Distinguishing barriers to insurance in Thai villages*

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Abstract

Informal insurance is an important risk-smoothing mechanism in developing countries, yet this risk sharing is incomplete. Models of limited commitment, moral hazard, and hidden income have been proposed to explain incomplete informal insurance. Using the first-order conditions characterizing optimal insurance under each constraint, the way history matters in forecasting consumption can be used to distinguish hidden income from limited commitment and moral hazard. These implications do not rely on particular specifications of the production or utility functions. In a panel from rural Thailand, limited commitment and moral hazard are rejected. The predictions of hidden income are supported by the data. **JEL codes**: D82, D91, O12

1 Introduction

Risk to households' incomes is widespread in developing countries—crops and businesses fail, jobs are lost, livestock die, prices fluctuate, family members become ill, etc. If perfect insurance were available, such income risk would not translate into fluctuations in household per capita consumption. Many households in developing countries are engaged in inter-household insurance arrangements involving state-contingent transfers, as documented by Scott (1976), Cashdan (1985), Platteau and Abraham (1987), Platteau (1991), Udry (1994), Collins et al. (2009) and others. However, households are generally not completely insured—income and consumption are typically found to be positively correlated. Rejection of full insurance is documented by Rosenzweig (1988), Townsend (1994), Townsend (1995), Udry (1994), Morduch (1995), Morten (2017) and others.

The consequences of uninsured risk can be dire: serious income shocks like severe illness translate into reduced household consumption (Gertler and Gruber (2002), de Weerdt and Dercon (2006)), and risk appears to depress risk-taking (e.g., Bianchi and Bobba (2012) and Dercon and Christiaensen (2011)). Some households appear particularly vulnerable, such as those without access to financial institutions (Kinnan and Townsend 2012).

In general, households neither live hand to mouth, with shocks to income translating one-for-one to fluctuations in consumption, nor are they fully insured, with consumption completely buffered against idiosyncratic shocks to

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income. A natural question is then, why—given the welfare costs of uninsured risk and the evidence that inter-household insurance takes place—is this insurance not complete? Several explanations have been proposed for the failure of full insurance. One is that one household's actions are not observable to others so shirking is possible (moral hazard). Another is that households receiving high income draws may leave the insurance arrangement instead of making transfers to others (limited commitment). A third possibility is that households' income realizations are unobservable by others, so that it is possible to claim income is lower than it is (hidden income).

The limited commitment and moral hazard models have become workhorses of the empirical and theoretical literature on interpersonal insurance, yet the predictions of limited commitment and moral hazard are rejected in the Thai data used in this paper, as I show below. Given the difficult-to-verify nature of many income shocks (e.g., shocks to agricultural production, the price one's livestock fetched at market outside the village, or whether relatives in the city found work or sent remittances), the hidden income model deserves consideration as an explanation for incomplete insurance, yet the hidden income model has, to my knowledge, been empirically tested by only two other papers. Their findings are contrasted with this paper below.

Hidden income may severely limit informal insurance arrangements: households have incentives to misreport incomes and have been shown to do so if faced with transfer schemes which are not designed to elicit truth telling (see, e.g., Martinelli and Parker 2009, Baland et al. 2011, Jakiela and Ozier 2015 and Fiala 2017).[1] Firms have also been shown to misreport income to tax authorities in the absence of incentives for truth-telling (Kumler, Verhoogen, and Frías 2013, Pomeranz 2015). Therefore, the primary focus of this paper is to develop and implement tests of hidden income. To do so, I integrate tests of limited commitment, moral hazard and hidden income into a common framework.

Knowing what barrier to full informal risk-sharing is most important in a given setting is important for evaluation of policies that may affect the sustainability of informal insurance. Policies that interact with existing informal risk-sharing mechanisms may have very different impacts depending on the nature of incomplete informal insurance. For instance, a work-guarantee program such as India's National Rural Employment Guarantee Scheme could crowd out insurance constrained by moral hazard (by reducing the penalty for exerting low effort) or limited commitment (by making exclusion from the informal insurance network less painful)[2], but could crowd *in* insurance constrained by hidden income by ruling out the possibility that a household received a very low income, since households have recourse to the work-guarantee program.

If binding, the participation constraints of the limited commitment model, the incentive-compatibility constraints of the moral hazard model and the truth-telling constraints of the hidden income model all preclude full insurance. All three models predict a positive correlation between income and consumption changes[3], as well as predicting that one household's income realizations will affect the consumption of other households in the village, through partial co-

[1]However, if incentives take the ability to misreport into account, then in equilibrium members of the insurance network will be correctly informed about each other's incomes. For this reason, and because surveyors do not attempt to provide insurance, it is reasonable to expect that household surveys can obtain correct income data (modulo measurement error) even if hidden income constraints are present.

[2]Morten (2017) shows that an employment guarantee scheme decreases risk sharing in the presence of limited commitment.

[3]The relationship between income and consumption need not be everywhere positive under a moral hazard model, even if the likelihood ratio is monotone (Milgrom 1981), (Grossman and Hart 1983). However, incentive compatibility requires that consumption be increasing in output on average. Moreover, if agents can costlessly "burn output," monotonicity is required (Bolton and Dewatripont 2005).

insurance. Therefore, finding a positive income-consumption correlation is not sufficient to distinguish between these barriers. Most of the existing literature on barriers to informal insurance, which I briefly review below, tests one model of incomplete insurance against one or both of two benchmark cases—full insurance and borrowing-saving only. Such tests, while they can reject full insurance, lack power against models of incomplete insurance other than the particular insurance friction they consider. The contribution of this paper is to develop and empirically implement a set of testable predictions which distinguishes *between* moral hazard-, limited commitment- and hidden income-constrained insurance.

I show that, when insurance is constrained by limited commitment or moral hazard, a household's "history" matters in a specific way in predicting that household's current inverse marginal utility (hence consumption): conditional on the aggregate shock faced by the village and the household's lagged inverse marginal utility (LIMU), no other past information will improve the forecast of that household's current inverse marginal utility. The intuition for this result is that, under limited commitment or moral hazard, there is no equilibrium uncertainty: households do not shirk or leave the insurance arrangement in equilibrium. Therefore, the social planner controls a household's consumption, and therefore utility, by choosing the level of (positive or negative) net transfers the household receives. Due to concavity of the utility function, the most efficient way to deliver this utility is to equate current inverse marginal utility with expected future inverse marginal utility, giving the household a smooth (expected) consumption path over time. Therefore, if the current value of inverse marginal utility is known, it captures all information relevant to forecasting next period's value.

This result is robust to the possibility that the distribution of household income depends on actions taken by the household in the past (due to durable investment or multi-period production, for instance), and to serial correlation in a household's income over time. These generalizations do not require more than one lag of inverse marginal utility to forecast current inverse marginal utility. The reason is that, even if time $t-1$ income is informative about future income (relevant under limited commitment) or past effort (relevant under moral hazard), the punishment or reward is always delivered at time $t-1$. As a result, time $t-1$ inverse marginal utility fully summarizes all information from $t-1$ and before that is relevant to forecasting time t inverse marginal utility.

On the other hand, when hidden income constrains insurance, a household's LIMU is no longer sufficient to forecast current inverse marginal utility. Low-income households are optimally assigned low consumption, and hence high marginal utility. Therefore, households truthfully reporting low income value current consumption more than households misreporting low income. By contrast, truthful and misreporting households value promised *future* consumption equally. Therefore, incentive compatibility is attained by reducing the future surplus promised to low-income households relative to their current consumption. That is, the timing of households' consumption is distorted in the hidden income model, such that the community's expected cost of providing each household's marginal unit of consumption is not equated across periods.

This distortion arises because in the hidden income case, the planner needs to elicit information from the household, namely, the income level realized by the household. The distortion in the timing of consumption serves a screening purpose, constraining households tempted to falsely report low income from doing so. In a world without *ex post* private information, this distortion would be inefficient: a given level of expected utility can be provided most efficiently if the cost of the marginal unit is equated in expectation across periods. In the moral hazard and limited commitment models, there is no on equilibrium uncertainty and, as a result, LIMU contains all information necessary to predict current inverse marginal utility if moral hazard or limited commitment constrain insurance.

The tests of limited commitment and moral hazard I derive generalize existing results from the contracts literature (Kocherlakota 1996, Ligon et al. 2002, Rogerson 1985), while the hidden income test is a new result, building on the analysis in Thomas and Worrall (1990) and Ljungqvist and Sargent (2004). This new test is one key contribution of this paper. A second contribution is to empirically implement these tests, examining the relationship between current consumption, LIMU and past income in rural Thailand using the Townsend Thai Monthly Survey.[4] To do this, I employ two approaches: first, non-linear estimation based on constant relative risk aversion; second, a non-parametric test based on the reduced-form relationship between consumption and components of income. This second approach functions as test of the robustness of the results to various forms of possible misspecification in the first approach: non-classical measurement error, cross-household heterogeneity, and misspecification of the utility function. To my knowledge, this non-parametric approach is novel as a robust test of efficient insurance.

To preview the findings, past income has predictive power in forecasting current inverse marginal utility, indicating that neither limited commitment or moral hazard can fully explain incomplete insurance in these villages. Conditional on LIMU, there is a positive and significant correlation between consumption and lagged income, as predicted by the hidden income model.[5] Moreover, this correlation is strongest where the ability to hide income is likely to be greatest. Looking across occupations, it is stronger when income is less predictable based on rainfall (and therefore harder for other households to predict). And looking across income categories within households, the correlation is stronger for livestock income (which may be easier to hide/misreport) than crop income. Taken together, these findings suggest that the ability of households to hide their income plays a significant role in generating the observed comovement between income and consumption.

The rest of the paper is organized as follows: Section 2 provides a brief overview of related literature. Section 3 outlines the benchmarks of full insurance and pure borrowing-saving, discusses the three barriers to insurance (moral hazard, limited commitment and hidden income), and explains the theoretical approach to distinguishing among these barriers. Section 4 explains how these theoretical predictions can be empirically tested. Section 5 discusses the data used to implement these tests. Section 6 presents the results. Section 7 presents an additional, non-parametric test which is robust to non-classical measurement error in consumption and to household-level heterogeneity in the utility function. Finally, Section 8 concludes. Proofs are in Appendix A, and supplementary tables appear in Appendix B.

[4] Several other recent papers also use the joint distribution of consumption and income to investigate the nature of risk sharing in village economies. I contrast my approach with these other papers in section 2.

[5] In constrast, a model of borrowing constraints (Deaton 1991) predicts a negative correlation between lagged income and current consumption, conditional on lagged consumption. See Section 3.3.1.

2 Related literature

The implications of full consumption insurance have been characterized by Wilson (1968), Cochrane (1991), Mace (1991) and Townsend (1994). As mentioned above, a number of important papers have tested the empirical implications of full insurance at the level of the village or community. In general, full insurance is rejected at the village level. But an important related paper that draws a more nuanced conclusion is Chiappori et al. (2014), who use the same Townsend Thai dataset employed in this paper. They find, similarly to this paper's findings, that in the pooled sample of sixteen villages, full insurance is statistically rejected. However, they note that, when estimated one village at a time, in most villages full insurance cannot be rejected, although this is in part an issue of statistical power. They also show that, if the four sampled villages within a province are pooled together, full insurance is not rejected at the 5% or better in any province. They thus conclude that the data are fairly well-approximated by full insurance and estimate risk preference heterogeneity under the maintained assumption of full insurance. However, it is important to emphasize that Chiappori et al. (2014) and the results of this paper are consistent: full insurance is rejected at the 5% level or better, suggesting that some idiosyncratic risk, which would be diversified in the first best, remains un-diversified. (The extent of un-diversified risk appears even greater when an instrumental variables strategy is used to address measurement error in consumption, as shown below.)

Other studies have suggested that groups organized by caste or kinship may come closer to achieving the full insurance benchmark; these include Grimard (1997), Fafchamps and Lund (2003), De Weerdt and Dercon (2006), De Weerdt and Fafchamps (2011), and Mazzocco and Saini (2012). Mazzocco and Saini (2012), for instance, use data from the ICRISAT villages and find that, once heterogeneity in risk preferences is allowed for, full insurance is not rejected at the caste level, but is still rejected at the village level. But insofar as insurance at the village level would allow households to diversify additional risk which is covariate at the level of kinship or caste groups, the question remains: why is there not full insurance at the level of the village?

Turning to characterizations of endogenously incomplete insurance, the inverse Euler equation implication of moral hazard-constrained insurance was first characterized by Rogerson (1985), and Phelan (1998) developed a recursive formulation of the moral hazard problem. Golosov, Kocherlakota, and Tsyvinski (2003) show that an Inverse Euler equation relationship is obtained in a large class of dynamic economies with hidden types (adverse selection) and very general production functions. Kocherlakota and Pistaferri (2009) examine the asset pricing implications of dynamic economies with hidden types. Attanasio and Pavoni (2011) show that adding the possibility of hidden savings to the moral hazard model can explain the "excess smoothness" of UK consumption data.

The limited commitment model was first characterized by Kimball (1988) and Coate and Ravallion (1993), and extended to a dynamic framework by Kocherlakota (1996) and Ligon et al. (2002). The hidden income model was first studied by Townsend (1982) and Green (1987). Green and Oh (1991) further characterize the hidden income model and discuss some implications that could be used to distinguish it from PIH and liquidity constrained models, but do not attempt an empirical test.

The method used in this paper, distinguishing hidden income from limited commitment and moral hazard using the first-order conditions of the social planner's problem, draws on the characterization of efficient limited commitment-constrained insurance in Kocherlakota (1996) (which is described in section 3), and on the recursive formulation of the hidden income problem developed in Thomas and Worrall (1990), Ljungqvist and Sargent (2004) and Marcet and Marimon (2011).

Several papers have examined whether limited commitment- or moral hazard-constrained insurance can explain consumption and income data from developing economies better than pure borrowing-saving or full insurance models. Using the inverse Euler implication of moral hazard and the Euler equation implication of the borrowing-saving model, Ligon (1998) uses a GMM approach to test moral hazard-constrained insurance against full insurance and borrowing-saving in India using ICRISAT village data, and finds that moral hazard best explains consumption data in 2 of 3 villages; in the third some households' consumptions are better explained by pure borrowing-saving. Ligon, Thomas and Worrall (2002) use a maximum likelihood (ML) approach to test full insurance against limited commitment, also in the ICRISAT villages. They find that limited commitment explains consumption dynamics, but not why high-income households consume as little as they do relative to low-income households. Laczó (2015) studies a model with limited commitment and preference heterogeneity and finds that this model better explains consumption dynamics in the ICRISAT villages than models with full commitment and/or without preference heterogeneity.[6] Lim and Townsend (1998) incorporate capital assets and livestock into a moral hazard-constrained insurance model, and find using a ML approach that the moral hazard model fits the ICRISAT consumption data better than the PIH or full insurance. Dubois et al. (2008) develop a model with limited commitment and incomplete formal contracts and find, using a ML approach, that its predictions are matched in Pakistani data.

A paper related to this one is Broer, Kapicka and Klein (2017). They develop a model with both limited commitment and hidden income, and argue that the model better matches the observed distribution of consumption changes than a model with limited commitment alone. Like this paper, they characterize the role of "history," i.e. lagged variables, in predicting the current state. However, their characterization of the role of history is specific to the case of a two-point income distribution.

Karaivanov and Townsend (2014) use an ML approach to test across several moral hazard models as well as the PIH in the same Thai dataset used in this paper. For the rural sample, used in this paper, they find that overall a PIH model best fits the data on consumption, income and investment; while using only consumption and income data, a moral hazard model is also found to fit. An extension in the working paper version (Karaivanov and Townsend 2013) considers a hidden income model and finds that it is rejected in the rural data (but preferred in the urban sample); however, computational constraints imposed by the hidden income model in an ML framework require the use of a parametric income process.

The body of recent work using ML approaches to test models of risk sharing is a testament to the power of this approach. By using the full joint distribution of consumption and income, ML estimation is typically able to achieve greater power, allowing for structural modelling of, e.g., preference heterogeneity (as in Laczó 2015) or measurement error (Karaivanov and Townsend 2014). The tradeoff is the need to make additional assumptions regarding the dis-

[6] Laczó (2015) argues (footnote 3) that a hidden income model would follow an inverse Euler equation. However, this is specific to the case where income is a deterministic function of effort so that there is no ex post uncertainty; this version of the the hidden income model is a relabelling of the moral hazard model.

tribution of income shocks in order to specify the likelihood functions. This approach is well-suited to models such as limited commitment and moral hazard in which only realized (hence, observed) income appears in the equation determining realized consumption. However, as shown below, under hidden income, marginal utility evaluated at non-realized income levels appear in the equation determining consumption. Therefore, approaches requiring a parametric income process may be less-well suited for testing the hidden income model; for this reason, this paper develops two approaches which do not rely on a particular income distribution. The first relies on assumptions of CRRA utility and no measurement error; the second, non-parametric approach relaxes these assumptions. The cost of this agnosticism is that my results cannot directly be used to estimate the welfare cost of hidden income or to perform counterfacutal experiments. Combining non-parametric testing across models with subsequent structural modelling and out-of-sample prediction under the "preferred" friction may be a fruitful area for future research.

The next section presents the benchmark cases of full consumption insurance and pure borrowing-saving, and then shows how the full insurance benchmark is altered by the presence of limited commitment, moral hazard and hidden income.

3 Models of optimal consumption smoothing

Tests derived within a framework that only considers one particular insurance friction versus borrowing-saving or full insurance may conclude in favor of the particular partial insurance model if the true data-generating process is in fact another insurance friction. For this reason, it is useful to derive implications of each candidate insurance friction within a common framework. That is the goal of this section, which begins by reviewing the full-insurance benchmark. Then, one by one, moral hazard, limited commitment and hidden income are introduced. Appendix A contains proofs of all propositions.

