanent shocks** The true average value of the insurance coefficient  $\phi^\eta$  is virtually the same in the two economies, 0.23.<sup>26</sup> It may seem puzzling that, when borrowing constraints are tightened, insurance does not worsen. However, when doing this thought experiment, total wealth is kept constant. Therefore, wealth shifts from old to young households in the form of higher precautionary saving which increases insurance coefficients for the young.

BPP report that when they allow the insurance coefficient for permanent shocks to vary linearly with age, they estimate a slope that is not significantly different from zero. Figure 3 reveals a very different scenario for both economies. In the NBC economy,  $\phi_t^\eta$  are mildly decreasing at young ages, but are increasing steadily after age 35 and are markedly convex in age. The BPP estimator is always very close to its true value, except at young ages,

<sup>26</sup>This insurance coefficient implies a “marginal propensity to consume” out of permanent shocks of roughly 0.77. Based on his buffer-stock model of consumption, Carroll (2001) explains that the “conventional intuition” that this marginal propensity should be one (as in the strict version of the PIH) is flawed in a life-cycle model.



**Figure 3:** Age profiles of insurance coefficients for permanent shocks.

where agents have the largest debt and are close to their natural limit. The overall shape of the profile in the ZBC economy is similar, except for the initial decrease. As one could have anticipated, the BPP methodology severely underestimates  $\phi_t^\eta$  at young ages, because a large fraction of households is at the constraint. The bias gradually reaches zero only around age 45.

The general shape of the true insurance coefficient is driven by two forces. First, there is the wealth composition effect. As agents accumulate financial wealth, for precautionary and life-cycle reasons, they consume more out of financial wealth and less out of human wealth (i.e., the expected discounted value of their earnings), so permanent shocks to earnings have a smaller impact on consumption. As a result, insurance coefficients have a strong tendency to rise with age. This also explains why in the NBC economy insurance coefficients decline in the early part of the life cycle. The deterministically increasing age-profile for earnings provides a strong incentive to borrow early in life to smooth consumption and, as explained, insurance coefficients for permanent shocks are increasing in net financial wealth.<sup>27</sup>

<sup>27</sup>We have uncovered that the true insurance coefficient  $\phi_t^\eta$  may go slightly negative over the first decade. A negative value for  $\phi_t^\eta$  is obtained when  $cov(\Delta c_{it}, \eta_{it}) > var(\eta_{it})$ , i.e. consumption responds more than one-for-one to a particular shock. The reason this may happen is due to the interaction of transitory shocks and permanent shocks in the model, as explained by Carroll (1997). With  $\sigma_\varepsilon > 0$ , households will accumulate a target level of wealth which they use to buffer the effects of transitory shocks. When a positive permanent shock hits, transitory shocks become a smaller component of lifetime income, both in the current period, and

Data	Permanent Shock		Transitory Shock	
	0.36 (0.09)		0.95 (0.04)	
	Model TRUE	Model BPP	Model TRUE	Model BPP
Benchmark	0.23	0.22	0.94	0.94
Initial Wealth Distribution	0.23	0.22	0.94	0.94
Risk Aversion:				
$\gamma = 1$	0.22	0.21	0.94	0.94
$\gamma = 5$	0.27	0.24	0.93	0.93
$\gamma = 10$	0.32	0.29	0.92	0.92
$\gamma = 15$	0.37	0.32	0.92	0.92
Social Security:				
Rep. ratio = 0.25	0.19	0.17	0.93	0.93
Rep. ratio = 0.65	0.27	0.26	0.94	0.94
Variance Permanent Shock:				
$\sigma_\eta = 0.02$	0.25	0.24	0.93	0.93
$\sigma_\eta = 0.005$	0.22	0.20	0.94	0.94
Variance Initial Permanent:				
$\sigma_{z_0} = 0.2$	0.23	0.22	0.94	0.94
$\sigma_{z_0} = 0.1$	0.24	0.22	0.94	0.94
Variance Transitory Shock				
$\sigma_\varepsilon = 0.075$	0.24	0.22	0.94	0.94
$\sigma_\varepsilon = 0.025$	0.23	0.22	0.94	0.94

**Table 2:** Sensitivity analysis for the model with NBC

Second, there is the time horizon effect. By definition, permanent shocks rescale the entire earnings profile during work-life, and also have an effect on retirement income whose size is inversely proportional to the progressivity of the pension system. As households get closer to retirement, less of their human wealth is affected in this way by permanent shocks.<sup>28</sup>

in all future periods. Hence the utility cost of not being able to smooth transitory shocks falls. Households reduce the optimal level of wealth they desire to buffer transitory shocks. Consumption may thus respond to the full effect of the positive permanent shock, plus an additional amount that is the decrease in the optimal precautionary wealth level. A similar logic applies to negative permanent shocks. We have verified that when we simulate the model without transitory shocks ( $\sigma_\varepsilon = 0$ ), then  $\phi_t^\eta$  is always positive.

<sup>28</sup>Interestingly, the true insurance coefficients for both permanent and transitory shock at retirement are equal (see the Figures). In the absence of any pension system (or in presence of the most redistributive system, where benefits are a lump-sum disconnected from lifetime earnings) both insurance coefficient at retirement should be approximately one. Since in the model social security benefits depends also on income in the last year of work, we find that they are both slightly less than one.