3.1 Setting

As an approximation to the environment in a village, consider N risk-averse households who interact over an infinite time horizon in a mutual insurance network. Let i index households and t index time. Each household evaluates per capita consumption and effort plans according to the utility function:

$$U(\mathbf{c}_i, \mathbf{e}_i) = \mathbb{E} \sum_{t=0}^{\infty} \beta^t \left[v(c_{it}) - z(e_{it}) \right] \tag{1}$$

I make the following assumptions:

Assumption 1 *All households have a common discount factor β, and common, additively separable utility of per capita consumption and disutility of effort functions $v(c)$ and $z(e)$.*[7] *Utility is increasing and concave in per capita consumption: $v' > 0$ and $v'' < 0$.*

[7]This is not a trivial assumption, although it is common in the empirical risk-sharing literature. Schulhofer-Wohl (2011) and Mazzocco and Saini (2012) show that allowing for heterogeneity may change the result of tests of full insurance. In Section 7, I present a test which is robust to household-level heterogeneity.

Assumption 2 *Absolute risk aversion is non-increasing:*

$$d\left(\frac{-v''(c_{it})}{v'(c_{it})}\right)/dc_{it} \leq 0 \tag{2}$$

and $lim_{c\to 0^+} u'(c) = \infty$.

Assumption 3 *As long as any household participates in the village insurance network, the household's borrowing and savings decisions are contractible.*

Assumption 4 *Households cannot take savings accumulated while in the insurance network with them into autarky.*

Finally, the following assumptions are made on the production technology:

Assumption 5a *Household output can take on* S *values. Let* r index an arbitrary income realization, $y_r \in \{y_1, ..., y_S\}$. Indices are chosen so that a higher index means more output.

Assumption 5b *Effort can take on two values in each period, working* $(e_t = 1)$ *or shirking* $(e_t = 0)$. Effort costs are normalized as:

$$\begin{aligned} z(1) &= z \\ z(0) &= 0 \end{aligned}$$

Assumption 5c *For every feasible level of promised utility* u*, there exists a feasible transfer schedule* $\{\tau_{r1}(u)\}$ *that delivers, in expectation, exactly* $u + z(1)$*, gross of effort costs, when high effort is exerted, and a feasible transfer schedule* $\{\tau_{r0}(u)\}$ *that delivers exactly* $u + z(0)$ *in expectation when low effort is exerted.*

Assumption 5d *The distribution of a household's income at time* t *is affected by the household's effort at time* t *and at time* $t-1$. Furthermore, conditional on effort choices, income follows a Markov process. Thus:

$$\Pr(y_t = y_r) = \pi\left(y_t | y_{t-1}, e_t, e_{t-1}\right)$$

Assumption 5e *Each of the* S *income realizations occurs with positive probability under either high or low effort, regardless of last period's income realization:*

$$\pi\left(y_t | y_{t-1}, e_t, e_{t-1}\right) \in (0,1), \forall e_t, e_{t-1}, y_t, y_{t-1}$$

Assumption 5f *Effort at time* t $(e_t = 1$ $)$ *raises expected surplus, regardless of the effort choice and the income realization at* $t-1$*:*

$$\begin{aligned} \sum_{r=1}^{S}\left[\pi\left(y_t|y_{t-1},1,1\right)-\pi\left(y_t|y_{t-1},0,1\right)\right]y_r &> z(1)-z(0), \forall y_{t-1} \\ \text{and } \sum_{r=1}^{S}\left[\pi\left(y_t|y_{t-1},1,0\right)-\pi\left(y_t|y_{t-1},0,0\right)\right]y_r &> z(1)-z(0), \forall y_{t-1} \end{aligned}$$

These assumptions are standard in the literature, with the exception of Assumption 5d. This assumption states that output at time t depends on effort exerted at times t and $t-1$ and may be serially correlated over time. These are natural assumptions in the context of agricultural households in a developing country. In many agricultural settings output is likely to depend on multiple lags of effort and to exhibit correlation over time. In the dataset used here, the serial correlation in household income, across years, is 0.30, using the Arellano-Bond estimator (Arellano and Bond 1991) to control for differences in mean income across households.

3.2 Full insurance

The set of first-best allocations–those exhausting both intertemporal and interpersonal gains from trade–can be characterized by considering the problem of a hypothetical risk-neutral planner who maximizes the utility of household N such that each household 1 to $N-1$ gets at least a value u_{it} in period t. Let $\mathbf{u}_t \equiv \{u_{it}\}_{i=1}^{N-1}$ be the vector of time t utility promises, $\mathbf{y}_{t-1} \equiv \{y_{i,t-1}\}_{i=1}^{N-1}$ the vector of time $t-1$ income realizations, and $\mathbf{e}_{t-1} \equiv \{e_{i,t-1}\}_{i=1}^{N-1}$ be the vector of efforts that were exerted at time $t-1$. The state variables of the planner's problem are $\mathbf{u}_t, a_t, \mathbf{y}_{t-1}, \mathbf{e}_{t-1}$: time t utility promises, time t village aggregate assets, and time $t-1$ income realizations and effort choices. The planner chooses time t effort recommendations e_{it} for each household, and a vector of transfers $\{\tau_{it}(\mathbf{y}_t)\}$, and future promises $\{u_{i,t+1}(\mathbf{y}_t)\}$. Transfers and future promise are functions of the time t income realization—though this dependence will be degenerate in the case of full insurance. Transfers are equal to the difference between a household's income and its consumption, $\tau_{it}(\mathbf{y}_t) \equiv c_{it}(\mathbf{y}_t) - y_{it}(\mathbf{y}_t)$. Future promises summarize the utility the household can expect from next period onward (Spear and Srivastava 1987).

The planner's value function is:

$$\begin{aligned}
&u_N(\mathbf{u}_t, a_t, \mathbf{y}_{t-1}, \mathbf{e}_{t-1}) \equiv \max_{\mathbf{e}_t, \{\boldsymbol{\tau}_{rt}\}, \{\mathbf{u}_{r,t+1}\}} \\
&\sum_{\mathbf{y}_t} \pi\left(y_t | \mathbf{y}_{t-1}, \mathbf{e}_t, \mathbf{e}_{t-1}\right) v(y_r + \tau_{Nt}(\mathbf{y}_t)) - z(e_N) \\
&+\beta \sum_{\mathbf{y}_t} \left(y_t | \mathbf{y}_{t-1}, \mathbf{e}_t, \mathbf{e}_{t-1}\right) u_N(\mathbf{u}_{n,t+1}(\mathbf{y}_t), a_{t+1}, (\mathbf{y}_t), \mathbf{y}_t, \mathbf{e}_t)
\end{aligned} \tag{3}$$

subject to the promise-keeping constraints that each household 1 to $N-1$ must get their promised utility u_{it} (in expectation):

$$\sum_{y_t} \left(y_t | \mathbf{y}_{t-1}, \mathbf{e}_t, \mathbf{e}_{t-1}\right) \left[v(y_{it} + \tau_{it}(\mathbf{y}_t)) - z(e_i) + \beta u_{i,t+1}(\mathbf{y}_t)\right] = u_{it}, \forall i < N \tag{4}$$

and the law of motion for assets, which states that assets evolve according to:

$$a_{t+1}(\mathbf{y}_t) = a_t - R \sum_{i=1}^{N} [\tau_{it}(\mathbf{y}_t) - y_{it}(\mathbf{y}_t)], \forall \mathbf{y}_t \tag{5}$$

Let the multiplier on household i's time t promise-keeping constraint be λ_{it} and the multiplier on the village's time t budget constraint be η_t.

As is well known, absent problems of commitment or information, every village member's consumption is independent of their own income realization, given aggregate village resources. Full insurance predicts a complete decoupling of idiosyncratic income shocks and consumption changes. Since this implication fails to hold in many datasets where it has been tested, the next question is how to distinguish among models that do predict a correlation between income shocks and consumption changes. The paper first presents the other benchmark case of no interpersonal insurance (borrowing and saving only) and then the moral hazard, limited commitment and hidden income models.

3.3 Borrowing-saving only (PIH)

Hall (1978) showed that, when households discount the future at rate β and can save and borrow at rate R, but have access to no interpersonal insurance or state-contingent assets, marginal utility follows a random walk, even if income is correlated over time[8]:

$$\beta R \mathbb{E}_{t-1} u'(c_t) = u'(c_{t-1}) \tag{6}$$

When a household can borrow and save, information about current or future household income is incorporated into consumption in the period in which the information is received, and is fully smoothed across all subsequent periods. As a result, marginal utility will follow a random walk (possibly with drift if $\beta \neq R$.)

3.3.1 Saving only

A household that can save, but not borrow, will not follow a standard Euler equation if the liquidity constraint ever binds (Deaton 1991).[9] Consumption will follow a modified Euler equation in periods when the liquidity constraint does not bind, but if income is low enough, for long enough, the constraint will bind. At that point, consumption equals income until income is high enough that the household finds it optimal to save. Therefore, in a savings-only model, lagged income may contain additional information not captured by lagged consumption: the knowledge that last period's income was very low suggests that the household may have been borrowing-constrained, causing last period's consumption to be lower than desired (Deaton 1991). Current consumption will then be higher than predicted by last period's consumption when last period's income was low. This property of the borrowing-constrained model is significant because it yields a different prediction from the other models considered here. Importantly, it can be distinguished from the hidden income model (below).

[8] In general, this result requires that the marginal utility of consumption is infinite when consumption equals zero, as I assume here (Carroll 1992).

[9] Similar results obtain if households can borrow only up to a fixed amount. Liquidity constraints will bind in the long run if households are impatient, with a rate of time preference greater than the interest rate; and will imply precautionary savings if they are also prudent, with $u''' > 0$ so that marginal utility is convex.

3.4 Moral hazard

In the moral hazard model, agents[10] are asked to exert effort or undertake costly investment, which cannot be directly observed or contracted on, giving agents an incentive to "shirk." Thus the agent must be given incentives to choose the level of effort desired by the planner. The moral hazard model has been widely used to explain imperfect insurance in developing and developed countries. The effort choice occurs before output is realized and affects the expected level of output. Introducing incentive compatibility constraints to the optimal insurance setup implies that full insurance may not be feasible. With two effort levels, and a utility function separable in consumption and effort, an incentive-compatibilty constraint will be binding at the optimum (Grossman and Hart 1983). The constraint is:

$$\sum_{\mathbf{y}_t} \pi\left(y_t|\mathbf{y}_{t-1}, \mathbf{e}_t = 1, \mathbf{e}_{t-1} = 1\right)\left[v\left(y_{it}\left(\mathbf{y}_t\right) + \tau_{it}\left(\mathbf{y}_t\right)\right) + \beta u_{i,t+1}\left(\mathbf{y}_t\right)\right] - z \tag{7}$$

$$= \sum_{\mathbf{y}_t} \pi\left(y_t|\mathbf{y}_{t-1}, \mathbf{e}_t = 0, \mathbf{e}_{t-1} = 1\right)\left[v\left(y_{it}\left(\mathbf{y}_t\right) + \tau_{it}\left(\mathbf{y}_t\right)\right) + \beta \hat{u}_{i,t+1}\left(\mathbf{y}_t\right)\right] \tag{8}$$

Equation 7 requires that, net of the effort cost z, the household must expect the same level of surplus if it exerts effort in the current period as if it shirks and pays no effort cost. The constraint is written for a household that exerted effort in the previous period (i.e., the household compares the probability $(y_t|\mathbf{y}_{t-1}, \mathbf{e}_t = 1, \mathbf{e}_{t-1} = 1)$ with the probability $(y_t|\mathbf{y}_{t-1}, \mathbf{e}_t = 0, \mathbf{e}_{t-1} = 1)$, both of which reflect having exerted effort in the previous period) since households will exert effort along the equilibrium path. The incentive-compatibility constraints which ensure this are discussed below.

This leads to the inverse Euler equation implication of moral hazard-constrained insurance:

$$\beta R \mathbb{E}_{t-1}\left(\frac{1}{v'(c_{it})}\right) = \frac{1}{v'(c_{i,t-1})} \tag{9}$$

Equation (9), first derived by Rogerson (1985) was derived under the assumption that the distribution of time t output was affected only by the agent's effort at time t. However, in many settings output is likely to depend on multiple lags of effort: for instance, the productivity of a field today may depend on fallowing, fertilizer use and other decisions taken over several years; the value of animals may depend on the care received over several years, a household's current productivity may depend on past decisions regarding investments in health, education, etc. Moreover, income is likely to be serially correlated over time since, e.g., high income today may improve health and hence future productivity.

A natural question is whether, if output depends on multiple lags of effort or is serially correlated, additional lags of inverse marginal utility are needed to predict current inverse marginal utility.

Fernandes and Phelan (2000) show that when the distribution of income depends on past as well as current effort, the moral hazard problem still has a recursive formulation, with two[11] additional "threat-keeping" constraints added to the planner's problem. Using Fernandes and Phelan's recursive setup, this paper shows that the inverse Euler equation also holds under moral hazard even if the distribution of output depends on actions taken in past periods as well as the current period. Therefore, a single lag of inverse marginal utility (LIMU) is sufficient for forecasting expected

[10] In some cases, such as this, I will refer to "agents" rather than "households" if the reference is to principal-agent problems more generally, where the agent may not be a household. However, in this paper, "household" is always synonymous with "agent."

[11] If there are N effort levels instead of 2, there are $N(N-1)$ threat-keeping constraints, but the solution method is unchanged.

current inverse marginal utility, even with technological linkages between periods through past effort choices and serial correlation in income:

Proposition 1 *When insurance is constrained only by moral hazard, conditional on LIMU* $\left(\frac{1}{u'(c_{i,t-1})}\right)$ *and the time* t *innovation to the shadow price of resources* η_t*, a household's time* t *inverse marginal utility is mean-independent of all information dated* $t-1$ *or before:*

$$\mathbb{E}\left(\frac{1}{v'(c_{it})}|\frac{1}{v'(c_{i,t-1})},\eta_t,x_{i,t-s}\right)=\mathbb{E}\left(\frac{1}{v'(c_{it})}|\frac{1}{v'(c_{i,t-1})},\eta_t\right),\forall x_{i,t-s},s>0 \tag{10}$$

Proof. *In Appendix A.* ■

The intuition for this result is that in the moral hazard-constrained model, income is observed. As a result, the planner or community controls consumption, and therefore marginal utility, by choosing the level of transfers. Due to concavity of the utility function, the most efficient way to deliver a given promised level of utility is to equate current inverse marginal utility with expected future inverse marginal utility. (As noted by Ligon (1998), *inverse* marginal utility is equated because the planner's cost of providing a small amount of additional utility to the agent is that agent's inverse marginal utility.) Therefore, if the former is known, it captures all information relevant to forecasting the latter.

Even if time $t-1$ income contained good or bad "news"[12] about earlier effort, the punishment or reward is still delivered at time $t-1$. As a result, time $t-1$ inverse marginal utility fully summarizes all information from $t-1$ and before that is relevant to forecasting time t inverse marginal utility.

3.5 Limited commitment

As with moral hazard, if an agent can walk away from the insurance network at any time if he can do better in autarky, full insurance may be infeasible (Coate and Ravallion 1993). Relative to the first best, limited commitment imposes a participation constraint on the planner's problem, requiring that the expected utility an agent gets in the insurance network be at least as great as the expected utility he could achieve in autarky. That is, after income is realized, a household will only carry out their assigned transfer if the utility associated with receiving the (possibly negative) net transfer $\tau_{it}(y_t)$ in the current period and remaining in the network in the next period with expected utility promise $u_{i,t+1}(y_t)$ is greater than reneging on the assigned transfer and entering autarky:

$$v\left(y_{it}+\tau_{it}\left(y_t\right)\right)+\beta u_{i,t+1}\left(y_t\right)\geq U^{aut}(y_{it},0),\forall i,y_t \tag{11}$$

where $U^{aut}(y_{it},0)$ represents the value of entering autarky with income y_{it} and zero savings (see Appendix A for details).

Kocherlakota (1996) showed that, under limited commitment, the vector of lagged marginal utility ratios for every

[12]The planner knows that high effort will be exerted along the equilibrium path, so income does not actually convey information about effort. Nonetheless, as noted by Hart and Holmstrom (1987), the contract will be structured as if the planner is receiving good or bad news about effort.

member of the insurance group,

$$\left\{ \frac{v'(c_{N,t-1})}{v'(c_{i,t-1})} \right\}_{i=1}^{N-1} \tag{12}$$

is a sufficient statistic for history when forecasting any household's consumption.[13] This vector specifies a unique point on the Pareto frontier and therefore captures all relevant information in forecasting any households' future consumption. This result has been extended to serial correlation in income by Ligon et al. (2002) and Laczó 2015. However, Kocherlakota's result is not directly testable if the econometrician does not have information on all the members of the insurance group. Since consumption and income data generally come from surveys, rather than censuses, the test has limited empirical applicability. This paper shows that a lower-dimensional predictor for the household's expected current inverse marginal utility is available: the shadow price of resources at time t serves as a summary measure of how much consumption must be given to other households in the village. This leads to the following result, which is testable with panel data for only a sample of households in a network.

Proposition 2 *When insurance is constrained only by limited commitment, conditional on LIMU* $\left(\frac{1}{u'(c_{i,t-1})}\right)$ *and the time* t *innovation to the village shadow price of resources* η_t*, a household's time* t *inverse marginal utility is mean-independent of all information dated* $t-1$ *or before: equation (10) holds.*

Proof. *In Appendix A.* ■

The intuition for this result is that, when the only barrier to full insurance is the fact that the household can walk away when the value of autarky is high relative to the value of remaining in the insurance agreement, the principal can allocate consumption to a household who is tempted to walk away without affecting the incentive of any other household to stay in the network, except through the tightness of the village's budget constraint. This is true whether the household is tempted because of high current income, or, in the case of serial correlation, because today's income implies "good news" about future income.

A constrained household gets current consumption and a future promise that make it exactly indifferent between staying in or leaving the network. At the optimum, providing a household with utility in the current period (through current consumption c_{it}) should be exactly as effective as providing promised utility in the future (through the utility promise $u_{i,t+1}$). Therefore, the household's lagged inverse marginal utility fully captures all the information from time $t-1$ and earlier that is relevant in predicting the mean of household i's time t consumption, conditional on the time t shadow price of resources, η_t. The need to control for η_t arises because it captures the "size of the pie" at time t, while lagged inverse marginal utility $\left(\frac{1}{v'(c_{i,t-1})}\right)$ captures the share of the pie that will, in expectation, go to household i.

Why does lagged inverse marginal utility serve as a sufficient predictor for current inverse marginal utility—leaving no additional predictive role of lagged income—even when incomes are correlated over time? Consider a household whose time $t-1$ income reflected "good news" about future income at t. Assume moreover that the combination of current $(t-1)$ income and the improved prospects regarding future income (at time t) are such that the household's

[13] Kocherlakota also discusses an additional implication of limited commitment, called "amnesia" or "forgiveness". Kinnan (2011) presents an empirical test of this implication.

participation constraint was binding at time $t-1$. At $t-1$, the period in which this news was realized and the binding constraint occurred, the household would have been offered a "better deal" to prevent it from entering into autarky. Due to concavity of the utility function, this better deal will optimally include both a higher time $t-1$ transfer and higher promised utility for time t. Moreover, at the optimum, the transfer and promise will be such that expected inverse marginal utility at time t is equal to time $t-1$ inverse marginal utility. In other words, the information contained in time $t-1$ income that is relevant in forecasting time t inverse marginal utility was fully reflected in time $t-1$ inverse marginal utility, leaving no additional predictive value of lagged income over and above lagged inverse marginal utility.

This result echoes the result in Laczó (2015), who shows that, under limited commitment when income is Markovian, the ratio of the Pareto weight of household i to the Pareto weight of a composite household reflecting the rest of the village is a sufficient statistic in forecasting the evolution of consumption of household i. (Laczó also considers the possibility of preference heterogeneity.) The contribution of this paper relative to Laczó's work is to show that the first-order conditions of the planner's problem imply that, not only is the multiplier on the promise-keeping constraint of a given household a sufficient statistic in forecasting the evolution of consumption, but that this promise-keeping constraint has a one-to-one relationship with inverse marginal utility, so that lagged inverse marginal utility is a sufficient predictor of current inverse marginal utility.

A natural question is what causes the difference between the result shown here and the result of Kocherlakota (1996). The difference arises, first due to the assumption that the planner has access to a savings technology, whereas Kocherlakota assumes no storage. Second, the claim of Proposition 2 is more modest than Kocherlakota's, in the sense that Proposition 2 is a statement about predicting the expected value of time t inverse marginal utility. Kocherlakota's implication is stronger: if the LIMU of all village members were known, the vector $\left\{\frac{v'(c_{N,t-1})}{v'(c_{i,t-1})}\right\}_{i=1}^{N-1}$ would be a sufficient statistic, sufficient for predicting not merely for the level of time t inverse marginal utility, but all moments of inverse marginal utility (variance, etc.).

3.6 Hidden income

As well as issues of *ex ante* information (moral hazard) and of limited commitment, *ex post* informational asymmetries may also restrict the (implicit or explicit) contracts that agents can enter into, and thereby restrict insurance. Namely, it may be that income is not observable by the community, and households must be given incentives to report it (Townsend 1982). Such *ex post* informational asymmetries cause the sufficiency result of limited commitment and moral hazard to break down. The difference between moral hazard (*ex ante* hidden information) and hidden income (*ex post* information) is that, in the moral hazard case, there is no uncertainty in equilibrium: the planner knows what effort choice the agent will optimally make (Hart and Holmstrom 1987). In the case of hidden income, there *is* equilibrium uncertainty: the planner needs to learn what level of income has been realized in order to provide insurance, which introduces a screening problem. As shown below, this screening problem is solved by distorting the intertemporal allocation of consumption.

Assume now that there are no issues of moral hazard or limited commitment: agents can commit to the insurance arrangement and effort is contractible. However, household income is not observable by other households.[14] Potentially $S(S-1)$ incentive-compatibility constraints are added to the planner's problem, requiring that a household realizing any of the S income levels must not gain by claiming any of the $S-1$ other possible levels. However, Thomas and Worrall (1990) show that only the $S-1$ local downward constraints, which require that an agent getting income y_r not prefer to claim the next-lower income level y_{r-1}, will be binding at the optimum.[15]

Because off-equilibrium levels of consumption appear in the incentive-compatibility constraints, additional notation is necessary. Write y_{irt} as shorthand for $y_{it} = y_r$, and write $\tau_{irt}(\mathbf{y}_t)$ for and $u_{ir,t+1}(\mathbf{y}_t)$ for the transfer and utility promise given to household i when i reports income y_r and the village income realization is $\mathbf{y}_t$. The values $\tau_{irt}(\mathbf{y}_t)$ and $u_{ir,t+1}(\mathbf{y}_t)$ represent the transfer and future promise awarded to household i for truthfully reporting income y_r at time t.

Turning to the values associated with local mis-reporting, i.e., claiming income was y_{r-1} when it was y_r, write $\tau_{it}(y_{i,r-1}, \mathbf{y}_{-i,t})$ for the transfer given to household i when i reports income y_{r-1} and the rest of the village reports the vector of incomes $\mathbf{y}_{-i,t}$, and write $u_{i,t+1}(y_{i,r-1}, \mathbf{y}_{-i,t})$ for the analogous future promise. Then the local downward constraints constraints are:

$$
\begin{aligned}
&v(y_{irt} + \tau_{irt}(\mathbf{y}_t)) + \beta u_{ir,t+1}(\mathbf{y}_t) = v(y_{irt} + \tau_{it}(y_{i,r-1}, \mathbf{y}_{-i,t})) \\
&+\beta u_{i,t+1}(y_{i,r-1}, \mathbf{y}_{-i,t}), r = 2, ..., S
\end{aligned} \tag{13}
$$

The first-order conditions of the problem imply the following result:

Proposition 3 *When agents can commit to the insurance agreement, and effort is contractible, but output is hidden, the vector* $\left(\frac{1}{v'(c_{i,t-1})}, \eta_t\right)$ *is not sufficient to forecast expected current inverse marginal utility; the one-period lag of income* $(y_{i,t-1})$ *has additional predictive power:*

$$
\mathbb{E}\left(\frac{1}{v'(c_{it})} | \frac{1}{v'(c_{i,t-1})}, \eta_t, y_{i,t-1}\right) \neq \mathbb{E}\left(\frac{1}{v'(c_{it})} | \frac{1}{v'(c_{i,t-1})}, \eta_t\right)
$$

Proof. *In Appendix A.* ■

Lemma 4 *Assume that equilibrium marginal utility falls, in percentage terms, more quickly with income than promise-keeping constraint multipliers* (ξ) *rise with income:*

$$
\frac{v'(y_{ipt} + \tau_{ipt}(\mathbf{y}_t)) - v'(y_{i,p+1,t} + \tau_{ipt}(\mathbf{y}_t))}{v'(y_{i,p+1,t} + \tau_{ipt}(\mathbf{y}_t))} > \frac{\xi_{ip,t-1} - \xi_{i,p+1,t-1}}{\xi_{i,p+1,t-1}}, \forall p \in \{1, S-1\} \tag{14}
$$

[14] The standard hidden income model–and the test derived here–assumes that households' levels of borrowing/saving are observable/ contractable. That is, the planner's problem does not include the Euler equation (equation 6, above). If both income and assets are unobservable, no interpersonal insurance is possible (Allen 1985, Cole and Kocherlakota 2001). The planner can at best allow the agent to borrow and lend a risk-free bond. Thus the evidence of interpersonal insurance presented below is also a rejection of the hidden income-hidden savings model. The assumption of observable savings appears plausible in the Thai context given that a large share of wealth is held in observable assets such as land, and savings balances with rural banks such as the Bank for Agriculture and Agricultural Cooperatives (BAAC) are often recorded on publicly-visible signboards.

[15] Thomas and Worrall's result requires that absolute risk aversion is non-increasing (Assumption 2, above). This assumption is satisfied by the commonly-used constant relative risk aversion and constant absolute risk aversion utility functions. As pointed out by Arrow (1971), increasing absolute risk aversion would imply that higher-wealth individuals would be more averse to a given absolute gamble than lower-wealth individuals, which appears implausible.

Then current inverse marginal utility will be positively correlated with $y_{i,t-1}$, conditional on $\left(\frac{1}{v'(c_{i,t-1})}, \eta_t\right)$:

$$\frac{\partial}{\partial y_{i,t-1}} \left(\frac{1}{v'(c_{it})} - \mathbb{E}\left(\frac{1}{v'(c_{it})} | \frac{1}{u'(c_{i,t-1})}, \eta_t \right) \right) > 0 \tag{15}$$

Proof. *In Appendix A.* ■

3.6.1 An additional implication of hidden income: reduced insufficiency of LIMU when income is less variable

An additional prediction of the hidden income model is related to the effect of a reduction in the variability of a household's income process. Such a reduction makes truth-telling constraints less binding, which in turn implies a reduced "wedge" between LIMU $\left(\frac{1}{v'(c_{i,t-1})}\right)$ and expected promised utility:

Proposition 5 *A decrease in variability of the income process, in the sense of that the less-variable distribution is second-order stochastically dominated by the more-variable distribution, reduces the degree to which current inverse marginal utility will be correlated with y_{t-1}, conditional on $\left(\frac{1}{v'(c_{i,t-1})}, \eta_t\right)$.*

Proof. *In Appendix A.* ■

Intuitively, the less uncertainty about a household's income, the less binding are the truth-telling constraints facing the household. Since the truth-telling constraints are the cause of the wedge between LIMU and expected promised utility, relaxing the constraints reduces the wedge.

3.7 Summary: Distinguishing barriers to insurance

The preceding discussion suggests three tests that, in combination, can be used to distinguish among limited commitment, moral hazard, hidden income, and borrowing-saving (PIH). These tests are summarized in the following table:

	Borrowing-saving (PIH)	Saving only	Limited commitment	Moral hazard	Hidden income
$f(c_{t-1}) =$	$v'(c_{it})$	$v'(c_{it})$	$\frac{1}{v'(c_{it})}$	$\frac{1}{v'(c_{it})}$	$\frac{1}{v'(c_{it})}$
Correlation of $f(c_{t-1})$ with y_{t-1}	0	neg.	0	0	$\neq 0$/pos.†
Inverse Euler Eqn				✓	
†Correlation of $f(c_{t-1})$ with y_{t-1} is positive if Lemma 4 holds: see Appendix A.					

Under the PIH, limited commitment, or moral hazard, all information needed to forecast current consumption is encoded in a function of past consumption–if this function is in the information set, no other lagged information, including lagged income, should improve the forecast. It is still the case that, unconditionally, lagged income should help to predict current consumption. The results derived above state that the information in lagged income operates solely through (a function of) lagged consumption. Under hidden income, on the other hand, the information contained in lagged income is not fully captured by lagged marginal utility or inverse marginal utility.

The intuition for the difference between hidden income on one hand, and limited commitment and moral hazard on the other is that, when income is observed, the planner controls consumption, and therefore pins down marginal utility, by choosing the level of transfers. Due to concavity of the utility function, the most efficient way to deliver utility is to equate current inverse marginal utility with expected future inverse marginal utility. Therefore, if the former is known, it serves as a sufficient predictor for the expectation of the latter.

However, when income is private information, consumption is not directly controlled by the planner. Instead, the planner faces a screening problem: distinguishing a truly low-income household from a higher-income household *claiming* low income. The constrained-optimal schedule of transfers and promised utilities distorts the tradeoff between current consumption and future expected utility. Households announcing low incomes are penalized more in terms of future utility, which is equally valuable to truthful and misreporting households.[16] Current consumption, however, is more valuable to truthful households, who have lower income than households who are tempted to falsely claim the same level of income. The magnitude of this distortion is a function of the income realization and so the expectation of time t inverse marginal utility depends on time $t-1$ income as well as time $t-1$ inverse marginal utility.

In the limited commitment and moral hazard cases, mis-reporting income is not possible, and as a result there is no deviation from the optimal division of promised utility across periods–utility in the current period (via transfers) and utility in future periods (via promised utility) are equally valuable to the household and so the planner's cost of providing them, which is equal to the household's inverse marginal utility, is equated, in expectation, over time. As a result, all past information relevant to forecasting current inverse marginal utility is encoded in last period's inverse marginal utility under limited commitment and moral hazard, but not under hidden income.

The next section describes how the implications of each model can be taken to data in order to test for the source of market incompleteness in a given setting.

4 Distinguishing barriers to insurance

4.1 Testable implication of limited commitment or moral hazard

Under either limited commitment or moral hazard, all past information relevant to forecasting current inverse marginal utility is encoded in last period's inverse marginal utility and a village-month fixed effect.[17] Thus:

$$\mathbb{E}_{t-1}\left[\frac{1}{v'(c_{it})}\right] = f\left(\frac{1}{v'(c_{i,t-1})}, \eta_t\right) \tag{16}$$

This implies that there should be no predictive power of lagged income in the equation

$$\frac{1}{v'(c_{it})} = f\left(\frac{1}{v'(c_{i,t-1})}, \eta_t, y_{i,t-1}\right) \tag{17}$$

[16] If income is serially correlated over time, the same intuition applies as long as the intertemporal correlation is not perfect; if the intertemporal correlation were perfect there would be no uncertainty about income after the first period.

[17] It is assumed that rational expectations hold for η_t, so that η_t is in the time $t-1$ information set.

With a CRRA utility function, this becomes

$$c_{it}^{\rho} = f\left(c_{i,t-1}^{\rho}, \eta_t, y_{i,t-1}\right) \tag{18}$$

since $\frac{1}{c_{i,t-1}^{-\rho}} = c_{i,t-1}^{\rho}$. Exponentiating each side by $1/\rho$,

$$c_{it} = f\left(c_{i,t-1}^{\rho}, \eta_t, y_{i,t-1}\right)^{1/\rho} \tag{19}$$

To test this prediction, I first use the fact that all three models–limited commitment, moral hazard and hidden income–imply a multiplicative relationship between LIMU ($c_{i,t-1}^{\rho}$), and the village-month fixed effect η_t. If $\rho = 1$ and $c_{i,t-1}$ and η_t enter as $\alpha c_{i,t-1} + \beta c_{i,t-1} \times \eta_t + \eta_t$, so equation (19) becomes:

$$c_{it} = \alpha c_{i,t-1} + \beta c_{i,t-1} \times \eta_t + \eta_t + \gamma y_{i,t-1} \tag{20}$$

which can be estimated via OLS.

If $\rho = 1$, but more general interactions between $c_{i,t-1}$ and η_t are allowed, this becomes

$$c_{it} = f(c_{i,t-1}, \eta_t) + \gamma y_{i,t-1} \tag{21}$$

where $f()$ can be estimated flexibly using splines.

To allow for the possibility that $\rho \neq 1$, nonlinear least squares (NLS) can be used to estimate:

$$c_{it} = \left(\alpha c_{i,t-1}^{\rho} + \beta c_{i,t-1}^{\rho} \times \eta_t + \eta_t + \gamma y_{i,t-1}\right)^{1/\rho} \tag{22}$$

or an alternative specification allowing for arbitrary interactions between LIMU and η_t by including splines in LIMU, η_t, and in LIMU$\times\eta_t$.

The results, both imposing $\rho = 1$ and estimating ρ via NLS estimation, are discussed in Section 6.

4.2 Classical measurement error in expenditure

Measurement error in right-hand variables is often seen as a threat to power, causing under-rejection of the null hypothesis (in this case, sufficiency of LIMU). However, for the tests used in this paper, measurement error can distort the size of the test, causing over-rejection of the null. If expenditure is measured with classical error, uncorrelated with the true value and over time, the estimated coefficient on LIMU will be attenuated toward zero. This will result in biased predictions of consumption using LIMU. Moreover, this can create bias against sufficiency of LIMU and in favor of the implications of the hidden income model. If measurement error is classical, it could be addressed by instrumenting the first lag of consumption with its second lag (see Proposition 7 in Appendix A).[18] However, in the

[18]Appendix B presents results estimating the linearized version of equation (16) via two-stage least squares, instrumenting $\ln c_{iv,t-1}$ with $\ln c_{iv,t-2}$. The results are quantitatively similar to OLS instruments, suggesting that classical measurement error is not driving the results. However,

context of panel data on consumption, measurement error may be nonclassical: correlated over time or correlated with the true level of consumption. This creates a form of misspecification in the estimating equation which is not solved with an IV approach. Misspecification may also arise if households have heterogeneous risk preferences, preferences with nonseparabilities between consumption and leisure, or preference shocks which are correlated with income. In Section 7, I propose a non-parametric test which addresses the possibility that misspecification is driving the results. First, however, Section 5 discusses the data, and Section 6 presents results maintaining the assumption of no measurement error and no risk preference heterogeneity.