Data	Permanent Shock		Transitory Shock	
	0.36 (0.09)		0.95 (0.04)	
	Model TRUE	Model BPP	Model TRUE	Model BPP
Benchmark	0.23	0.07	0.82	0.82
Initial Wealth Distribution	0.24	0.09	0.83	0.83
Risk Aversion:				
$\gamma = 1$	0.23	0.05	0.81	0.81
$\gamma = 5$	0.23	0.12	0.85	0.85
$\gamma = 10$	0.29	0.19	0.88	0.88
$\gamma = 15$	0.33	0.23	0.88	0.88
Social Security:				
Rep. ratio = 0.25	0.21	−0.00	0.78	0.78
Rep. ratio = 0.65	0.25	0.13	0.86	0.85
Variance Permanent Shock:				
$\sigma_\eta = 0.02$	0.23	0.15	0.83	0.83
$\sigma_\eta = 0.005$	0.23	−0.09	0.82	0.82
Variance Initial Permanent:				
$\sigma_{z_0} = 0.2$	0.23	0.07	0.82	0.82
$\sigma_{z_0} = 0.1$	0.24	0.08	0.83	0.83
Variance Transitory Shock				
$\sigma_\varepsilon = 0.075$	0.24	0.00	0.83	0.83
$\sigma_\varepsilon = 0.025$	0.23	0.14	0.82	0.82

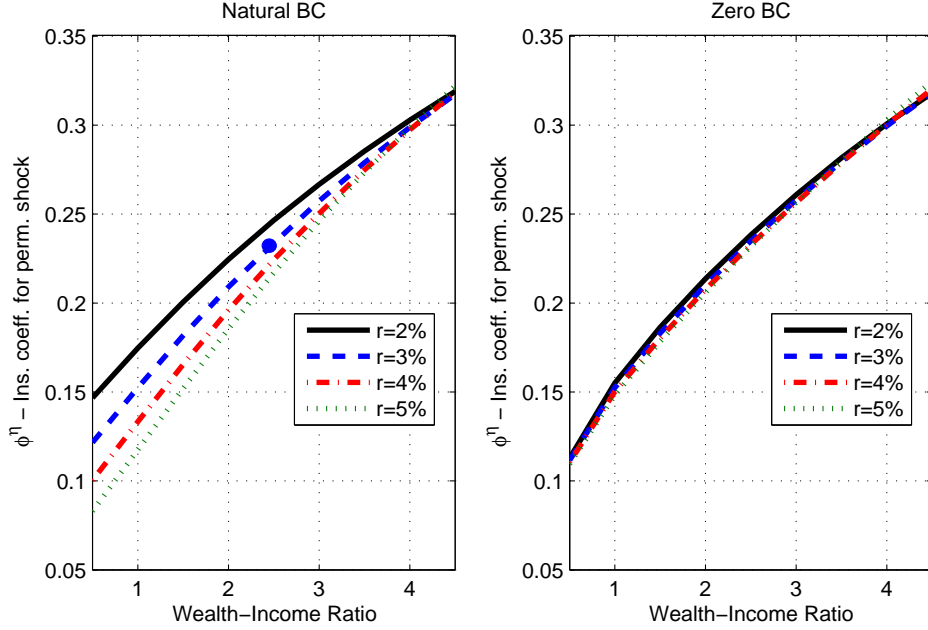
**Table 3:** Sensitivity analysis for the model with ZBC

## 4.5 Sensitivity analysis

Tables 2 and 3 report a wide set of sensitivity analysis on the baseline economy with NBC and ZBC respectively. In each of these experiments, we recalibrate the economy (i.e., we reset  $\beta$ ) in order to maintain a wealth-income ratio of 2.5.

The right-hand side of the tables shows that our computed insurance coefficient against transitory shocks is extremely robust across different parameterizations. The left-hand side of the tables reports results for the permanent shock. Allowing for an initial wealth distribution—calibrated on the asset holdings of the young in the SCF—has very little effect on the insurance coefficients. Households with high levels of risk aversion are less tolerant of consumption fluctuation, thus as  $\gamma$  rises insurance coefficients for permanent shocks increase. However, only for values of  $\gamma$  beyond fifteen do we reach insurance coefficients close to those estimated in the data. When we reduce the average replacement ratio of the social security





**Figure 4:** Sensitivity of  $\phi^\eta$  with respect to  $r$  and  $K/Y$  in the NBC and ZBC economies.

system from 0.45 to 0.25 insurance coefficients drop and when we increase it to 0.65 they increase, as expected. The amount of insurance in the model does not depend on the size of the shocks, when the latter is varied within a plausible range.

In the NBC economy, the bias in the BPP estimator is always of the same order of magnitude, and rather small, except for the high  $\gamma$  case. In the ZBC economy, the bias is always large and particularly so in some cases. For example, with large transitory uncertainty, the borrowing limit will bind more often. With a small replacement rate, financial wealth shifts from young workers who are subject to income shocks to retirees who are not.

**Interest rate and K/Y ratio** Figure 4 plots values of  $\phi^\eta$  as a function of various wealth-income ratios (obtained by changing  $\beta$ ) and of various values of  $r$  in the two economies economy. Higher wealth-income ratios map into larger asset holdings that can be used to smooth income shocks, and hence into higher values for  $\phi^\eta$ . The idea that patient consumers can self-insure effectively goes back to Yaari (1976) in partial equilibrium, and Carroll (1997) and Levine & Zame (2002) in general equilibrium.<sup>29</sup> Lower interest rates increase insurance coefficients in the NBC economy, as they loosen the borrowing limit, and the effect is therefore stronger in an economy with low aggregate wealth. In the ZBC economy, lower interest rates

<sup>29</sup>As expected, we also find that the bias in the BPP coefficient grows as the wealth-income ratios are reduced.

reduce the cost of precautionary saving. Qualitatively consumption smoothing goes up, but we find that quantitatively the effects are negligible.

## 4.6 A welfare calculation

Is the data-model discrepancy in insurance coefficients for permanent shocks large or small? To answer this question, we perform a welfare calculation in an economy that “approximates” the Bewley model described above.<sup>30</sup>

Consider an economy where agents survive into the next period with constant probability  $1/(1+\pi)$ , discount the future at rate  $\beta = 1/(1+\rho)$ , and have intra-period CRRA utility with risk-aversion parameter  $\gamma$ . They face an idiosyncratic log-income process  $y_t = z_t$ , where  $z_t$  is a permanent component with innovation  $\eta_t \sim N(-\sigma_\eta/2, \sigma_\eta)$ .<sup>31</sup> Suppose that individual log-consumption follows the rule

$$c_{it} = (1 - \phi^\eta) z_{it} \quad (11)$$

which satisfies assumptions  $(NF)$  and  $(SM)$ .