5 Data

Data are from the January 1999- December 2005 waves of the Townsend Thai Monthly Survey, which covers 16 villages in central and northeastern Thailand, four in each of four provinces: two in the central region near Bangkok and two in the northeast. In each village, 45 households were initially selected at random and reinterviewed each month. (See Townsend et al. (1997) for details.) Detailed data were collected on households' demographic composition and their income, including farms, businesses, and wage employment.

Information on household expenditure was collected using detailed bi-weekly and monthly surveys. Thus expenditure is likely to be quite well-measured in this dataset, relative to datasets which measure expenditure over a longer recall period and/or which collect information on only a subset of expenditures, such as Living Standard Measurement Surveys or the Panel Survey of Income Dynamics in the US. The expenditure measure is constructed as the sum of the value of purchases, home production, and items acquired in other ways, such as gifts. These questions are asked separately for different items in categories of food, fuel, transportation, education, clothing, rent, etc., covering 63 specific items in total (See Townsend et al. (1997) for details.) The responses are summed across items and methods of acquisition (purchase, home production, other) to construct the measure of total expenditure. Total expenditure is converted to per capita terms using the equivalence scale used by Townsend (1994) for Indian villages.[19] The resulting value of per capita expenditure is used as the proxy for per capita consumption.

A total of 531 households appear in all 84 months of the survey period used here, out of 670 who were interviewed in January 1999. Summary statistics are reported in Appendix B, Table A1.[20] Average household size is 4.5, or 3.8 adult equivalents. Average reported monthly per capita expenditure was 5,213 2002 baht, or approximately $124 in 2002 US dollars. Due to investment, average reported monthly income per capita is higher than expenditure at 8,981

I regard the "omnibus" specification test discussed in Section 7 as a more compelling test as it is also robust to nonclassical measurement error and other forms of misspecification.

[19]The weights are: for adult males, 1.0; for adult females, 0.9. For males and females aged 13-18, 0.94, and 0.83, respectively; for children aged 7-12, 0.67 regardless of gender; for children 4-6, 0.52; for toddlers 1-3, 0.32; and for infants 0.05. Use of equivalence scales that incorporate economies of scale within the household yields similar results, available upon request.

[20]I focus on the continuously-observed sample to avoid missing values of lagged consumption due to migration in and out of the survey. Differences between the continuously-observed sample and the initial sample are reported in Table A1. Smaller households and those whose head is engaged in rice farming or construction are most likely not to be continuously observed, while corn and livestock farmers are more likely to be continuously observed. Reassuringly, residuals of income and consumption (partialing out demographic, village, year and occupation variables) do not differ across the two samples. Imputing income and expenditure data for missing household-months based on village, year, occupation and baseline demographic variables and running the analysis on this sample, yields results similar to the results for the continuously-observed sample (available on request).

baht.

Households are classified into occupations based on the primary occupation reported by the household head in the initial wave of the survey.[21] The most common occupation in the sample is rice farming (35% of household heads); followed by non-agricultural labor, including owning a non-agricultural business (12% of household heads); growing corn (10%), raising livestock (9%); and agricultural wage labor (5%). Growing other crops, raising fish or shrimp, growing orchard crops, and construction each account for less than 5%. Seven percent report an occupation classified as "other."

Another strength of the Townsend Thai Monthly Survey data is that households are asked separately about gifts and transfers (both money and in-kind) from organizations, from households in the village, and from households outside of the village. All of these types of transfers are prevalent: gifts given to other households in the same village equal 5.4% of average expenditure, while gifts from others in the same village equal 9% of average expenditure. Gifts/remittances given to those outside the household's village equal 17.5% of average expenditure, and gifts/remittances received from those outside the village equal 27.7% of average expenditure. Moreover, these numbers exclude transfers embodied in interest-free, low-cost and flexible loans, which are prevalent in these villages, as well as in other settings (Platteau and Abraham 1987, Udry 1994, Fafchamps and Lund 2003) The significant magnitude of intra-village transfers is direct evidence that within-village insurance is important, while transfers made with those outside the village may constitute a source of unobserved income.

Finally, using data from rain gauges located in each village, yielding a measure of total rainfall in each village in each month between 1999 and 2003, quarterly rainfall variables (deviations from the provincial average in that quarter over the entire period) were constructed following Paxson (1992):

$$\begin{aligned} &R_{qvt} - \bar{R}_{qp}, \left(R_{qvt} - \bar{R}_{qp}\right)^2, \\ &q = 1, 2, 3, 4 \end{aligned} \tag{23}$$

The rainfall variables are used to construct instruments for income in the tests of full insurance, and for a test of the hidden income model. The next section presents the main results.

6 Results

6.1 Insurance is imperfect...

If households were perfectly insured, there would be no need to look for evidence of a particular insurance friction—if household consumption did not move with contemporaneous household income, and all villagers' consumptions moved one-for-one with average village consumption, this would mean that none of hidden income, moral hazard, or limited commitment was a significant impediment to full insurance. This is not the case for rural Thailand. To

[21] Primary occupation is defined as "the occupation that [the respondent] earned the most from during the past 12 months." Households were not asked about changes to their primary occupation in subsequent waves of the survey.

demonstrate this, I estimate the standard omnibus test of full insurance (Townsend 1994) using the January 1999-December 2005 waves of the Townsend Thai Monthly Survey:

$$\ln c_{ivt} = \alpha \ln y_{ivt} + \beta_{iv} + \delta_{vt} + \varepsilon_{ivt} \tag{24}$$

where c_{ivt} is household i's per-capita consumption (indexing households by v to denote their village) at time t, y_{ivt} is household i's income at time t, β_{iv} is a household-fixed effect and δ_{vt} is a village-year dummy variable capturing common changes in villagers' consumption due to changes in aggregate resources. Results appear in Table I, Panel A.

As detailed in Section 4, income and expenditure data are collected monthly. However, the correspondence between expenditure and consumption is likely to be higher at annual frequencies than monthly frequencies. Aggregating to the annual level will also reduce the importance of measurement error if recall errors are uncorrelated across months. Therefore, columns (1) and (2) aggregate the 84 months of data to the annual level, while columns (3) and (4) use the data at the monthly level.

The results show that households are not fully insured. The estimated comovement of consumption and income is $\hat{\alpha} = .0699$ at the annual level, different from zero at the 1% level ($t = 9.16$) . (See Table I, Panel A, column 1.) That is, a 10% change in annual household income is associated with a 0.67% change in contemporaneous per capita annual consumption. At the monthly level, the comovement between consumption and income is smaller in magnitude, but still highly significantly different from zero ($\hat{\alpha} = .00645$, $t = 16.37$).

Measurement error in income is a concern in interpreting the OLS results. Classical measurement error in income (uncorrelated with the true values of income changes and with the error terms ε), will attenuate $\hat{\alpha}$ toward zero. This would make the extent to which income changes predict consumption changes in the data a lower bound on the true sensitivity of consumption to income. In this case, instrumenting income with variables correlated with true income but uncorrelated with the measurement error should then result in a higher estimate of α. Because many households in these villages work in agriculture, rainfall is a possible instrument. As discussed above, village-level monthly rainfall data is available for the years 1999-2003. Following the strategy of Paxson (1992), I instrument income changes with the interactions between occupation indicators[22] and deviations of quarterly income from the province-wide quarterly average defined in (23), and occupation interactions with squared deviations:

$$\begin{aligned}
&\mathbf{1}(occ_i = o) \times R_{qvt} - \bar{R}_{qp}, \\
&\mathbf{1}(occ_i = o) \times \left(R_{qvt} - \bar{R}_{qp}\right)^2, \\
&q = 1, 2, 3, 4; o \in \{1, 10\}
\end{aligned}$$

Using the occupation-quarterly rainfall variables as instruments for annual income raises the coefficient on income changes significantly, to $\hat{\alpha}^{IV} = .177$ ($t = 4.2$) at the annual level (Table I, Panel A, column 2). Using occupation-

[22]Households were asked in the initial wave of the survey about the primary occupation of each adult household member. The response of the household head was used to classify the household, with responses grouped into 10 categories: farm rice, farm corn, farm orchard crops, farm other crops, raise livestock, raise fish/shrimp, agricultural wage labor, non-agricultural wage labor, construction, and other.

Table I: Consumption smoothing at the individual and village level

	(1)	(2)	(3)	(4)
	Panel A			
	log household annual PCE		log household monthly PCE	
	OLS	IV	OLS	IV
log household income	0.0669	0.177	0.00645	0.0131
	(0.00730)	(0.0419)	(0.000394)	(0.00505)
Village-year fixed effects?	Yes	Yes	Yes*	Yes*
Village-year F statistic	5.256	3.461	5.534	4.913
Observations	3,323	1,879	44,604	25,921
R-squared	0.181		0.083	
	Panel B			
	village avg log annual PCE		village avg log monthly PCE	
	OLS		OLS	
village av. log income	0.172		0.0158	
	(0.0523)		(0.00300)	
Village-year fixed effects?	No		No	
Observations	112		1,344	
R-squared	0.111		0.0272	

Notes: In the top panel, household-level variables in columns (1), (2), (3) and (4) are deviations from individual means. In the bottom panel, variables are village level averages. Standard errors in brackets. F-statistic tests the joint significance of the village-year or village-month effects. In column (2), instruments are quarterly rainfall deviations and the squared rainfall deviations interacted with occupation. In column (4), instruments are the rainfalll deviations and squared rainfall deviations for the current and past 6 months interacted with occupation. Rainfall data is available for 1999-2003. *In columns (3) and (4), village-month fixed effects are used.

monthly rainfall variables as instruments for monthly income yields $\hat{\alpha}^{IV} = .0131$ ($t = 2.59$) at the monthly level (Table I, Panel A, column 4). Once measurement error in income is addressed, the evidence is even stronger that households bear a substantial fraction of their idiosyncratic income risk, although village-level insurance does smooth a significant portion of income risk, as discussed below.

Absent taste shocks or nonseparabilities, and with no heterogeneity in risk aversion, this dependence of consumption growth on idiosyncratic income growth is incompatible with full insurance. However, insurance constrained by either limited commitment, hidden income, or moral hazard would display this feature.

6.2 ...but villages do provide insurance

Finding $\alpha < 1$ in equation (24) does not establish that villages provide insurance: households could smooth consumption using borrowing and/or saving (Hall 1978, Deaton 1991). One suggestive sign of intravillage insurance is the fact that the village-year effects in equation (24) are highly significant in explaining household consumption changes. The hypothesis of no common component to within-village consumption changes is strongly rejected: $F = 5.256, p = 0.000$ in the OLS regression (table I, panel A, column 1) and $F = 3.461, p = 0.000$ in the IV regression (table I, panel A, column 2), indicating that there is a highly significant tendency for the consumption of households in the same village to move together.

Of course, this is also consistent with households facing common village-level shocks (e.g., prices or weather). Another piece of evidence of intra-village insurance is the fact that households in the Thai data receive state-contingent transfers from others in their village: as discussed above, households report gifts given to and received from others in the village which equal 5-9% of average expenditure.

Taken together, these results suggest that belonging to a village network does not remove all idiosyncratic risk, but village networks do reduce dependence of household consumption on household income. Section 3 discussed three models that attempt to rationalize this finding of partial insurance: limited commitment, hidden income, and moral hazard.

6.3 Credit is available

The form of the contract that the hypothetical village social planner can offer to a household depends on whether the village's budget must balance each period. If so, a constraint on the planner's problem is that, at each date and state of the world, total consumption among the villagers cannot exceed their total income. One-for-one dependence of village consumption at time t on village income at t can be tested by estimating a version of equation (24) with data aggregated to the village-year or village-month level and testing whether the coefficient is different from one. Table I, Panel B shows the results. Using OLS on annual data yields an estimate of $\hat{\alpha}^{Village} = .172$,significantly different from 1 ($t = -15.8$). Using monthly data yields $\hat{\alpha}^{Village} = .0158$, also significantly different from 1 ($t = 328$).[23] Therefore, at both the yearly and monthly level, villages are not constrained to consume total village income period-

[23]Instrumental variables estimates are not shown since rainfall interacted with occupation is not defined at the vilage level.

by-period. This suggests that village institutions (banks, moneylenders, local government, etc.) have access to a credit market or a set of equivalent institutions.

6.4 Testing across models of partial insurance: lagged inverse marginal utility and lagged income

The results in Table I demonstrate that inter-household insurance is present, but incomplete. Table II presents tests of the implication that, under limited commitment and moral hazard, lagged income will have no predictive power in forecasting current inverse marginal utility; while under hidden income it will be positively predictive of current inverse marginal utility. For these results (and those in Table III), the data is used at monthly frequency. Because zero income is observed in some months, the inverse hyperbolic sine transformation[24] is used for lagged income, rather than the log transformation.[25]

In the models allowing interactions between the village-month fixed effects and LIMU, it is not possible to treat the η_t as parameters to be estimated as fixed effects due to an incidental parameters problem. Therefore the estimates replace the fully flexible village-month fixed effects η_t with values calculated as the leave-out mean of average consumption at the village-month level:[26]

$$\eta'_{-i,t} = \frac{\sum_{j \neq i} c_{jt}}{N_v - 1}$$

where N_v is the size of the sample in village v.[27]

Column 1 estimates equation (20), which imposes that ρ, the curvature of the utility function, equals one. As expected, LIMU is strongly predictive of current inverse marginal utility: the coefficient on lagged consumption is 0.192 $(t = 4.13)$. However, sufficiency of LIMU is strongly rejected; the coefficient on lagged IHS income is positive and significant at the 1% level $(t = 19.1)$.[28]

Column 2 estimates equation (21), which relaxes the functional form assumption regarding LIMU using a spline in lagged consumption. Again, the effect of lagged IHS income is positive and significant at the 1% level $(t = 12.6)$. (No estimate of the effect of lagged consumption is reported in columns 2, 3 or 5 as the effect varies for each realization of $\eta'_{-i,t}$.)

In column 3, $f()$ is not imposed to be multiplicative in LIMU and η'_t; splines in lagged consumption, $\eta'_{-i,t}$ and lagged consumption interacted with the estimated village-year effects, are used to allow for arbitrary interactions.

[24]The inverse hyperbolic sine transformation is $sinh^{-1}(x) = \ln\left[x + \left(x^2+1\right)^{.5}\right]$. Its properties are similar to $\log(x)$ (Burbidge, Magee, and Robb 1988), but is defined for all x.

[25]In 29% of household-month observations, strictly negative net income is reported in the dataset, due to treatment of business expenses and depreciation. These observations are dropped because non-linear estimation of Eq. 19 is not possible if $f\left(c^{\rho}_{i,t-1}, \eta_t, y_{i,t-1}\right) < 0$, because $f\left(c^{\rho}_{i,t-1}, \eta_t, y_{i,t-1}\right)^{1/\rho}$ will then be undefined for $\rho \neq 1$. However, estimates imposing $\rho = 1$ are very similar for the sample including negative incomes: see Appendix B, Table A2.

[26]This specification is chosen to capture the role of the budget constraint representing the amount of consumption which must be given to all other households in the village. Results using the overall mean, $\eta'_t = \frac{\sum_j c_{jt}}{N_v}$, are very similar and available on request.

[27]N_v does not vary over time due to the use of a balanced panel of households who appear in all 84 months of the data. Results are similar if shorter panels, with larger cross-sectional dimension, are used instead; results available on request.

[28]All p-values in reference to Tables II and III are one-sided as, under Lemma 4 the hidden income model predicts that the coefficient on lagged income will be positive.

Table II: Testing the hidden income model: Predictive role of lagged income

	(1)	(2)	(3)	(4)	(5)
Lagged consumption	0.192			0.573	
	(0.0466)			(0.0562)	
Lagged IHS income	741.2	513.7	496.7	0.318	0.0166
	(38.83)	(40.90)	(40.52)	(0.1172)	(0.01248)
ρ (CRRA curvature)	1	1	1	0.244	0.115
				(0.0289)	(0.0431)
Village-month fixed effect?	Yes	Yes	Yes	Yes	Yes
Village-month fixed effect$\times c_{t-1}$?	Yes	Yes	Yes	Yes	Yes
Estimation method	OLS	OLS	OLS	NLLS	NLLS
R-squared	0.082	0.376	0.377	0.374	0.402
Observations	31,303	31,303	31,303	31,303	31,303

Notes: Standard errors clustered at the village-quarter level in brackets.
IHS is inverse hyperbolic sine (see text).
Model 1: $\rho = 1$, including village-month fixed effects $(\eta'_{-i,t})$ and $\eta'_{-i,t} \times c_{i,t-1}$.
Model 2: $\rho = 1$, including village-month fixed effects $(\eta'_{-i,t})$ and $\eta'_{-i,t} \times c_{i,t-1}$
and quadratic splines in lagged consumption $(c_{i,t-1})$.
Model 3: $\rho = 1$, including quadratic splines in estimated village-month effects $(\eta'_{-i,t})$
and quadratic splines in lagged consumption and lagged consumption$\times\eta'_{-i,t}$.
Model 4: $\rho \neq 1$, including village-month fixed effects $(\eta'_{-i,t})$ and $\eta'_{-i,t} \times c_{i,t-1}$.
Model : $\rho \neq 1$, including quadratic splines in estimated village-month effects $(\eta'_{-i,t})$
and quadratic splines in lagged consumption and lagged consumption$\times\eta'_{-i,t}$.

Sufficiency of LIMU is rejected: the effect of lagged IHS income is positive and significant at the 1% level $(t = 12.3)$. These results indicate that the functional form of $f()$ assumed in columns 1 and 2 is not driving the results.

Column 4, instead of imposing $\rho = 1$, estimates ρ via nonlinear least squares, but once again restricts $f()$ to be additive in LIMU, $\eta'_{-i,t}$ and LIMU$\times\eta'_{-i,t}$. The estimate of ρ is approximately 0.25, below one but significantly different from zero $(t = 8.4)$. Again, LIMU is strongly predictive, with a coefficient of 0.573 $(t = 10.2)$, but the effect of lagged income remains significantly positive at the 1% level $(t = 2.7)$. (Because of the different scaling of the equation, the estimated effect of lagged income is now smaller in magnitude than in columns 1-3.)

Finally, in column 5, corresponding to equation (19), ρ is estimated and $f()$ is estimated flexibly via splines in LIMU, $\eta'_{-i,t}$ and LIMU$\times\eta'_{-i,t}$. The estimated ρ is now 0.115, different from zero at the 1% level $(t = 2.7)$. The estimated effect of lagged income remains positive and significant at the 10% level in a one-sided test $(t = 1.33)$.

To summarize, the evidence presented in Table II is consistent with the hidden income model: conditional on LIMU, lagged income contains additional predictive power to predict current inverse marginal utility, and enters with a positive coefficient. The other candidate models are rejected: under moral hazard, limited commitment or a borrowing-saving model, lagged income would not be predictive. The borrowing-only/buffer stock model is also rejected: lagged income enters with a positive coefficient, while in a borrowing-only model the coefficient on lagged income would be negative, as discussed in section 3.3.1.

The positive coefficient on lagged income suggests that the need to provide incentives to high-income households to truthfully reveal their income constrains inter-household insurance. Those with low past incomes receive less current consumption (i.e., higher current marginal utility, hence lower current inverse marginal utility) than predicted by LIMU, while those with high past income receive more consumption (higher current inverse marginal utility). This finding is observed consistently across specifications as increasingly fewer restrictions are placed on the function relating LIMU to current inverse marginal utility. The value in presenting the more restrictive specifications in cols 1-4, as well as the most flexible specification in column 5 is, first, that the OLS estimates in columns 1-3 can be compared to estimates in the full sample, including household-month observations with negative net income, where the estimates are quite similar (see Appendix B, Table A2). Second, the restricted specifications provide increased statistical power, which is helpful when performing the test described in the next subsection, which serves as an additional test of the hidden income model: that households with "easier-to-forecast" income processes should display less departure from mean-independence between current inverse marginal utility and lagged income.

6.5 Testing hidden income: departure from sufficiency and predictive power of rainfall

Proposition 5 states that, if the barrier to insurance is the inability of the community to directly observe households' incomes, a barrier which is manifested through the predictive role of past income, then for households whose income processes are less uncertain, e.g., because they are predicted by observed factors, past income should be less predictive.

As a test of this prediction, I regress income on the rainfall variables $R_{qvt} - \bar{R}_{qp}$ and $\left(R_{qvt} - \bar{R}_{qp}\right)^2$, defined above, separately for households in each of 10 occupational categories.[29] The R^2 from this regression was interacted with lagged income. (The R^2s are shown in Appendix Table A3.[30]) Table III shows the results of allowing the coefficient on lagged income in equation (22) to vary by the occupation-specific R^2 of the rainfall variables in forecasting income:

$$c_{it} = f\left(c_{i,t-1}^{\rho}, \eta_t, y_{i,t-1}, R_i^2, y_{i,t-1} \times R_i^2\right)^{1/\rho} \tag{25}$$

If insufficiency of LIMU is reduced when a household's income is easier to forecast, the estimated coefficient on $y_{i,t-1} \times R_i^2$ will be negative, indicating that, for households with "more predictable" income, the role of lagged income in forecasting consumption is reduced. (As in Table II, $\eta'_{-i,t}$, the leave-out mean of average consumption at the village-month level, is used for η_t.)

Table III shows the results. Column 1 imposes that ρ, the curvature of the utility function, equals one and models the function $f()$ as multiplicative in LIMU (here, c_{t-1}) and $\eta'_{-i,t}$. The main effect of lagged IHS income (corresponding to the predicted effect of lagged income for a household with income completely uncorrelated with rainfall) is positive and significant at the 1% level $(t = 13.9)$; the interaction with the R^2 from the rainfall variables is negative and significant at the 1% level $(t = -6.2)$, as predicted. Column 2 relaxes the assumption on the form of $f()$ by including quadratic splines in c_{t-1}; again, the main effect of lagged income is positive and significant at the 1% level $(t = 8.6)$ while the interaction with the R^2 from the rainfall variables is negative and significant at the 1% level

[29] Households were only asked about their primary occupation in 1997, the first year of the survey. If households switch occupations over time, this introduces measurement error into the classification, reducing the power of the test and making the differential effects shown below lower bounds.

[30] The occupations with incomes best predicted by rainfall are rice farming, construction (where work is limited by heavy rain), and orchard fruit farming. Least well predicted are non-agricultural wage labor and corn farming (which is typically irrigated).

$(t = -3.9)$.

In column 3, splines in lagged consumption, $\eta'_{-i,t}$ and lagged consumption interacted with the estimated village-month effects, are included to allow $f()$ to include flexible interactions between LIMU and $\eta'_{-i,t}$. Again, the main effect of lagged IHS income is positive and significant at the 1% level $(t = 8.3)$, and the interaction with the rainfall R^2 is negative and significant at the 1% level $(t = -3.7)$.

Column 4 estimates ρ via nonlinear least squares, but once again restricts $f()$ to multiplicative in LIMU (here, c^{ρ}_{t-1}) and $\eta'_{-i,t}$. The estimate of ρ is approximately 0.19, significantly different from zero at the 1% level $(t = 7.8)$. As in the previous specifications, the main effect of lagged income is positive and significant at the 1% level $(t = 3.2)$, while the interaction with the rainfall R^2 is negative and significant at 1% $(t = -3.25)$.

Finally, in column 5 ρ is estimated, and $f()$ is flexibly estimated via splines in lagged consumption, $\eta'_{-i,t}$ and lagged consumption interacted with the estimated village-month effects. The estimated ρ is now 0.094, different from zero at the 5% level $(t = 1.94)$. The estimated effect of lagged income is positive, but insignificant, and the interaction with with the rainfall R^2 is also indistinguishable from zero. While in this most demanding specification the differential effect of lagged income by the rainfall R^2 is no longer detectable, on balance the results of this test suggest that the distortion caused by unobservable income is reduced when income is easier to externally verify, as predicted by theory.

In summary, the results presented in Tables II and III are inconsistent with the predictions of the limited commitment, moral hazard, and self-insurance models. They are, however, consistent with the hidden income model. However, a caveat is that these results have maintained the assumptions of no measurement error, no risk preference heterogeneity among households, and no preference shocks or consumption-leisure nonseparabilities. Section 7 presents a test which is robust to violations of these assumptions.

7 A nonparametric test of sufficiency

If present, household-level heterogeneity in risk aversion, non-classical measurement error in consumption, or non-separability between consumption and leisure may introduce misspecification into the estimating equations derived above. These issues may cause *measured* current inverse marginal utility to be positively correlated with lagged income, conditional on measured lagged inverse marginal utility, even if *true* inverse marginal utility does not have this property. (See Proposition 7 in Appendix A.) It is particularly important to address the possibility of household-level heterogeneity in risk aversion given that Chiappori et al. (2014) find evidence that the households in the Townsend Thai dataset do in fact exhibit meaningful heterogeneity in their tolerance for risk.

This section proposes testing over-identifying restrictions on the reduced form equations for current and lagged consumption as a test which is robust to these issues. The form of the test is closely related to tests of intra-household efficiency (e.g., Browning et al. 1994, Duflo and Udry 2004) which test whether income or other shocks realized by husbands vs. wives have differing effects on household-level outcomes. However, to my knowledge, the application of this method to address misspecification is novel.

Table III: Testing the hidden income model:
Heterogeneity by predictive power of rainfall

Lagged consumption	0.203			0.565	
	(0.0483)			(0.0549)	
Rainfall R^2	12,435	8,074	8,158	3.523	0.039
	(1,951)	(1,959)	(1,958)	(1.061)	(0.1410583)
lagged IHS income	1,059	706.6	685.9	0.208	0.010
	(76.20)	(82.33)	(82.76)	(0.0651)	(0.0109)
Rainfall $R^2\times$	-1,483	-936.0	-890.0	-0.365	0.001
lagged IHS income	(240.4)	(239.8)	(241.1)	(0.1123)	(0.0139)
ρ	1	1	1	0.188	0.093
				(0.0240)	(0.0483)
Village-month fixed effect?	Yes	Yes	Yes	Yes	Yes
Village-month fixed effect$\times c_{t-1}$?	Yes	Yes	Yes	Yes	Yes
Estimation method	OLS	OLS	OLS	NLLS	NLLS
R-squared	0.080	0.368	0.369	0.367	0.394
Observations	27,933	27,933	27,933	27,933	27,933

Notes: standard errors clustered at the village quarter level in brackets.
IHS is inverse hyperbolic sine (see text).
Model 1: $\rho = 1$, including village-month fixed effects $(\eta'_{-i,t})$ and $\eta'_{-i,t} \times c_{i,t-1}$.
Model 2: $\rho = 1$, including village-month fixed effects $(\eta'_{-i,t})$ and $\eta'_{-i,t} \times c_{i,t-1}$.
and quadratic splines in lagged consumption.
Model 3: $\rho = 1$, including quadratic splines in estimated village-month effects $(\eta'_{-i,t})$
and quadratic splines in lagged consumption and lagged consumption$\times\eta'_{-i,t}$.
Model 4: $\rho \neq 1$, including village-month fixed effects $(\eta'_{-i,t})$ and $\eta'_{-i,t} \times c_{i,t-1}$.
Model : $\rho \neq 1$, including quadratic splines in estimated village-month effects $(\eta'_{-i,t})$
and quadratic splines in lagged consumption and lagged consumption$\times\eta'_{-i,t}$.

The intuition behind this test is to use within-household information on how different types of income earned at the same point in time by the household predict consumption in adjacent years. As discussed above, under hidden income, the schedule of transfers and promised utilities distorts the tradeoff between current consumption and future expected utility, with households announcing low incomes penalized more in terms of future utility, which is equally valuable to truthful and misreporting households. Current consumption is more valuable to truthful households, who have lower income than households who are tempted to falsely claim the same level of income, so it is penalized less. The need to distort the current consumption/future utility tradeoff arises because income can be hidden; as shown in proposition 5, income that is easier to verify will be less subject to this tradeoff. So, within a household, harder-to-verify income (here, income from livestock or fish) will be associated with a more distorted consumption response than more verifiable income (income from crops).

Proposition 6 *If past income affects current consumption only through the first lag of consumption, then all components of past income ($x_{i,t-s}$) will satisfy the proportionality restriction*

$$\frac{d\ln c_{it}}{dx_{i,t-s}} / \frac{d\ln c_{i,t-1}}{dx_{i,t-s}} = \pi_i, \forall x_{i,t-s} \tag{26}$$

even in the presence of household-level heterogeneity, or non-classical measurement error in consumption, or in income when all x are affected proportionally.

Proof. In Appendix A. ■

Of course, different types of income may convey different information about effort (relevant under moral hazard), or about the household's prospects in autarky (relevant under limited commitment), or may be more persistent over time (relevant under the PIH).[31] However, under moral hazard, limited commitment or PIH, that information will be completely encoded in consumption in the year the income is realized, and the effect of that income on consumption in the following year will be proportional to its effect in the initial year, with the same constant of proportionality for all types of income. Under hidden income, in contrast, the components of lagged income will also affect current consumption directly, and this effect may differ across income types if truth-telling constraints bind differentially for different types of income. By looking *within* a household, concerns about household-level heterogeneity (e.g., risk aversion), or non-separability between consumption and the total level of effort exerted by the household, are minimized. By moving consumption from the right to the left-hand side of the equation, attenuation bias due to measurement error is addressed without the need to use lagged income as an instrument and hence assume that measurement error is classical.

Proposition 6 states that a unit change in an income component $x_{i,t-s}$ should have the same relative effect on current versus lagged consumption as a unit change in another component $x'_{i,t-s}$.

Under the null hypothesis of limited commitment/moral hazard/PIH, consumption depends on a household's initial Pareto weight and its subsequent income realizations. (Under these models, lagged income does not appear in the

[31] In the data, the degree of serial correlation over time does not differ significantly between livestock and animal income: the serial correlation in livestock income, across years, is 0.255 and the corresponding serial correlation in crop income is 0.285, using the Arellano-Bond estimator to control for differences in mean income across households.

structural equation for consumption, but it appears in the reduced form because y_{is} depends on c_{is}.) In the Thai data, three lags of annual income[32] are significant predictors of c_{it}, so the following reduced form is used:

$$\ln c_{it} = \sum\nolimits_{s=1}^{3} \alpha_s y_{i,t-s} + \phi_i + \varepsilon_{it} \tag{27}$$

where ϕ_i is an individual-fixed effect that captures the household's initial Pareto weight.

Since lagged income appears in the reduced form for consumption, lags of total income cannot be used to generate overidentifying restrictions. Instead, I test whether the *composition* of lagged income matters for predicting current consumption, beyond its effect on lagged consumption. In particular, I test whether income from crop cultivation matters differently than income from raising livestock or fish. Crops are likely to be more homogenous than animals because animals may unobservably vary in terms of fertility, milk production[33], etc.; crops may also be less susceptible to difficult-to-verify diseases. Crops may also simply be easier to observe by virtue of growing in a field. If income from raising animals is harder to verify, reporting low income from livestock or fish cultivation will result in a greater wedge between current and future utility than reporting low income from crop cultivation.

Then, under hidden income, animal cultivation income would be associated with high contemporaneous consumption relative to future consumption, while crop cultivation income would be associated with lower contemporaneous consumption relative to future consumption. This would not be the case under moral hazard, limited commitment or the PIH. So in the reduced-form regressions

$$\begin{aligned} \ln c_{it} &= \sum_{s=1}^{3} [\pi_{1Cs} y_{i,t-s}^{crops} + \pi_{1Ls} y_{i,t-s}^{livestock}] + \phi_i + \varepsilon_{it} \\ \ln c_{i,t-1} &= \sum_{s=1}^{3} [\pi_{2Cs} y_{i,t-s}^{crops} + \pi_{2Ls} y_{i,t-s}^{livestock}] + \phi_i + \varepsilon_{i,t-1} \end{aligned} \tag{28}$$

and

$$\begin{aligned} \ln c_{it} &= \sum_{s=1}^{3} [\pi_{1Cs} y_{i,t-s}^{crops} + \pi_{1Fs} y_{i,t-s}^{fish}] + \phi_i + \varepsilon_{it} \\ \ln c_{i,t-1} &= \sum_{s=1}^{3} [\pi_{2Cs} y_{i,t-s}^{crops} + \pi_{2Fs} y_{i,t-s}^{fish}] + \phi_i + \varepsilon_{i,t-1} \end{aligned} \tag{29}$$

if the first lag of income does not directly (i.e., structurally) affect current consumption, we will find

$$\frac{\pi_{1C1}}{\pi_{2C1}} = \frac{\pi_{1L1}}{\pi_{2L1}} \tag{30}$$

and

$$\frac{\pi_{1C1}}{\pi_{2C1}} = \frac{\pi_{1F1}}{\pi_{2F1}} \tag{31}$$

[32] In this section, annual consumption and income are used to avoid seasonality concerns which would arise in monthly data.

[33] Anagol (2016) provides evidence that the quality of dairy cows in India is difficult to observe, especially when the animals are not lactating.

These overidentifying restrictions can be used to test whether the rejection of moral hazard and limited commitment is driven by measurement error or household-level heterogeneity. Classical measurement error in consumption, which appears on the left-hand side, will reduce the precision with which the πs are estimated, reducing the power of the test; classical measurement error in income will attenuate the π's proportionally, and will not affect the ratio $\frac{\pi_1}{\pi_2}$. Non-classical measurement error in income may bias the π, but if the measurement error is common across components of income, the ratio $\frac{\pi_1}{\pi_2}$ will be unaffected. Household-level heterogeneity in the discount factor, the degree of risk aversion, etc. may cause the ratio $\frac{\pi_1}{\pi_2}$ to differ across households, but not across different types of income earned by the same household.[34]

The results testing (30) and (31) are presented in Table IV. Columns 1 and 2 present the results of comparing the reduced forms of $\ln c_{it}$ and $\ln c_{i,t-1}$ using crop and livestock income. Time $t-1$ crop income is associated with higher consumption at time t than at $t-1$, while the opposite is true for time $t-1$ livestock income, consistent with what would be expected if crop income were easier to observe than livestock income. The hypothesis that $\frac{\pi_{1C1}}{\pi_{2C1}} = \frac{\pi_{1L1}}{\pi_{2L1}}$ is rejected at the 1% level ($p = .006$). Columns 3 and 4 present the results of comparing the reduced forms of $\ln c_{it}$ and $\ln c_{i,t-1}$ using crop and fish income, and the results are similar, again consistent with what would be expected if crop income were easier to observe than income from aquaculture, although in this case the hypothesis that $\frac{\pi_{1C1}}{\pi_{2C1}} = \frac{\pi_{1F1}}{\pi_{2F1}}$ is rejected at the 5% level ($p = .016$). This suggests that the rejection of sufficiency of LIMU is not due to measurement error in lagged consumption, but in fact arises because reporting low levels of difficult-to-observe income is associated with a greater penalty in terms of future consumption than contemporaneous consumption.