Based on the derivations in Heathcote et al. (2007), we can show that the long-run average welfare differential  $\omega$  (in terms of consumption equivalent units) between an economy where households have an insurance parameter  $\phi^\eta$  and one where they have a lower insurance parameter  $\tilde{\phi}^\eta$  is approximately

$$\omega \simeq \frac{\gamma}{2} \left[ (1 - \phi^\eta)^2 - (1 - \tilde{\phi}^\eta)^2 \right] \frac{\sigma_\eta}{\rho + \pi}.$$

With  $\gamma = 2$ ,  $\rho = 0.03$ ,  $\pi = 0.0286$  (35 years of average working life), and  $\sigma_\eta = 0.01$ , the discrepancy between  $\phi = 0.36$ , the BPP estimate on US data, and  $\tilde{\phi} = 0.23$ , the true value in the two economies, is equivalent to 3.1% of permanent consumption. This simple calculation (a lower bound since we have ignored the downward bias) suggests that the data-model discrepancy is not negligible.

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<sup>30</sup>To calculate the welfare benefits of moving from an economy with  $\phi^\eta$  to one with  $\tilde{\phi}^\eta$  in general one needs to know the consumption allocation. That is, changes in  $\phi^\eta$  are not a sufficient statistic for changes in welfare. We perform an illustrative welfare calculation using a simple and transparent consumption allocation that, according to Blundell, Low & Preston (2005) approximates well the optimal behavior of a Bewley consumer with loose liquidity constraints.

<sup>31</sup>We abstract from heterogeneity in initial draws of  $z_0$ . Introducing it would strengthen our conclusions. Since we focus our calculation on differences in  $\phi^\eta$ , we also abstract from transitory shocks.

## 5 Advance information

In this section, we assess whether allowing the agents to know more about their future income growth than the “econometrician” can reconcile the gap between the insurance coefficients estimated by BPP with those computed in the benchmark models.<sup>32</sup> If part of a measured income change at date  $t$  was known to the agents in advance, then this change would have been already incorporated into consumption decisions at the time it was learned, and would not affect consumption growth at  $t$ . The contemporaneous correlation of measured income growth with consumption growth at date  $t$  would be lower than if all of the growth in income was news at  $t$ .

It is necessary to take a stand on the particular form that the advance information takes. We examine two cases which make different assumptions about the timing of receipt of the advance information. In the first model, agents learn about a component of their permanent shock to income one period in advance. An interpretation is that of receiving a signal about a future pay-rise, wage cut, promotion, or demotion, in the period before the change actually takes place. In the second model, we allow agents to foresee the slope of their own income profile upon entry in the labor market, i.e. at age  $t = 0$ . This model is a version of the heterogeneous income profiles model studied by Lillard & Weiss (1979), Baker (1997), Haider (2001), and Guvenen (2007), among others. An interpretation of this view is that, by choosing a specific occupation, an individual knows what income profile to expect.

We are also interested in knowing what the BPP estimator captures in these two cases. BPP state that, in the presence of advanced information, “the estimated coefficient has to be interpreted as reflecting a combination of insurance and information” (BPP, 2008, page 15). We will show that, while this is exactly true in the second model, in the first one only the insurance component is reflected in the value of  $\phi_{BPP}^\eta$ .

### 5.1 Preempting permanent shocks

Consider a modification of the information set of the agent whereby the permanent change in income at date  $t$ ,  $\eta_{it}$ , consists of two additive orthogonal components,  $\eta_{it}^s$ , and  $\eta_{it}^a$ . The component  $\eta_{it}^s$  is the true shock which becomes known to the agent only at date  $t$  and affects

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<sup>32</sup>The interest in the role of “advance information” has been revived in a series of recent papers by Cunha, Heckman & Navarro (2005), Guvenen (2007), Huggett, Ventura & Yaron (2006) and Primiceri & van Rens (2006), among others.

income at date  $t$ . The component  $\eta_{it}^a$  is in the agent's information set already at date  $t - 1$ , but it is only incorporated into income at date  $t$ . The permanent component of earnings is given by

$$z_{it} = z_{i,t-1} + \eta_{it}^s + \eta_{it}^a,$$

where  $\mathbb{E}(\eta_{it}^s) = \mathbb{E}(\eta_{it}^a) = 0$ , and the variances of the two components are varied in a way that keeps  $\text{var}(\eta_{it}) = \text{var}(\eta_{it}^s + \eta_{it}^a)$  constant at its baseline value of 0.01.

**Permanent shocks** In the economy with NBC, from the definition of insurance coefficient for permanent shocks,

$$\begin{aligned} \phi^\eta &= 1 - \frac{\text{cov}(\Delta c_{it}, \eta_{it})}{\text{var}(\eta_{it})} = 1 - \frac{\text{cov}(\Delta c_{it}, \eta_{it}^s + \eta_{it}^a)}{\text{var}(\eta_{it}^s + \eta_{it}^a)} \\ &= (1 - \alpha) \phi^{\eta^s} + \alpha \phi^{\eta^a} \\ &\approx (1 - \alpha) \phi^{\eta^s} + \alpha \end{aligned} \quad (12)$$

where  $\phi^{\eta^s}$  and  $\phi^{\eta^a}$  are “insurance coefficients” with respect to the two components of permanent earnings growth (the shock and the change known in advance), and  $\alpha$  is the share of the variance of permanent earnings growth which is known one period ahead (i.e., the advance information ratio). The approximate equality in the last line holds because, when borrowing constraints are unimportant, as for the NBC economy,  $\text{cov}(\Delta c_{it}, \eta_{it}^a) \approx 0$ , since  $\eta_{it}^a$  is fully incorporated in consumption growth at  $t - 1$ . It follows that the true insurance coefficient  $\phi^\eta$  is a combination of smoothing ( $\phi^{\eta^s}$ ) and advance information, whose relative magnitude is regulated by  $\alpha$ .

However, when the BPP methodology is used to estimate insurance coefficients for permanent shocks, we reach a different conclusion. In what follows, it is useful to ignore the (small in the NBC economy) downward bias discussed in Section 4.3 due to the failure of assumption (SM) and associated to the covariance between  $\Delta c_{it}$  and shocks  $\varepsilon_{i,t-2}$  and  $\eta_{i,t-1}^s$ .

From the definition of  $\phi_{BPP}^\eta$ , we have:

$$\begin{aligned} \phi_{BPP}^\eta &= 1 - \frac{\text{cov}(\Delta c_{it}, \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1})}{\text{cov}(\Delta y_{it}, \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1})} \approx 1 - \frac{\text{cov}(\Delta c_{it}, \eta_{it}^s + \eta_{i,t+1}^a)}{\text{var}(\eta_{it}^s + \eta_{it}^a)} \\ &= 1 - \frac{\text{cov}(\Delta c_{it}, \eta_{it}^s)}{\text{var}(\eta_{it}^s)} \left[ \frac{\text{var}(\eta_{it}^s)}{\text{var}(\eta_{it}^s + \eta_{it}^a)} \right] - \frac{\text{cov}(\Delta c_{it}, \eta_{i,t+1}^a)}{\text{var}(\eta_{it}^a)} \left[ \frac{\text{var}(\eta_{it}^a)}{\text{var}(\eta_{it}^s + \eta_{it}^a)} \right] \\ &= (1 - \alpha) \phi^{\eta^s} + \alpha \left[ 1 - \frac{\text{cov}(\Delta c_{it}, \eta_{i,t+1}^a)}{\text{var}(\eta_{it}^a)} \right] \\ &\approx \phi^{\eta^s}. \end{aligned} \quad (13)$$

The first line uses the fact that  $cov(\Delta c_{it}, \eta_{it}^a) \approx 0$ . As evident from the third line, the BPP estimator is a weighted average of the insurance coefficient for the current shock ( $\phi^{\eta^s}$ ) and a term which looks like an insurance coefficient for the component of the  $t + 1$  earnings growth which is known at  $t$ . This last term enters the expression through the component  $\Delta y_{i,t+1}$  of the BPP instrument, i.e. assumption  $(NF)$  fails to hold. Since, in the NBC economy, consumption growth  $\Delta c_{it}$  should react equally to  $\eta_{it}^s$  and to  $\eta_{i,t+1}^a$  (except for a minor difference due to discounting), we have  $\phi_{BPP}^\eta \approx \phi^{\eta^s}$ , as stated in the last line.

We conclude that, whereas the true insurance coefficient  $\phi^\eta$  reflects a combination of insurance and advance information as seen in (12), the BPP coefficient  $\phi_{BPP}^\eta$  is roughly independent of the amount of foresight. As a result, this form of advance information cannot account for the data-model discrepancy.

**Transitory shocks** For transitory shocks, we have exactly the opposite result. The true insurance coefficients  $\phi^\varepsilon$  are unaffected by the presence of advanced information because the response of consumption growth to transitory shocks is invariant to the timing of news about permanent shocks. However, the BPP estimator  $\phi_{BPP}^\varepsilon$  has an upward bias which increases with the size of  $\alpha$ . To understand this bias, note that:

$$\begin{aligned} \phi_{BPP}^\varepsilon &= 1 - \frac{cov(\Delta c_{it}, \Delta y_{i,t+1})}{cov(\Delta y_{it}, \Delta y_{i,t+1})} = \phi^\varepsilon + \frac{cov(\Delta c_{it}, \eta_{i,t+1}^a)}{var(\varepsilon_{it})} \\ &\approx \phi^\varepsilon + \alpha (1 - \phi^{\eta^s}) \left[ \frac{var(\eta_{it})}{var(\varepsilon_{it})} \right], \end{aligned} \tag{14}$$

where the second line uses the fact that  $cov(\Delta c_{it}, \eta_{i,t+1}^a) \approx cov(\Delta c_{it}, \eta_{it}^s)$ . The upward bias results from a failure of the identification assumption  $(NF)$ , since a fraction of next period permanent income growth in  $\Delta y_{i,t+1}$  is known in advance and transmits to consumption growth at date  $t$ . Quantitatively, this upward bias is small. Since the variance of the permanent innovation is 1/5 of that of transitory shocks, with  $\alpha = 1/3$  the bias would be around 0.05.<sup>33</sup>

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<sup>33</sup>Simulations confirm these results and show that in the ZBC, the usual severe downward bias is always at work, but qualitatively the findings are the same.

	Permanent Shock		Transitory Shock	
Data	0.36 (0.09)		0.95 (0.04)	
	Model TRUE	Model BPP	Model TRUE	Model BPP
Natural BC				
40%	0.23	0.25	0.94	0.94
60%	0.23	0.28	0.94	0.94
80%	0.22	0.37	0.94	0.94
Zero BC				
40%	0.23	−0.01	0.82	0.82
60%	0.23	−0.10	0.82	0.82
80%	0.23	−0.31	0.82	0.82

**Table 4:** Results for the model with heterogeneous income slopes

## 5.2 Foreseen income slopes

Consider a generalization of the income process in (5) that includes heterogeneous slopes in individual income profiles:

$$\begin{aligned}
y_{it} &= \beta_i t + z_{it} + \varepsilon_{it} \\
z_{it} &= z_{i,t-1} + \eta_{it},
\end{aligned}$$

with  $\mathbb{E}(\beta_i) = 0$  in the cross-section, and  $\text{var}(\beta_i) = \sigma_\beta$ .<sup>34</sup> We assume that  $\beta_i$  is in the information set of the agents at age zero. In the experiments that follow we keep  $\sigma_\varepsilon$  as in the benchmark calibration, gradually change the value for  $\sigma_\beta$  and set  $\sigma_\eta$  residually so that the overall rise in the cross-sectional variance of log earnings from age 25 to age 60 is unchanged.

The results of this experiment for the two economies are reported in Table 4. To get a sense of the size of advance information in each experiment, in the first column of Table 4 we report the fraction of the variance in log earnings at age 60 that is known by the agents upon entering the labor market.<sup>35</sup>

The true insurance coefficients for permanent and transitory shocks  $(\phi^\eta, \phi^\varepsilon)$  are unchanged from the benchmark model. The reason is that the full effect of knowledge about  $\beta_i$  is incorporated into the level consumption from the outset, but insurance coefficients are

<sup>34</sup>We retain the unit root specification for the permanent component of the income process, notwithstanding the empirical evidence for substantially lower persistence when heterogeneous slopes are present. We do this to provide a clean analysis of the effects of heterogeneous slopes without confounding the effects of lower persistence. We separately analyze the issue of persistence in Section 6.