8 Conclusion

This paper suggested a set of tests that can be used to determine whether different models of endogenously incomplete insurance—limited commitment, moral hazard or hidden income—as well as self-insurance via saving/borrowing, are consistent with the relationship between current consumption, lagged consumption and other lagged information. If past information helps to forecast current consumption, conditional on one lag of inverse marginal utility, neither limited commitment or moral hazard can fully explain incomplete insurance. However, if a household's past income helps to forecast current consumption, such that past income is positively predictive of current consumption given past consumption, this is consistent with a model in which households cannot directly observe one another's incomes and must be given incentives for truthful reporting. This pattern is not consistent with a borrowing-constrained model (à la Deaton 1991), which has been suggested as another explanation of incomplete consumption smoothing (Kaboski and Townsend 2011).

Results from an 84-month (7-year) panel of households in rural Thailand are inconsistent with pure moral hazard or limited commitment, and suggest that hidden income plays a role in constraining households from achieving full

[34]A limitation of this test is that it assumes either that intra-household allocations are efficient (Bourguignon, Browning, and Chiappori 2009), or that there are no differences across income sources in the extent to which income is controlled by different members of the household. While in these villages men and women both work in crop cultivation, livestock raising, and aquaculture, the share of total household hours worked by women vs. men does vary: women provide 75% of hours in aquaculture, 59% of hours in livestock raising and 54% of hours in crop cultivation. Thus generalizing this test to incorporate non-cooperative household dynamics and differential control of different income sources is an interesting avenue for future work.

Table IV: Test overidentifying restrictions on reduced form for consumption

	(1) $ln(c_t)$	(2) $ln(c_{t-1})$	(1)/(2)	(3) $ln(c_t)$	(4) $ln(c_{t-1})$	(3)/(4)
$Cultivation_{t-1}$	0.0707	0.048	1.473	0.0698	0.0484	1.442
	[0.0226]	[0.0151]		[0.0226]	[0.0152]	
$Cultivation_{t-2}$	0.0102	0.0561		0.0087	0.0574	
	[0.0169]	[0.0164]		[0.0169]	[0.0166]	
$Cultivation_{t-3}$	0.0049	0.0173		0.0037	0.0177	
	[0.0300]	[0.0248]		[0.0298]	[0.0250]	
$Livestock_{t-1}$	-0.0068	0.0066	-1.030			
	[0.0019]	[0.0034]				
$Livestock_{t-2}$	-0.004	-0.0012				
	[0.0034]	[0.0065]				
$Livestock_{t-3}$	0.0055	0.0037				
	[0.0023]	[0.0029]				
$Fish_{t-1}$				-0.0029	0.0184	-0.158
				[0.0085]	[0.0080]	
$Fish_{t-2}$				-0.0074	-0.0076	
				[0.0113]	[0.0090]	
$Fish_{t-3}$				-0.0034	0.0055	
				[0.0063]	[0.0057]	
N	2124	2124		2124	2124	
Chi-sqared statistic (p-value) on ratios of t-1 coefficients equal	7.5548	(0.006)		5.803	(0.016)	

Notes: Standard errors clustered at the household level in brackets. Coefficients and standard errors on income variables (in levels) are multiplied by 100,000. “Cultivation” is income from growing crops (rice, corn, orchard crops, etc.). “Livestock” is income from raising cows, pigs, ducks, etc. “Fish” is income from raising fish and shrimp.

risk sharing. Note that this conclusion is not inconsistent with findings that households in rural developing settings often have good information about one another's incomes (Takasaki et al. 2000, Macours 2003, Alatas et al. 2012). Instead, it suggests that this is the equilibrium outcome of an insurance arrangement designed to give individuals incentives to tell the truth.

Measurement error in right-hand side variables is commonly seen as a threat to power, causing underrejection of the null. However, with tests of the type used here, mismeasurement of the proposed explanatory variable (in this case, lagged inverse marginal utility) can distort the *size* of the test, causing *over*rejection of the null. This will occur if those variables which are excluded under the null hypothesis are correlated with the true value of the explanatory variable. This concern is addressed by testing overidentifying restrictions on the reduced forms for the left- and right-hand-side variables; the results support the conclusion that hidden income constrains insurance.

Understanding what barrier to full informal risk-sharing is most important in a given community is important for evaluation of policies that may affect the sustainability of informal insurance. One such group of policies is those that aim to increase individuals' access to savings, such as rural bank expansion, cell phone banking and microsavings accounts. Access to savings can crowd out limited commitment-constrained insurance if savings can be used after individuals renege on their informal insurance obligations (Ligon, Thomas, and Worrall 2000). Savings access may crowd out insurance subject to hidden income if individuals' savings are not observable by the community (Doepke and Townsend 2006).

Technologies and policies may make observing others' incomes easier, such as disseminating information on crop prices or weather, or publicly posting lists of households eligible to receive a public program (Banerjee, Hanna, Kyle, Olken, and Sumarto 2015). Other technologies and policies may make such observation harder, such as taking individual deposits rather than collecting savings at a group meeting; paying government benefits electronically rather than via highly visible "pay parades" (Goldberg 2017); or providing access to more distant or anonymous markets. Such changes may affect informal insurance constrained by hidden income, but not if the only barrier to insurance is limited commitment or moral hazard. (Of course, a policy or technology that made observing others' incomes harder could also *create* a hidden income problem where none had existed previously.) Weather insurance, which makes leaving community insurance more palatable will crowd out insurance under limited commitment (Attanasio and Rios-Rull 2000), but not under hidden income or moral hazard. Policies that expand communities' sanctioning ability (such as community-allocated aid; see Olken (2005)), or restrict it (such as road access; see Townsend 1995) will also affect limited commitment constraints, while community-allocated aid may reduce problems of hidden income, since the community knows the amount of aid each household is getting. Conditional cash transfer programs may also have differing effects on insurance constrained by limited commitment, moral hazard or hidden income.

The tests derived and implemented in this paper do not allow for a quantification of the extent to which insurance is constrained by hidden income. However, evidence from a laboratory experiment in rural India suggests that allowing individuals to misreport income has quantitatively significant effects (Chandrasekhar, Kinnan, and Larreguy 2011). Thus, the findings of this paper suggest that policies which make it easier (harder) for villagers to infer one another's incomes may significantly improve (worsen) risk sharing. Since policies that have the potential to worsen observability of income may also raise the average *level* of income and/or improve household's ability to self-insure, this is not to suggest that such policies be avoided. However, when possible they should be designed with consideration of the consequences for informal insurance.

In many respects, the tests used in this paper do not rely on strong assumptions such as a parametric income process, a known function form of the utility function, or very large risk-sharing groups such that the law of large numbers would apply. However, several further interesting generalizations are possible. Consumption-effort nonseparabilities may also cause consumption and income to co-move; deriving tests akin to those developed in this paper in such a setting is left to future work. Exploring generalizations of the nonparametric test that incorporate and test for the possibility of non-cooperative household dynamics is another interesting extension left for future work.

This paper also does not consider explanations for incomplete insurance rooted in non-neoclassical features such as lack of trust in, or information about, the workings of insurance systems (considered by Cole et al. (2013) in the context of rainfall insurance); ambiguity aversion (considered by Bryan (2013) for crop insurance); or loss aversion (considered by Cohen (2014) in the contexts of informal insurance and lifecycle behavior). However, the fact that a constrained-optimizing model—hidden income—appears to fit the data in several key respects suggests that much of the explanation for incomplete informal insurance in rural Thailand may lie in neoclassical contracting frictions, rather than in behavioral explanations.

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A Appendix: Proofs

Throughout, let λ_{it} be the multiplier on household i's time t promise-keeping constraint, and η_t be the multiplier on the village's time t budget constraint. Let Y^N be the set of possible realizations of incomes for all households in the village, and let the vector of income realizations at time t be $\mathbf{y}_t \in Y^N$. To reduce notation, set $\beta = R = 1$.

A.1 Proof of Proposition 1: Under moral hazard, LIMU is sufficient to predict expected current inverse marginal utility

Planner's problem

The probability $\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_t, \mathbf{e}_{t-1})$ defines a Markov transition matrix for the probability of a given set of realizations of household income across all households in the village, $\boldsymbol{y}_t$ given $\boldsymbol{y}_{t-1}$ when the vector of effort choices at time t was $\mathbf{e}_t$ and the vector of effort choices at time $t-1$ was $\mathbf{e}_{t-1}$. Incomes are independent across households (but not across time). Therefore, $\pi\left(\boldsymbol{y}_t|\boldsymbol{y}_{t-1}, \mathbf{e}_t, \mathbf{e}_{t-1}\right) = \prod_i \pi\left(y_t|y_{t-1}, e_t, e_{t-1}\right)$, where $\pi\left(y_t|y_{t-1}, e_t, e_{t-1}\right) = \pi\left(y^t|y^{t-1}\right)$ is the probability of an individual household's income being y_t given y_{t-1}, e_t, e.

Conditional on the state $\mathbf{y}_t$, the planner chooses transfers $\boldsymbol{\tau}_t(\mathbf{y}_t) = (\tau_{1t}(\mathbf{y}_t), ..., \tau_{Nt}(\mathbf{y}_t))$, promised utilities $\mathbf{u}_{t+1}(\mathbf{y}_t) = (u_{1,t+1}(\mathbf{y}_t), ..., u_{N-1,t+1}(\mathbf{y}_t))$, threatened utilities $\hat{\mathbf{u}}_{t+1}(\mathbf{y}_t) = (\hat{u}_{1,t+1}(\mathbf{y}_t), ..., \hat{u}_{N,t+1}(\mathbf{y}_t))$ and assets $a_{t+1}(\mathbf{y}_t)$.

To simplify the notation below, in some constraints $u_{N,t+1}(\mathbf{y}_t)$ will be used to denote $u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_{t+1}(\mathbf{y}_t), \mathbf{y}_t)$.

The planner maximizes the following recursive objective function, which is household N's expected utility at time t.

$$u_N(\mathbf{u}_t, \hat{\mathbf{u}}_t, a_t, \mathbf{y}_{t-1}) = max_{\boldsymbol{\tau}_t(\mathbf{y}_t), \mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_{t+1}(\mathbf{y}_t)} \sum_{\mathbf{y}_t \in Y^N} \pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_t = \mathbf{1}, \mathbf{e}_{t-1}) \times \left(v(y_{it} + \tau_{it}(\mathbf{y}_t) + u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_{t+1}(\mathbf{y}_t), \mathbf{y}_t) - z\right) \quad (32)$$

The planner faces the following constraints.

The promise keeping constraints: for every $i < N$, the household must receive its utility promise, u_{it}, in expectation:

$$\sum_{\mathbf{y}_t \in Y^N} \pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_t = \mathbf{1}, \mathbf{e}_{t-1} = \mathbf{1})[v(y_{it} + \tau_{it}(\mathbf{y}_t)) + u_{i,t+1}(\mathbf{y}_t)] - z \geq u_{it} \quad \forall \mathbf{y}_t \quad (33)$$

The law of motion of assets:

$$a_{t+1}(\mathbf{y}_t) = a_t - \sum_{i=1}^{N} [\tau_{it}(\mathbf{y}_t) - y_{it}] \quad \forall \mathbf{y}_t \quad (34)$$

The incentive compatibility (IC) constraints, which state for every $i = 1, ..., N$, the household must be indifferent between choosing $e = 1$ rather than $e = 0$:[35]

[35] Assumption 5c ensures that there are feasible transfers that allow the IC to bind.

$$\sum_{\mathbf{y}_t \in Y^N} [\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_t = \mathbf{1}, \mathbf{e}_{t-1} = \mathbf{1}) - \pi(\mathbf{y}_t|\mathbf{y}_{t-1}, e_{it} = 0, \mathbf{e}_{-i,t} = \mathbf{1}, \mathbf{e}_{t-1} = \mathbf{1})][v(y_{it} + \tau_{it}(\mathbf{y}_t)) + u_{i,t+1}(\mathbf{y}_t)] \geq z \tag{35}$$

And the two threat keeping constraints, which place upper bounds on the utility of a household who shirked last period (Fernandes and Phelan, 2000):

1. Threat keeping constraint if the household exerts effort at t, but shirked at $t-1$: for every $i = 1, ..., N$,

$$\sum_{\mathbf{y}_t} \pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_t = \mathbf{1}, e_{i,t-1} = 0, \mathbf{e}_{-i,t-1} = \mathbf{1})[v(y_{it} + \tau_{it}(\mathbf{y}_t)) + u_{i,t+1}(\mathbf{y}_t) - z] \leq \hat{u}_{i,t} \tag{36}$$

2. Threat keeping constraint if the household shirked at t and $t-1$: for every $i = 1, ..., N$,

$$\sum_{\mathbf{y}_t} \pi(\mathbf{y}_t|\mathbf{y}_{t-1}, e_{i,t} = 0, \mathbf{e}_{-i,t} = \mathbf{1}, e_{i,t-1} = 0, \mathbf{e}_{-i,t-1} = \mathbf{1})[v(y_{it} + \tau_{it}(\mathbf{y}_t)) + \hat{u}_{i,t+1}(\mathbf{y}_t) - z] \leq \hat{u}_{i,t} \tag{37}$$

Notice that the planner implements effort $e_{it} = 1$ for all agents and in all periods along the equilibrium path (Assumption 5f). Thus, the IC constraints (equation 35) assume that agents exerted effort in period $t-1$. The threat keeping constraints (equations 36 and 37) guarantee the time-consistency of the resulting allocation.

Define $h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) = 1 - \frac{\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, e_{it}=0, \mathbf{e}_{-i,t}=1, \mathbf{e}_{t-1}=\mathbf{1})}{\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_{i,t}=1, \mathbf{e}_{t-1}=\mathbf{1})}$ as a measure of the importance of agent i's effort to the realization of $\mathbf{y}_t$. Also, denote the following ratios of probabilities as:

$$r_i^1(\mathbf{y}_t, \mathbf{y}_{t-1}) = \frac{\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_t = 1, e_{i,t-1} = 0, \mathbf{e}_{-i,t-1} = \mathbf{1})}{\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_{i,t} = 1, \mathbf{e}_{t-1} = \mathbf{1})}$$
$$r_i^2(\mathbf{y}_t, \mathbf{y}_{t-1}) = \frac{\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, e_{it} = 0, \mathbf{e}_{-i,t} = \mathbf{1}, e_{i,t-1} = 0, \mathbf{e}_{-i,t-1} = \mathbf{1})}{\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_{i,t} = 1, \mathbf{e}_{t-1} = \mathbf{1})}$$

The term $r_i^1(\mathbf{y}_t, \mathbf{y}_{t-1})$ is the likelihood ratio for income realization $\mathbf{y}_t$ occurring when household i shirked vs. exerted effort at $t-1$, holding constant high effort by all households at t and high effort by all other households at $t-1$. The term $r_i^2(\mathbf{y}_t, \mathbf{y}_{t-1})$ is the likelihood ratio for income realization $\mathbf{y}_t$ occurring when household i shirked vs. exerted effort at t and $t-1$, holding constant high effort at t and $t-1$ by all other households.

Then the Lagrangian for the moral hazard problem is:

$$\mathcal{L} = \sum_{\mathbf{y}_t \in Y^N} \pi(\mathbf{y}_t | \mathbf{y}_{t-1}, \mathbf{e}_t = 1, \mathbf{e}_{t-1} = \mathbf{1}) \Big\{ v(y_{it} + \tau_{it}(\mathbf{y}_t) + u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_{t+1}(\mathbf{y}_t), \mathbf{y}_t) - z$$

$$+ \sum_{i<N} \lambda_{it} \big(v(y_{it} + \tau_{it}(\mathbf{y}_t)) + u_{i,t+1}(\mathbf{y}_t) - \kappa \big) + \eta_t(\mathbf{y}_t) \big[a_t - \sum_{i=1}^{N} (\tau_{it}(\mathbf{y}_t) - y_{it}) - a_{t+1}(\mathbf{y}_t) \big]$$

$$+ \sum_{i=1}^{N} \psi_{it}^1 \big[r_i^1(\mathbf{y}_t, \mathbf{y}_{t-1}) \big(v(y_{it} + \tau_{it}(\mathbf{y}_t)) + u_{i,t+1}(\mathbf{y}_t) - z \big) - \hat{u}_{i,t} \big]$$

$$+ \sum_{i=1}^{N} \psi_{it}^2 \big[r_i^2(\mathbf{y}_t, \mathbf{y}_{t-1}) \big(v(y_{it} + \tau_{it}(\mathbf{y}_t)) + \hat{u}_{i,t+1}(\mathbf{y}_t) - z \big) - \hat{u}_{i,t} \big]$$

$$+ \sum_{i=1}^{N} \varphi_{it} \big[h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) (v(y_{it} + \tau_{it}(\mathbf{y}_t)) + u_{i,t+1}(\mathbf{y}_t)) - z \big] \Big\}$$

where λ_{it} is the multiplier on the promise-keeping constraint, φ_{it} is the multiplier on the incentive-compatibility constraint, and ψ_{it}^1 and ψ_{it}^2 are the multipliers on the two threat-keeping constraints.