<sup>35</sup>The fraction of dispersion at age  $t$  known at birth is computed as  $(\sigma_\beta t^2) / \text{var}(y_{it})$ .

a measure of how much consumption growth responds to contemporaneous shocks. This response is not affected by the presence of heterogeneous slopes known at  $t = 0$ .

We now turn to the implications for the BPP coefficients. Table 4 shows that the downward bias in the BPP estimator decreases (and eventually becomes positive) as the amount of advance information is increased. The source of this additional upward bias is as follows. Ignoring the usual sources of downward bias due to the failure of assumption  $(SM)$ , the BPP insurance coefficient is given by

$$\begin{aligned}
\phi_{BPP}^\eta &= 1 - \frac{\text{cov}(\Delta c_{it}, \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1})}{\text{cov}(\Delta y_{it}, \Delta y_{i,t-1} + \Delta y_{it} + \Delta y_{i,t+1})} \\
&= 1 - \frac{\text{cov}(\Delta c_{it}, \eta_{it} + 3\beta_i)}{\text{var}(\eta_{it}) + 3\text{var}(\beta_i)} \\
&= (1 - \alpha) \phi^\eta + \alpha \left[ 1 - \frac{\text{cov}(\Delta c_{it}, \beta_i)}{\text{var}(\beta_i)} \right] \\
&\approx (1 - \alpha) \phi^\eta + \alpha \phi^\beta
\end{aligned} \tag{15}$$

where  $\alpha = 3\text{var}(\beta_i) / [\text{var}(\eta_{it}) + 3\text{var}(\beta_i)]$  is another version of the advance information ratio.

In the NBC model, the term  $\phi^\beta$  is close to one, since  $\Delta c_{it}$  should be roughly invariant to  $\beta_i$  at any  $t$ . This is a source of upward bias in the BPP estimator, and the bias is larger the larger is  $\alpha$ . However Table 4 shows that only in the case where 80% of the variance of income at age 60 is known already at age 25, arguably an upper bound for advance information, is the BPP coefficient in the model at the level of its empirical counterpart.<sup>36</sup>

In the ZBC economy,  $\phi^\beta$  is close to zero. This induces a further source of downward bias which worsens as one increases the amount of advance information in the economy. As  $\sigma_\beta$  grows, the economy is populated by a larger fraction of agents with steep income profile who would like to borrow against their future income, but are liquidity constrained. As already explained, the larger the fraction of constrained agents, the stronger the downward bias.

## 6 Persistent income shocks

Following BPP, we have focused on a particular income process that restricts shocks to be either fully permanent or fully transitory. There is no scope for income shocks that have

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<sup>36</sup>In the NBC model, as the fraction of information known in advance approaches 100%, the BPP estimator should approach 1.0. Simulations confirm this prediction.

lasting but not permanent effects on income. In this section we relax this assumption. One plausible explanation for why we find higher insurance coefficients in the data than in model is that, in reality, shocks are not purely permanent. Persistent shocks are easier to smooth by precautionary saving and borrowing.

Consider a variant of the income process whereby  $z_t$  follows an AR(1) process with parameter  $\rho < 1$ :

$$z_{it} = \rho z_{it-1} + \eta_{it}. \quad (16)$$

In the terminology of the more general model in equation (1), we now have  $\mathbf{a}_0 = (1, 1)$  and  $\mathbf{a}_j = (\rho^j, 0)'$ ,  $j \geq 0$ .

**Identification** With this income process the identification strategy of Section 2.1 is no longer valid. We propose two new  $g_t^x(\mathbf{y})$  functions that identify the two insurance coefficients for  $x = \{\eta, \varepsilon\}$ . In order to do this, we assume that an external estimate of  $\rho$  is available.<sup>37</sup>

Define the quasi-difference of log income as  $\tilde{\Delta}y_t \equiv y_t - \rho y_{t-1}$ . Identification of the two insurance coefficients can be achieved by setting  $g_t^\varepsilon(\mathbf{y}) = \tilde{\Delta}y_{t+1}$  and  $g_t^\eta(\mathbf{y}) = \rho^2 \tilde{\Delta}y_{t-1} + \rho \tilde{\Delta}y_t + \tilde{\Delta}y_{t+1}$ . For the transitory shock, we have

$$\begin{aligned} \text{cov}(\tilde{\Delta}y_{it}, \tilde{\Delta}y_{i,t+1}) &= -\rho \text{var}(\varepsilon_{it}), \\ \text{cov}(\Delta c_{it}, \tilde{\Delta}y_{i,t+1}) &= -\rho \text{cov}(\Delta c_{it}, \varepsilon_{it}), \end{aligned}$$

and for the persistent shock,

$$\begin{aligned} \text{cov}(\tilde{\Delta}y_{it}, \rho^2 \tilde{\Delta}y_{i,t-1} + \rho \tilde{\Delta}y_{it} + \tilde{\Delta}y_{i,t+1}) &= \rho \text{var}(\eta_{it}), \\ \text{cov}(\Delta c_{it}, \rho^2 \tilde{\Delta}y_{i,t-1} + \rho \tilde{\Delta}y_{it} + \tilde{\Delta}y_{i,t+1}) &= \rho \text{cov}(\Delta c_{it}, \eta_{it}). \end{aligned}$$

Thus, in both cases, expression (4) yields a consistent estimator of  $\phi^x$ , under exactly the same pair of assumptions (NF) and (SM).

**Results** In Table 5 we present insurance coefficients from the NBC and the ZBC models, where  $z_{it}$  follows the process in (16). As we decrease  $\rho$ , we increase  $\sigma_\eta$  in order to keep the rise in the variance of log earnings over the life cycle unchanged, and equal to the data counterpart. The column headed “Model TRUE” reports insurance coefficients

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<sup>37</sup>This is a reasonable assumption, since  $\rho$  can be identified using panel data on income alone, and thus can be estimated in a separate first stage, before the estimation of insurance coefficients. Obviously, with short panels, distinguishing between a unit root and a stationary, but very persistent AR(1), is challenging.



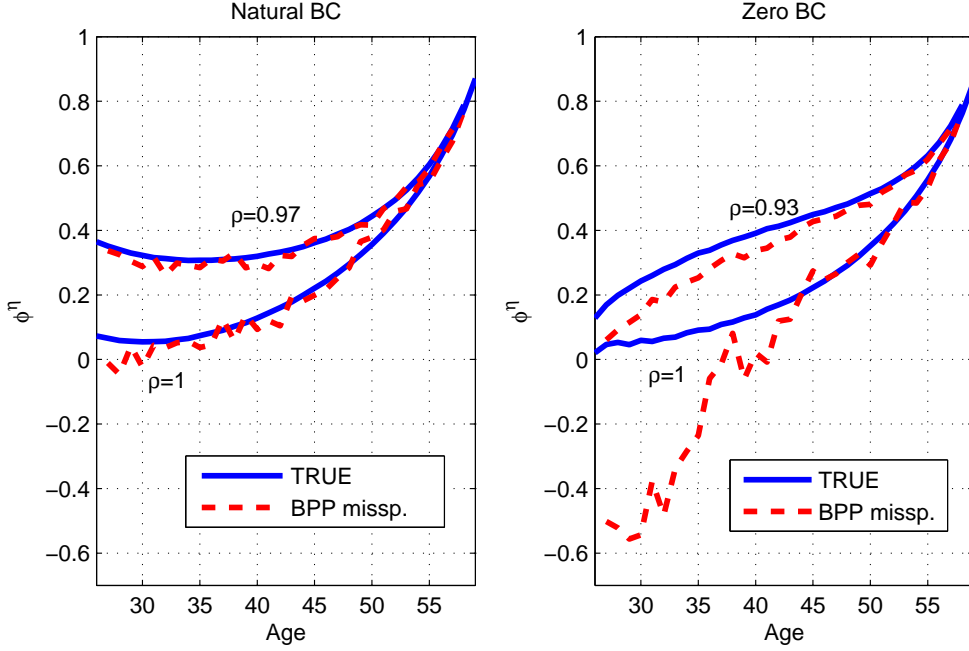
	Persistent Shock			Transitory Shock		
Data	0.36 (0.09)			0.95 (0.04)		
	Model TRUE	Model BPP	Model BPP misspecified	Model TRUE	Model BPP	Model BPP misspecified
Natural BC:						
$\rho = 0.99$	0.30	0.28	0.28	0.93	0.93	0.93
$\rho = 0.98$	0.35	0.34	0.34	0.93	0.93	0.92
$\rho = 0.97$	0.39	0.39	0.39	0.93	0.93	0.92
$\rho = 0.95$	0.47	0.46	0.46	0.93	0.93	0.90
$\rho = 0.93$	0.52	0.53	0.52	0.92	0.93	0.88
Zero BC:						
$\rho = 0.99$	0.27	0.17	0.16	0.82	0.82	0.82
$\rho = 0.98$	0.30	0.24	0.22	0.82	0.82	0.81
$\rho = 0.97$	0.33	0.28	0.27	0.81	0.81	0.81
$\rho = 0.95$	0.38	0.35	0.33	0.81	0.81	0.80
$\rho = 0.93$	0.42	0.42	0.38	0.81	0.82	0.78

**Table 5:** Results from the models with persistent earnings shocks

calculated using the realized values of the shocks. The column headed “Model BPP” reports estimates using the estimation procedure just described. Finally, the column headed “Model BPP misspecified” reports the estimates that would obtain if one were to use the (invalid) instruments from the model with permanent shocks. This last column is the correct model counterpart of the BPP estimates.

The coefficients obtained with the misspecified BPP instruments are very close to those obtained with the correct instruments, at all levels of  $\rho$ . This is true both for the model with and without tight borrowing constraint. Hence the bias that results from applying the instruments from the permanent shock case on data generated by an AR(1) process, is not at all severe. It is thus justified to take the empirical BPP estimate of 0.36 seriously, even in the case it was estimated under a misspecified income process.

Of course, it is still true that the BPP methodology underestimates true insurance coefficients, but the bias is not increased by the income process misspecification. On the contrary, in the ZBC economy, as  $\rho$  decreases, the downward bias in the BPP estimator vanishes. With shocks which are less durable than unit root, precautionary savings are more useful. Agents start accumulating wealth right away, and move far from the debt constraint early



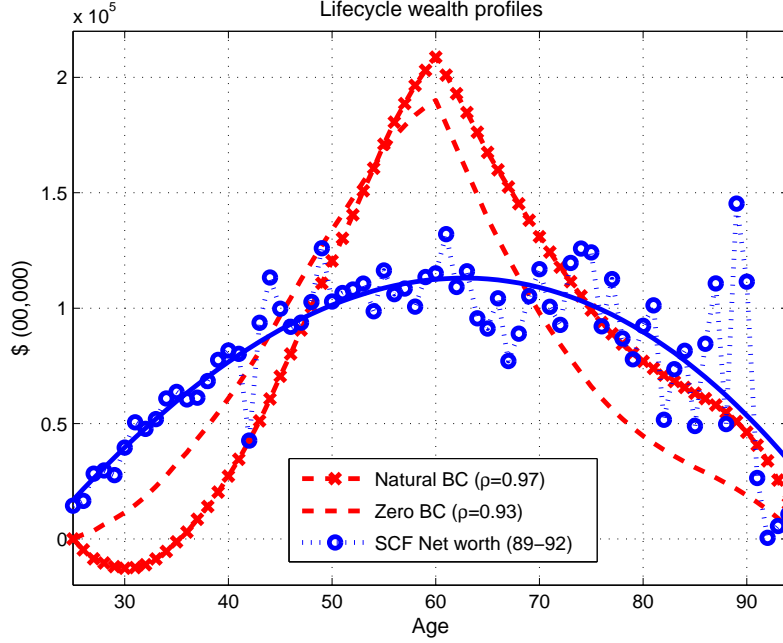
**Figure 5:** Age profiles of insurance coefficients in the NBC and ZBC economies.

in life, which explains why the bias is now very small.