The problem yields the following first-order conditions:

1. with respect to $\tau_{it}(\boldsymbol{y}_t)$:

$$\big[\lambda_{it} + \varphi_{it} h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi_{it}^1 r_i^1(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi_{it}^2 r_i^2(\mathbf{y}_t, \mathbf{y}_{t-1}) \big] v'(y_{it} + \tau_{it}(\mathbf{y}_t)) = \eta_t(\mathbf{y}_t) \tag{38}$$

2. with respect to $u_{i,t+1}(\boldsymbol{y}_t)$:

$$\begin{aligned} \lambda_{it} + \varphi_{it} h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi_{it}^1 r_i^1(\mathbf{y}_t, \mathbf{y}_{t-1}) \quad = \quad & -\big[1 + \phi_{Nt} h_N(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi_{Nt}^1 r_N^1(\mathbf{y}_t, \mathbf{y}_{t-1}) \\ & \times \big] \frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial u_{i,t+1}(\boldsymbol{y}_t)} \end{aligned} \tag{39}$$

3. with respect to $\hat{u}_{i,t+1}(\boldsymbol{y}_t)$:

$$\begin{aligned} \psi_{it}^2 r_i^2(\mathbf{y}_t, \mathbf{y}_{t-1}) \quad = \quad & -\big[1 + \phi_{Nt} h_N(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi_{Nt}^1 r_N^1(\mathbf{y}_t, \mathbf{y}_{t-1}) \\ & \times \big] \frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial \hat{u}_{i,t+1}(\boldsymbol{y}_t)} \end{aligned} \tag{40}$$

4. with respect to $a_{t+1}(\boldsymbol{y}_t)$:

$$\frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial a_{t+1}} \big[1 + \phi_{Nt} h_N(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi_{Nt}^1 r_N^1(\mathbf{y}_t, \mathbf{y}_{t-1}) \big] = \eta_t(\mathbf{y}_t) \tag{41}$$

and the following three envelope conditions:

$$\frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial a_{t+1}} = \sum_{\mathbf{y}_{t+1} \in Y^N} \pi(\mathbf{y}_{t+1} | \mathbf{y}_t, \mathbf{e}_{t+1} = \mathbf{1}, \mathbf{e}_t = \mathbf{1}) \eta_{t+1}(\mathbf{y}_{t+1}) \tag{42}$$

$$\frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial u_{i,t+1}} = -\lambda_{i,t+1}(\mathbf{y}_t) \tag{43}$$

$$\frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial \hat{u}_{i,t+1}} = -\psi^1_{i,t+1}(\mathbf{y}_t) - \psi^2_{i,t+1}(\mathbf{y}_t) \tag{44}$$

To show Proposition 1, notice that the first-order condition for transfers (equation 38) can be written as:

$$\lambda_{it} + \varphi_{it} h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^1_{it} r^1_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^2_{it} r^2_i(\mathbf{y}_t, \mathbf{y}_{t-1}) = \frac{\eta_t(\mathbf{y}_t)}{v'(y_{it} + \tau_{it}(\mathbf{y}_t))} \tag{45}$$

and by taking the expectation of equation 45 with respect to time t income, we have that:

$$\lambda_{it} + \psi^1_{it} + \psi^2_{it} = \sum_{\mathbf{y}_t} \pi(\mathbf{y}_t | \mathbf{y}_{t-1}, \mathbf{e}_t = 1, \mathbf{e}_{t-1} = \mathbf{1}) \frac{\eta_t(\mathbf{y}_t)}{v'(y_{it} + \tau_{it}(\mathbf{y}_t))} \tag{46}$$

Note also that by combining the envelope conditions (43) and (44) and the first-order conditions for $u_{it}(\mathbf{y}_t)$ and $\hat{u}_{it}(\mathbf{y}_t)$ (equations 39 and 40), we obtain:

$$\lambda_{it} + \varphi_{it} h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^1_{it} r^1_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^2_{it} r^2_i(\mathbf{y}_t, \mathbf{y}_{t-1}) = \tag{47}$$

$$\left[1 + \phi_{Nt} h_N(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^1_{Nt} r^1_N(\mathbf{y}_t, \mathbf{y}_{t-1})\right] \left(\lambda_{it} + \psi^1_{it} + \psi^2_{it}\right) \tag{48}$$

Therefore, by combining equations 46 and 47, the solution satisfies:

$$\frac{\eta_t(\mathbf{y}_t)}{v'(y_{it} + \tau_{it}(\mathbf{y}_t))} = \left[1 + \phi_{Nt} h_N(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^1_{Nt} r^1_N(\mathbf{y}_t, \mathbf{y}_{t-1})\right] \tag{49}$$

$$\left[\times \sum_{\mathbf{y}_{t+1}} \pi(\mathbf{y}_{t+1} | \mathbf{y}_t, \mathbf{e}_{t+1} = 1, \mathbf{e}_t = \mathbf{1}) \frac{\eta_{t+1}(\mathbf{y}_{t+1})}{v'(y_{i,t+1} + \tau_{i,t+1}(\mathbf{y}_{t+1}))}\right]$$

or, rearranging,

$$\frac{1}{v'(y_{it} + \tau_{it}(\mathbf{y}_t))} = \sum_{\mathbf{y}_{t+1}} \pi(\mathbf{y}_{t+1} | \mathbf{y}_t, \mathbf{e}_{t+1} = 1, \mathbf{e}_t = \mathbf{1}) \frac{\tilde{\eta}_{t+1}(\mathbf{y}_{t+1})}{v'(y_{i,t+1} + \tau_{i,t+1}(\mathbf{y}_{t+1}))} \tag{50}$$

$$= \mathbb{E} \frac{\tilde{\eta}_{t+1}(\mathbf{y}_{t+1})}{v'(y_{i,t+1} + \tau_{i,t+1}(\mathbf{y}_{t+1}))} \tag{51}$$

which is the inverse Euler equation. The left-hand side is lagged inverse marginal utility, while the right-hand side consists of the expectation of the product between the inverse marginal utility and a village-year fixed effect, $\tilde{\eta}_{t+1}(\mathbf{y}_{t+1}) = \frac{\eta_{t+1}(\mathbf{y}_{t+1})}{\eta_t(\mathbf{y}_t)} \left[1 + \phi_{Nt} h_N(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^1_{Nt} r^1_N(\mathbf{y}_t, \mathbf{y}_{t-1})\right]$.■

A.2 Proof of Proposition 2: LIMU is sufficient for forecasting expected current inverse marginal utility under limited commitment

Planner's problem

Because effort is contractible in the limited commitment model and high effort is always implemented (Assumption 5f), the dependence of output on current and past effort is suppressed to avoid additional notation. The cost of effort is also suppressed, so that the promised utilities are interpreted as net of effort costs. Therefore denote $\pi(\mathbf{y}_t | \mathbf{y}_{t-1}, \mathbf{e}_t = \mathbf{1}, \mathbf{e}_{t-1} = \mathbf{1})$ by $\pi(\mathbf{y}_t | \mathbf{y}_{t-1})$, which defines a Markov transition matrix for the probability of a given set of realizations of household income across all households in the village, $\boldsymbol{y}_t$ given $\boldsymbol{y}_{t-1}$. Incomes are independent across households (but not across time). Therefore, $\pi\left(\boldsymbol{y}_t|\boldsymbol{y}_{t-1}\right) = \prod_i \pi\left(y_t|y_{t-1}\right)$, where $\pi\left(y_t|y_{t-1}\right) = \pi\left(y^t|y^{t-1}\right)$ is the probability of an individual household's income being y_t given y_{t-1} and hence of history y^t given the history y^{t-1}.

To guarantee differentiability of the planner's value function (Koeppl 2006), the following assumption is made:

Assumption A.1: There is at least one realization $\boldsymbol{y}_t$ such that no household's participation constraint is binding.

The planner maximizes the following recursive objective function, which is household N's expected utility at time t.

$$u_N\left(\boldsymbol{u}_t, a_t, \boldsymbol{y}_{t-1}\right) \equiv \max_{\{\tau_{it}(\boldsymbol{y}_t)\},\{u_{i,t+1}(\boldsymbol{y}_t)\}} \sum_{y_t} \left\{\pi\left(\boldsymbol{y_t}|\boldsymbol{y_{t-1}}\right) v\left(y_{Nt}(\boldsymbol{y}_t) + \tau_{Nt}(\boldsymbol{y}_t)\right)\right. \\ \left. + \sum_{\boldsymbol{y}_t} \pi\left(\boldsymbol{y}_t|\boldsymbol{y}_{t-1}\right) u_N\left(\boldsymbol{u}_{t+1}(\boldsymbol{y}_t), a_{t+1}, \boldsymbol{y}_t\right)\right\} \tag{52}$$

The maximization is subject to the following constraints:

The promise-keeping constraints

$$\sum_{\mathbf{y}_t} \pi\left(\boldsymbol{y}_t|\boldsymbol{y}_{t-1}\right) \left\{v\left(y_{it} + \tau_{it}(\boldsymbol{y}_t)\right) + u_{i,t+1}(\boldsymbol{y}_t)\right\} = u_{it}, \forall i < N \tag{53}$$

The law of motion for assets:

$$a_{t+1}(\boldsymbol{y}_t) = a_t + \sum_{i=1}^{N} (y_{it} - \tau_{it}(\boldsymbol{y}_t)) \tag{54}$$

And the participation constraints

$$v\left(y_{it} + \tau_{it}(\boldsymbol{y}_t)\right) + u_{it+1}(\boldsymbol{y}_t) \geq U^{aut}\left(y_{it}, 0\right), \forall \boldsymbol{y}_t, i \tag{55}$$

The value of entering autarky with income y_{it} is given by

$$U^{aut}\left(y_{it}, 0\right) \equiv \max_{w} u(y_{it} - w) \\ + \sum_{y_{t+1}} \pi\left(y_{t+1}|y_t\right) \left[U^{aut}\left(y_{t+1}, w\right)\right] \tag{56}$$

reflecting the assumption that households enter autarky with no savings ($w = 0$), but thereafter can borrow and save at gross rate $R = 1$.[36]

The Lagrangian for the planner's problem is:

[36]Dependence of $U^{aut}\left(y_{irt}, 0\right)$ on effort is suppressed since Assumption 5f ensures that the household, who in autarky is now the residual claimant of its income, will always choose high effort.

$$
\begin{aligned}
\mathcal{L} = \sum_{\mathbf{y}_t} \pi(\mathbf{y}_t|\mathbf{y}_{t-1}) \Big\{ & v(y_{Nt} + \tau_{Nt}(\mathbf{y}_t) + u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), a_{t+1}(\mathbf{y}_t), \mathbf{y}_t) \\
& + \sum_{i<N} \lambda_{it} \big(v(y_{it} + \tau_{it}(\mathbf{y}_t)) + u_{i,t+1}(\mathbf{y}_t) - u_{i,t} \big) \\
& + \eta_t(\mathbf{y}_t) \big[a_t - \sum_{i=1}^{N} (\tau_{it}(\mathbf{y}_t) - y_{it}) - a_{t+1}(\mathbf{y}_t) \big] \\
& + \sum_{i=1}^{N} \phi_{it}(\mathbf{y}_t) \big[v(y_{it} + \tau_{it}(\mathbf{y}_t) + u_{i,t+1}(\mathbf{y}_t) - U^{aut}(y_{it}, 0) \big] \Big\}
\end{aligned}
\tag{57}
$$

Call the multiplier on household i's time t promise-keeping constraint λ_{it}, denote the multiplier on the participation constraint in state $\boldsymbol{y}_t$ as $\phi_{it}(\boldsymbol{y}_t)$ and denote the multiplier on the resource constraint in state $\boldsymbol{y}_t$ as $\eta_t(\boldsymbol{y}_t)$. The solution is characterized by the following first order conditions:

1. with respect to $\tau_{it}(\mathbf{y}_t)$:
$$
\eta(\boldsymbol{y}_t) = (\lambda_{it} + \phi_{it}(\boldsymbol{y}_t)) v'(y_{it} + \tau_{it}(\boldsymbol{y}_t)) \tag{58}
$$

2. with respect to $u_{i,t+1}(\mathbf{y}_t)$:
$$
\frac{\partial u_N(\mathbf{u}_{t+1}, a_{t+1}, \boldsymbol{y}_t)}{\partial u_{i,t+1}(y_{irt})} = -\lambda_{it} - \phi_{it}(\boldsymbol{y}_t), \forall y_i, i < N \tag{59}
$$

3. with respect to $a_{t+1}(\boldsymbol{y}_t)$:
$$
\frac{\partial u_N(\mathbf{u}_{t+1}(\boldsymbol{y}_t), a_{t+1}, \boldsymbol{y}_t)}{\partial a_{t+1}(\boldsymbol{y}_t)} = \eta_t(\boldsymbol{y}_t) \tag{60}
$$

and the envelope condition for current promises:

$$
\frac{\partial u_N(\mathbf{u}_t, a_t, \mathbf{y}_{t-1})}{\partial u_{it}(\boldsymbol{y}_{t-1})} = -\lambda_{it}, \forall i < N \tag{61}
$$

and the envelope condition for and assets:

$$
\frac{\partial u_N(\mathbf{u}_t, a_t, \boldsymbol{y}_{t-1})}{\partial a_t(\boldsymbol{y}_{t-1})} = \eta_{t-1}(\boldsymbol{y}_{t-1}) \tag{62}
$$

Advancing the envelope condition for $u_{it}(\mathbf{y}_{t-1})$, equation (61), by one period, yields:

$$
\frac{\partial u_N(\mathbf{u}_{t+1}, a_{t+1}, \boldsymbol{y}_t)}{\partial u_{i,t+1}(\boldsymbol{y}_t)} = -\lambda_{i,t+1}(\mathbf{y}_t), \forall i < N \tag{63}
$$

Combining the first-order condition for $u_{i,t+1}(\mathbf{y}_t)$,equation (59) and equation (63) we have that the time $t+1$ promise-keeping multiplier is equal to the time t promise-keeping multiplier plus the time t participation constraint multiplier:

$$
\lambda_{i,t+1}(\mathbf{y}_t) = \lambda_{it} + \phi_{it}(\mathbf{y}_t) \tag{64}
$$

Using the first-order condition for $\tau_{it}(\mathbf{y}_t)$, equation (58), it follows that the time $t+1$ promise-keeping multiplier is also equal to time t inverse marginal utility, scaled by the time t multiplier on the budget constraint:

$$\frac{\eta_t(\mathbf{y}_t)}{v'(y_{it}+\tau_{it}(\mathbf{y}_t))} = \lambda_{it} + \phi_{it}(\mathbf{y}_t) = \lambda_{i,t+1}(\mathbf{y}_t) \tag{65}$$

Lagging equation (65) yields:

$$\frac{\eta_{t-1}}{v'(y_{i,t-1}+\tau_{i,t-1})} = \lambda_{it} \tag{66}$$

Combining equations (65) and (66) and rearranging, we can write:

$$\frac{\eta_t(\mathbf{y}_t)}{v'(y_{it}+\tau_{it}(\mathbf{y}_t))} - \frac{\eta_{t-1}}{v'(y_{i,t-1}+\tau_{i,t-1})} = \lambda_{i,t+1}(\mathbf{y}_t) - \lambda_{it} = \phi_{it}(\mathbf{y}_t) \tag{67}$$

In words, the innovation to inverse marginal utility (scaled by the multiplier on the budget constraint) is equal to the innovation to the promise-keeping multiplier. That innovation, in turn, is the time t participation constraint multiplier. Rewrite equation (67) as:

$$\frac{\eta_t(\mathbf{y}_t)}{v'(y_{it}+\tau_{it}(\mathbf{y}_t))} = \frac{\eta_{t-1}}{v'(y_{i,t-1}+\tau_{i,t-1})} + \phi_{it}(\mathbf{y}_t)$$

Thus,

$$\mathbb{E}\left(\frac{\eta_t(\mathbf{y}_t)}{v'(y_{it}+\tau_{it}(\mathbf{y}_t))} | \frac{1}{v'(y_{i,t-1}+\tau_{i,t-1})}, \eta_t(\mathbf{y}_t)\right) = \frac{\eta_{t-1}}{v'(y_{i,t-1}+\tau_{i,t-1})}$$

since, conditional on $\left(\frac{1}{v'(y_{i,t-1}+\tau_{i,t-1})}, \eta_t(\mathbf{y}_t)\right)$, $\phi_{it}(\mathbf{y}_t)$ is an innovation, not forecastable based on time $t-1$ information since, as noted by (Ligon et al. 2002, p 215), with a Markov structure the participation constraints of the limited commitment model are forward looking, and therefore the set of sustainable continuation contracts depends only on the current state. It is necessary to condition on $\frac{1}{v'(y_{i,t-1}+\tau_{i,t-1})}$ since, to the extent that y_{it} contains "good news" about future income, this is reflected in the household's time t transfer, hence inverse marginal utility.

Therefore lagged inverse marginal utility, conditional on the current shadow price of resources $\eta_t(\mathbf{y}_t)$, captures all past information relevant to forecasting the expectation of current marginal utility of consumption.■

A.3 Proof of proposition 3: Under hidden income, LIMU is not sufficient to predict expected current inverse marginal utility

Because effort is contractible in the hidden income model and high effort is always implemented (Assumption 5f), the dependence of output on current and past effort is suppressed to avoid additional notation. The cost of effort is also suppressed, so that the promised utilities are interpreted as net of effort costs. Therefore denote $\pi(\mathbf{y}_t|\mathbf{y}_{t-1}, \mathbf{e}_t = \mathbf{1}, \mathbf{e}_{t-1} = \mathbf{1})$ by $\pi(\mathbf{y}_t|\mathbf{y}_{t-1})$, which defines a Markov transition matrix for the probability of a given set of realizations of household income across all households in the village, $\boldsymbol{y}_t$ given $\boldsymbol{y}_{t-1}$. Incomes are independent across households (but not across time). Therefore, $\pi\left(\boldsymbol{y}_t|\boldsymbol{y}_{t-1}\right) = \prod_i \pi\left(y_t|y_{t-1}\right)$, where $\pi\left(y_t|y_{t-1}\right) = \pi\left(y^t|y^{t-1}\right)$ is the probability of an individual household's income being y_t given y_{t-1} and hence of history y^t given the history y^{t-1}. Because it is relevant to keep track of the index (r) of household $i's$ income realization, the probability that household i will realize income $y_{it} = y_r$ and that the rest of the village will realize the vector of incomes $\boldsymbol{y}_{-i,t}$, given the full vector of time $t-1$ income realizations is denoted $\pi\left(y_{irt}, \boldsymbol{y}_{-i,t}|\boldsymbol{y}_{t-1}\right)$.