The insurance coefficients for persistent shocks quickly increase as  $\rho$  declines. In the NBC economy, with an autoregressive parameter as high as 0.97, the amount of insurance against persistent shocks in the model is roughly consistent with that in the data. In the ZBC economy, not surprisingly, one needs to lower  $\rho$  somewhat further, to 0.93. These findings imply that a Bewley economy with a highly persistent (but not permanent) income process can generate, on average, the right level of insurance against persistent shocks.

Turning to insurance coefficients for the transitory shocks, here the model with persistent shocks is slightly less successful. The reason for why the model generates less smoothing with respect to transitory shocks is that now agents shift the use of savings from the smoothing of transitory shocks to the smoothing of persistent shocks, and are willing to tolerate larger fluctuations in consumption due to transitory shocks.

Figure 5 plots the age profile of insurance coefficients for persistent shocks in the two economies. Relative to the model with permanent shocks, the age profile of insurance coefficients is now less steep (and thus more consistent with the data). This is because the difference between a permanent and a highly persistent shocks is more pertinent for a young household with many periods ahead.

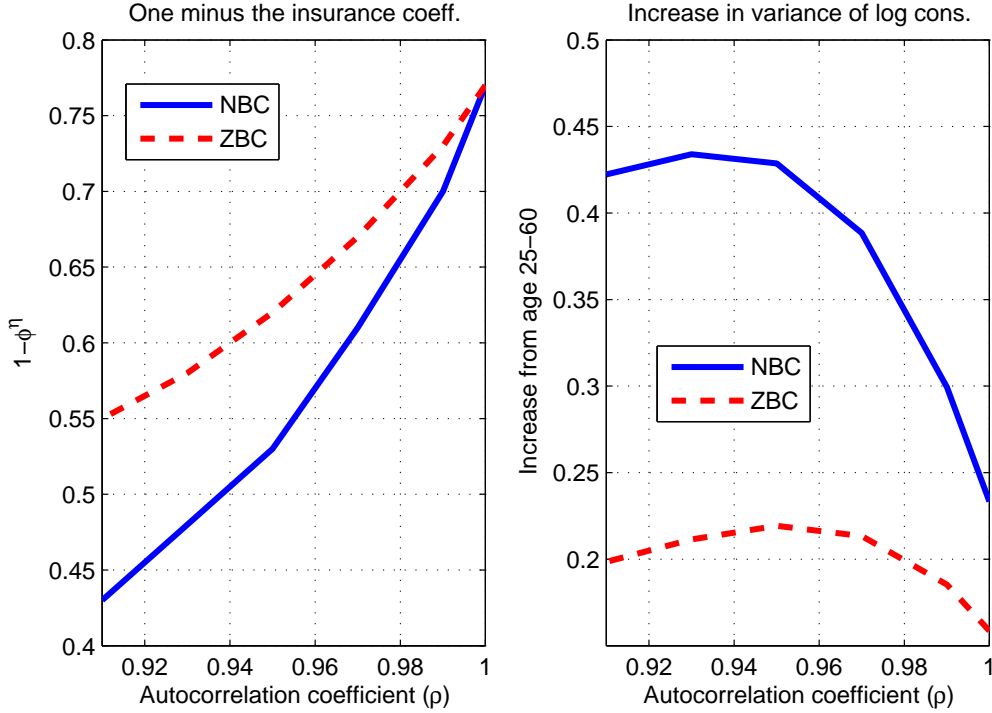


**Figure 6:** Life cycle profile of wealth in the data and in the model.

**Age-wealth profiles** Even though the model with  $\rho < 1$  is, on average, successful in replicating the BPP estimates, the age profile is too steep relative to the data. The model has too little insurance for young agents and too much for old agents. Figure 6 provides an explanation for this result. In the data, the distribution of wealth is much less concentrated at retirement than in the model.

Extensions of the standard Bewley model that incorporate saving motives for young (e.g., down payment constraints) and for older households (e.g., bequest) would shift wealth in the right way and help the model to reproduce flatter age-insurance profiles. Based on Hubbard et al. (1995), we can conjecture that additional precautionary saving associated to medical expenditures shocks and survival risk would also work, qualitatively, in the right direction.<sup>38</sup> The presence of internal habits should also increase the fraction of precautionary saving and shift wealth towards the young and low-income households (Diaz, Pijoan-Mas & Ríos-Rull 2003). In this paper, we have chosen to focus on the baseline life cycle model with standard preferences and income risk alone, and make a first step towards understanding the data-model gap. In ongoing work (Kaplan & Violante 2009), we are exploring whether all these extensions can quantitatively account for the gap.

<sup>38</sup>A key difficulty is that the BPP measures of consumption include out-of-pocket medical expenses which usually are modelled as part of the budget constraint but not in preferences (Hubbard et al. 1995).



**Figure 7:** A comparison between consumption inequality and insurance coefficients

## 6.1 Comparison with Storesletten-Telmer-Yaron

Following the influential papers by Deaton & Paxson (1994) and Storesletten et al. (2004), many authors associate the growth of consumption dispersion over the life-cycle to the extent of risk-sharing present in an economy. How does this index of risk-sharing compare to our insurance coefficients against permanent shocks?

In terms of measurement, one may argue that the former is more direct and less dependent on assumptions than the BPP methodology. However, measuring the life cycle rise in consumption inequality is also fraught with difficulties. Choosing how to model time and cohort effects, or how to equalize household consumption, or which items to include in the definition of consumption expenditures (Aguiar & Hurst 2008) can make a large difference. For example, more recent estimates (Heathcote, Storesletten & Violante 2005, Heathcote, Perri & Violante 2008) set the gradient of the consumption inequality over the life cycle to a third of the original Deaton-Paxson estimate. As a result, what target one should use is not yet clear. By using year-by-year individual-level consumption and income growth, one does not face any of these problems.

With respect to the information contained in these two measures, Figure 7 shows, some-

what surprisingly, that they do not always agree. The left panel plots  $1 - \phi^\eta$ , while the right panel plots the alternative measure of (the lack of) insurance, the rise in the variance of log consumption from age 25 to 60. As  $\rho$  declines from 1.00 to 0.90, the insurance coefficients  $\phi^\eta$  grow monotonically, but the increase in the variance of log consumption has a non monotonic shape.<sup>39</sup> First it grows, then it falls. Hence, for values of  $\rho$  close to one these two criteria disagree on whether less persistent shocks increase or decrease consumption smoothing in the model.

To understand the discrepancy, recall that in the experiment calibration requires that  $\sigma_\eta$  rises as  $\rho$  falls. The decline in  $\rho$  induces both measures to signal more insurance, but the rise in  $\sigma_\eta$  has a different impact. The insurance coefficient is a “relative measure”, i.e. its is largely independent of the variance of the shock  $\sigma_\eta$  since it is normalized by this variance (see Tables 2 and 3). However the growth in consumption dispersion is an “absolute measure” and, as such, it is directly affected by the size of  $\sigma_\eta$ . Storesletten, Telmer & Yaron (Figure 6, 2004) explain that the rise in consumption inequality may be larger with lower  $\rho$  (and higher  $\sigma_\eta$ ) because earnings inequality grows faster early in the life cycle, when households have small wealth holdings and households consumption is most vulnerable to shocks.

## 7 Conclusions

This paper is inspired by the important empirical findings reported by Blundell, Pistaferri & Preston (2008, BPP). BPP estimate that in the US economy, during 1980-1992, 36% of the variance of permanent income shocks and 95% of the variance of transitory shocks to after-tax household earnings can be insured away by households, i.e. do not translate into contemporaneous consumption growth. These two numbers, we argue, should become central in quantitative macroeconomics. They represent a yardstick to investigate whether current incomplete-markets macroeconomic models used for quantitative analysis admit the right amount of household insurance.

In this paper, we make a step forward in this direction by addressing two questions. First, is the Bewley model (arguably the workhorse of heterogenous agents macroeconomics) able to replicate such findings? And if not, what modifications of the standard model can narrow the model-data gap? In this respect, our paper is an investigation into one of the

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<sup>39</sup>Consistently with the earlier experiment, when we decrease  $\rho$ , we increase  $\sigma_\eta$  in order to keep the rise in the variance of log earnings unchanged.

central properties of Bewley economies. Second, does the BPP methodology provide an unbiased estimator of true insurance coefficients, under the hypothesis that the US economy is accurately described by a Bewley model? In this respect, the paper is an investigation into the reliability of the most up-to-date and exhaustive empirical measure of consumption insurance for US households.

We have uncovered several interesting results. When the log-income process is the sum of a permanent and a transitory component, as assumed by BPP, then a plausibly calibrated Bewley model has less insurance than the data against permanent shocks, and about the same as the data against transitory shocks. The model’s shortcoming is particularly stark in environments when debt limits are tight. We have shown that this conclusion is robust across a series of sensitivity analysis, including models with advance information.

In the model, the age profile of insurance coefficients against permanent shocks is sharply increasing, whereas BP document that in the data it is flat. Hence, to bring together model and data, the model must be modified in such a way to provide relatively more insurance to younger households. We have shown that allowing for a mean reverting shock with autocorrelation around 0.97, instead of a pure permanent shock, helps to reconcile model and data. However, even though the overall degree of insurance is higher, the age profile of insurance coefficient remains rather steep.

We have also assessed the accuracy of the estimation method proposed by BPP by generalizing their approach and clarifying that its validity depends on two key orthogonality conditions: “no foresight”, and “short memory” of the consumption growth allocation. Estimates of insurance coefficients are, in general, downward biased, with the bias exacerbated whenever households are close to their borrowing constraint. This is the result of the short memory assumption being violated –hitting the borrowing constraint lengthens the memory of the allocation. Put it differently, the actual insurability of shocks in the US economy may be higher than what was measured by BPP, especially for young and poor households. However, we also showed that in an economy with loose borrowing limits where the income process contains an individual-specific slope known to the agent there is a strong source of upward bias in the BPP estimator which stems from the violation of the no advance information assumption.

Our investigation suggests several important avenues for future research.

Extending the empirical and theoretical analysis to different income definitions (e.g.,

hourly wages, individual earnings, pre-government household earnings) would shed light on the relative importance of the various insurance mechanisms households have access to, beyond self-insurance through borrowing/saving (e.g., individual labor supply, intra-household insurance, government redistribution, interpersonal transfers).<sup>40</sup>

The question which motivates the paper -whether the standard incomplete-markets model features the right amount of insurance- could be approached differently. For example, one could rely on the large literature on the consumers' response to tax rebates to replicate in detail one of the latest refunds (2001, or 2008) and compare the model's prediction to the econometric and survey-based estimates.

The appropriate statistical representation of individual income fluctuations, which is critical in our context, is a long-standing question in labor and macroeconomics. Since from a purely statistical viewpoint it is almost impossible to distinguish a unit root from a highly persistent but stationary process in short panels, economic theory should come to the rescue. For example, structural estimation of search models based data on workers' flows and workers' wages have implications for the resulting individual earnings dynamics (Low, Meghir & Pistaferri 2007, Postel-Vinay & Thuron 2008). Often, though, search models abstract from the consumption/saving decision under uncertainty. The recent work by Lise (2006) is an exception.

The misalignment between the age-profile of insurance coefficients in the model and the data is particularly acute for young individuals. This suggests that modifications of the model that flatten its age-wealth profile, bringing it closer to the data, would also improve its performance in this dimension. Alternatively, future research should try to identify additional sources of insurance against permanent shocks for the young, over and above borrowing and saving. Kaplan (2008), who explores the role of co-residence decisions for unskilled youths, is a promising example.

Finally, future research should explore whether endogenously incomplete markets models (e.g., environments with limited enforcement or private information) can replicate the two key BPP empirical estimates of the degree of household insurance against permanent and transitory shocks. Krueger & Perri (2005), Krueger & Perri (2008), and Attanasio & Pavoni (2007) make important progress in this direction.

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<sup>40</sup>Heathcote, Perri & Violante (2008) document the time-series of cross-sectional U.S. inequality in all these different definitions of income, and in nondurable consumption, since the late 1960s.

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