The planner maximizes the following recursive objective function, which is household N's expected utility at time

t.

$$u_N\left(\boldsymbol{u}_t, a_t, \boldsymbol{y}_{t-1}\right) \equiv \max_{\{\tau_{it}(\boldsymbol{y}_t)\},\{u_{i,t+1}(\boldsymbol{y}_t)\}} \sum_{y_t} \left\{\pi(y_{Nrt}, \boldsymbol{y}_{-N,t}|\boldsymbol{y}_{t-1}) v\left(y_{Nt}(\boldsymbol{y}_t) + \tau_{Nt}(\boldsymbol{y}_t)\right) + u_N\left(\boldsymbol{u}_{t+1}(\boldsymbol{y}_t), a_{t+1}, \boldsymbol{y}_t\right)\right\} \tag{68}$$

The maximization is subject to the following constraints:

The promise-keeping constraints for households $i < N$:

$$\sum_{y_t} \pi\left(y_{irt}, \boldsymbol{y}_{-i,t}|\boldsymbol{y}_{t-1}\right)\left\{v\left(y_{it} + \tau_{it}(\boldsymbol{y}_t)\right) + u_{i,t+1}(\boldsymbol{y}_t)\right\} = u_{it} \tag{69}$$

The law of motion for assets:

$$a_{t+1}(\boldsymbol{y}_t) = a_t + \sum_{i=1}^{N}(y_{it} - \tau_{it}(\boldsymbol{y}_t)) \tag{70}$$

and the set of interim truth-telling constraints. The local downward truth-telling constraints are binding (Thomas and Worrall 1990): for every income realization r (but the lowest) and every household i, the household realizing y_{irt} must prefer to truthfully report y_{irt} and receive transfer $\tau_{it}(y_{irt}, \boldsymbol{y}_{-i,t})$ and promise $u_{i,t+1}(y_{irt}, \boldsymbol{y}_{-i,t})$ associated with the actual income realization, rather than claiming their income was the lower one $y_{i,r-1,t}$ and getting transfer $\tau_{it}(y_{i,r-1,t}, \boldsymbol{y}_{-i,t})$ and promise $u_{i,t+1}(y_{i,r-1,t}, \boldsymbol{y}_{-i,t})$. Thus:

$$v(y_{irt} + \tau_{it}(y_{irt}, \boldsymbol{y}_{-i,t})) + u_{i,t+1}(y_{irt}, \boldsymbol{y}_{-i,t}) - v(y_{irt} + \tau_{it}(y_{i,r-1,t}, \boldsymbol{y}_{-i,t})) - u_{i,t+1}(y_{i,r-1,t}, \boldsymbol{y}_{-i,t}) \geq 0 \tag{71}$$

Let the Lagrange multiplier associated with the truth-telling constraint for a household realizing income r at time t be ξ_{irt}. The Lagrangian is:

$$\begin{aligned} L = \sum_{\boldsymbol{y}_t} \pi(\boldsymbol{y}_t|\boldsymbol{y}_{t-1})\{&v(y_{Nt} + \tau_{Nt}(\boldsymbol{y}_t) + u_N(\boldsymbol{u}_{t+1}(\boldsymbol{y}_t), a_{t+1}(\boldsymbol{y}_t), \boldsymbol{y}_t) \\ &+ \sum_{i<N} \lambda_{it}[v(y_{it} + \tau_{it}(\boldsymbol{y}_t)) + u_{i,t+1}(\boldsymbol{y}_t) - u_{it}(\mathbf{y}_{t-1})] \\ &+ \eta_t(\boldsymbol{y}_t)[a_t + \sum_{i=1}^{N}(y_{it} - \tau_{it}(\boldsymbol{y}_t)) - a_{t+1}(\boldsymbol{y}_t)]\} \\ &+ \sum_i \xi_{irt}[v(y_{irt} + \tau_{it}(\boldsymbol{y}_t)) + u_{i,t+1}(\boldsymbol{y}_t) - v(y_{irt} + \tau_{it}(y_{i,r-1,t}, \boldsymbol{y}_{-i,t})) - u_{i,t+1}(y_{i,r-1,t}, \boldsymbol{y}_{-i,t})] \end{aligned} \tag{72}$$

Therefore, the solution is characterized by the following first order conditions:

1. with respect to $a_{t+1}(\boldsymbol{y}_t)$:

$$\eta_t(\boldsymbol{y}_t) = \frac{\partial u_N(\boldsymbol{u}_{t+1}(\boldsymbol{y}_t), a_{t+1}(\boldsymbol{y}_t), \boldsymbol{y}_t)}{\partial a_{t+1}(\boldsymbol{y}_t)} \tag{73}$$

2. with respect to $u_{i,t+1}(\boldsymbol{y}_t)$:

$$-\pi\left(y_{irt},\boldsymbol{y}_{-i,t}|\boldsymbol{y}_{t-1}\right)\frac{\partial u_N(\boldsymbol{u}_{t+1}(\boldsymbol{y}_t),a_{t+1}(\boldsymbol{y}_t),\boldsymbol{y}_t)}{\partial u_{i,t+1}(\boldsymbol{y}_t)}=\pi\left(y_{irt},\boldsymbol{y}_{-i,t}|\boldsymbol{y}_{t-1}\right)\lambda_{it}+\zeta_{irt}-\zeta_{i,r+1,t} \tag{74}$$

3. with respect to $\tau_{it}(\boldsymbol{y}_t)$:

$$\begin{aligned}\pi(\boldsymbol{y}_t|\boldsymbol{y}_{t-1})\eta_t(\boldsymbol{y}_t)=[\pi(\boldsymbol{y}_t|\boldsymbol{y}_{t-1})\lambda_{it}+\xi_{irt}]v'(y_{irt}+\tau_{it}(y_{irt},\boldsymbol{y}_{-i,t}))\\ -\xi_{i,r+1,t}v'(y_{i,r+1,t}+\tau_{it}(y_{irt},\boldsymbol{y}_{-i,t}))\end{aligned} \tag{75}$$

and the two Envelope conditions:

$$\frac{\partial u_N(\mathbf{u}_t,a_t,\boldsymbol{y}_{t-1})}{\partial a_t(\boldsymbol{y}_{t-1})}=\eta_{t-1}(\boldsymbol{y}_{t-1}) \tag{76}$$

and

$$\frac{\partial u_N(\mathbf{u}_t,a_t,\mathbf{y}_{t-1})}{\partial u_{it}(\boldsymbol{y}_{t-1})}=-\lambda_{it},\forall i<N \tag{77}$$

The FOC for $u_{ir,t+1}$ (74) and the envelope condition for u_{it} (77) imply

$$\lambda_{i,t+1}=\lambda_{it}+\frac{\xi_{irt}-\xi_{i,r+1,t}}{\pi\left(y_{irt},\boldsymbol{y}_{-i,t}|\boldsymbol{y}_{t-1}\right)} \tag{78}$$

or, lagging equation (78) by one period, and denoting the time $t-1$ realized income level as y_p :

$$\lambda_{it}=\lambda_{i,t-1}+\frac{\xi_{ip,t-1}-\xi_{i,p+1,t-1}}{\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)} \tag{79}$$

The FOCs for time $t-1$ transfers awarded to households announcing incomes of $y_{ip,t-1}$ and $y_{i,p+1,t-1}$ imply that

$$\lambda_{i,t-1}=\frac{\eta_{t-1}}{v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))}\times\left(1-\frac{\xi_{ip,t-1}v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-\xi_{i,p+1,t-1}v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))}{\eta_{t-1}\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)}\right)$$

Since, unconditionally, λ_{it} is a martingale (Ljungqvist and Sargent 2004), $\lambda_{i,t-1}=\mathbb{E}(\lambda_{it}|\eta_t)$, yielding:

$$\mathbb{E}(\lambda_{it}|\eta_t)=\frac{\eta_{t-1}}{v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))}\times\left(1-\underbrace{\frac{\xi_{ip,t-1}v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-\xi_{i,p+1,t-1}v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))}{\eta_{t-1}\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)}}_{\equiv\theta_{ip}(\boldsymbol{y}_{t-1})}\right) \tag{80}$$

That is, the term

$$\theta_{ipt}(\boldsymbol{y}_{t-1}) \equiv \frac{\xi_{ip,t-1}v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-\xi_{i,p+1,t-1}v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))}{\eta_{t-1}\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)} \tag{81}$$

is the wedge between LIMU (scaled by η_{t-1}) and the expectation of current inverse marginal utility.

As long as the wedge $\theta_{ip}(\boldsymbol{y}_{t-1})$ is non-degenerate, i.e., $\frac{\partial\theta_{ip}(\boldsymbol{y}_{t-1})}{\partial y_{ip,t-1}} \neq 0$, LIMU and η_t are not sufficient to forecast future consumption.

To see that $\frac{\partial\theta_{ip}(\boldsymbol{y}_{t-1})}{\partial y_{ip,t-1}} \neq 0$, note that the marginal utility of the household when truthfully claiming income $y_{ip,t-1}$ is higher than that of the household when claiming income $y_{ip,t-1}$ but actually receiving income $y_{i,p+1,t-1}$:

$$v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right) >' \left(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)\right) \tag{82}$$

But, on average $\xi_{ip,t-1}=\xi_{i,p+1,t-1}$, since there is no truth-telling constraint associated with the lowest income level y_1, because there is no lower income level which can be claimed and there is no truth-telling constraint associated with the the $(S+1)\,th$ income level since the highest possible income is y_S ((Ljungqvist and Sargent 2004), p 668). Thus

$$\sum_{s=1}^{S}\left(\xi_{i,s+1,t-1}-\xi_{i,s,t-1}\right)=\xi_{i,S+1,t-1}-\xi_{i,1,t-1}=0 \tag{83}$$

From equation (79),

$$\lambda_{it}-\lambda_{i,t-1}=\frac{\xi_{ip,t-1}-\xi_{i,p+1,t-1}}{\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)}. \tag{84}$$

That is, if λ_{it} (the promise-keeping multiplier based on the $t-1$ income realization) is, on average greater than $\lambda_{i,t-1}$ (the promise-keeping multiplier based on the $t-2$ income realization), then $\xi_{ip,t-1}>\xi_{i,p+1,t-1}$, i.e. the truth-telling constraint associated with income $y_{ip,t-1}$ is tighter than that associated with income $y_{ip,t-1}$. Thus $\xi_{ip,t-1}>\xi_{i,p+1,t-1}$ when y_p is a better-than-average income draw. When $y_p<\bar{y}$, the opposite is true: $\xi_{ip,t-1}<\xi_{i,p+1,t-1}$.■

The sign of $\frac{\partial\theta_{ip}(\boldsymbol{y}_{t-1})}{\partial y_{ip,t-1}}$ can be determined when the condition of Corollary 4 is satisfied. That is, when:

$$\begin{aligned} & \frac{v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))}{v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))} \\ > \quad & \frac{\xi_{i,p,t-1}-\xi_{i,p+1,t-1}}{\xi_{i,p+1,t-1}}, \forall p\in\{1,S-1\} \end{aligned}$$

implying that equilibrium marginal utility falls, in percentage terms, more quickly with income than promise-keeping constraints tighten with income:

A.3.1 Proof of Corollary 4: If equilibrium marginal utility falls more quickly with income than promise-keeping constraints tighten with income, inverse marginal utility will be positively correlated with past income:

Proof: Rewrite the numerator of $\theta_{ip}(\boldsymbol{y}_{t-1})$ (eq 81) by adding and subtracting $\xi_{ip,t-1}v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)$. The sign of $\theta_{ip}(\boldsymbol{y}_{t-1})$ is the sign of:

$$\begin{aligned}&\xi_{ip,t-1}\left[v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)\right]\\&-\left[\xi_{i,p+1,t-1}-\xi_{ip,t-1}\right]v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)\end{aligned}\tag{85}$$

Dividing by $\xi_{ip,t-1}v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)$, which is strictly positive for $p\in\{2,...,S\}$, $\theta_{ip}(\boldsymbol{y}_{t-1})>0$ if

$$\frac{v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)}{v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)}>\frac{\xi_{i,p,t-1}-\xi_{i,p+1,t-1}}{\xi_{i,p+1,t-1}}.\tag{86}$$

That is, if the equilibrium marginal utility levels associated with income levels grow faster, in percentage terms, than the truth-telling constraints associated with those income levels, then $\frac{\partial\theta_{ip}(\boldsymbol{y}_{t-1})}{\partial y_{ip,t-1}}>0.$

Substitute the envelope condition for $u_{i,t-1}$, equation (77) into equation (84). The magnitude of $\xi_{i,p,t-1}-\xi_{i,p+1,t-1}$ is given by:

$$\begin{aligned}&\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)\left[\frac{\partial u_N(\mathbf{u}_{t-1},a_{t-1},\mathbf{y}_{t-2})}{\partial u_{i,t-1}}-\mathbb{E}\left(\frac{\partial u_N(\mathbf{u}_t,a_t,\mathbf{y}_{t-1})}{\partial u_{it}}|\eta_t,y_{t-1}\right)\right]\\=\;&\xi_{i,p,t-1}-\xi_{i,p+1,t-1}.\end{aligned}\tag{87}$$

If the cost to the planner/village of providing i with utility rises more slowly with income than i's marginal utility falls with income, the lemma will be satisfied. Since, by assumption, the village has access to a credit technology which individuals cannot privately use, the cost to the village of increasing i's utility (reducing marginal utility) grows more slowly than marginal utility falls, because the village can borrow and save to smooth the costs across time.■

A.4 Proof of proposition 5: Less-variable income processes display a reduced wedge between LIMU and current inverse marginal utility

Proof: The term $\theta_{ip}(\boldsymbol{y}_{t-1})$, defined in (81) measures the "wedge" between λ_{it} and $\frac{\eta_{t-1}}{v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right))}$. Take the expectation of $\left|\theta_{ip}(\boldsymbol{y}_{t-1})\right|$ with respect to the time $t-1$ income realization $\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)$:

$$\begin{aligned}\mathbb{E}\left[|\theta(y_p)|\right]\;=\;&\sum_{p=1}^{S}\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)\\&\times\left|\frac{\xi_{ip,t-1}v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)}{\eta_{t-1}\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)}\right|\end{aligned}$$

Fixing the probability of each income realization, $\pi\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}|\boldsymbol{y}_{t-2}\right)$, a SOSD reduction in variability will reduce the quantity

$$\mathbb{E}\left|v'(y_{ip,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)-v'(y_{i,p+1,t-1}+\tau_{i,t-1}\left(y_{ip,t-1},\boldsymbol{y}_{-i,t-1}\right)\right|$$

since income levels are closer together (note these differences remain negative since $y_p < y_{p+1}$), and will reduce $\mathbb{E}\left|\xi_{ip,t-1} - \xi_{i,p+1,t-1}\right|$ by (87) since a reduction in the amount of uncertainty about the household's income moves $\mathbb{E}u_{it}$ and $u_{i,t-1}$closer together (insurance improves). By the concavity of the planner's value function, this in turn reduces the gap $\frac{\partial u_N(\mathbf{u}_{t-1},a_{t-1},\mathbf{y}_{t-2})}{\partial u_{i,t-1}} - \mathbb{E}\left(\frac{\partial u_N(\mathbf{u}_t,a_t,\mathbf{y}_{t-1})}{\partial u_{it}}|\eta_t, y_{t-1}\right)$. Therefore, $\mathbb{E}\left[\theta_{ip}(\boldsymbol{y}_{t-1})\right] \to 1$ as the variability of y decreases, so that the amount of additional information contained in y_{t-1} falls.■

A.5 Proof of proposition 6: Different components of income affect consumption in adjacent periods proportionally under limited commitment or moral hazard

Proposition 6 states that for any components of lagged income $x^k_{i,t-s}$, which predict (or are components of) lagged income, the following proportionality restriction will hold:

$$\frac{d\ln c_{it}}{dx^k_{i,t-s}} / \frac{d\ln c_{i,t-1}}{dx^k_{i,t-s}} = \pi_i, \forall k$$

even if household differ in their utility functions ($v'_i(y_r + \tau_{irt}) \neq v'_j(y_r + \tau_{irt})$ or $\beta_i \neq \beta_j$) and if observed consumption is measured with (possibly non-classical) error.

Under limited commitment, inverse marginal utility, through transfers, is determined according to FOC for transfers, equation (58):

$$\frac{\eta\left(\boldsymbol{y}_t\right)}{\lambda_{it} + \phi_{it}\left(\boldsymbol{y}_t\right)} = -\lambda_{it} - \phi_{it}\left(\boldsymbol{y}_t\right)$$

and the future promise according to its FOC, equation (59):

$$-\frac{\partial u_N(\mathbf{u}_{t+1}, a_{t+1}, \boldsymbol{y}_t)}{\partial u_{i,t+1}(y_{irt})} = -\lambda_{it} - \phi_{it}\left(\boldsymbol{y}_t\right) \tag{88}$$

where λ_{it} is the multiplier on the promise-keeping constraint and ϕ_{it} is the multiplier on the participation constraint. Thus

$$-\frac{\partial u_N(\mathbf{u}_{t+1}, a_{t+1}, \boldsymbol{y}_t)}{\partial u_{i,t+1}(y_{irt})} = \frac{\eta\left(\boldsymbol{y}_t\right)}{\lambda_{it} + \phi_{it}\left(\boldsymbol{y}_t\right)} \tag{89}$$

and changes to time t consumption arising from a change in any components of time t income, $x^k_{i,t}$ will be proportional to the corresponding change in the time $t+1$ promise.

Under moral hazard, inverse marginal utility, through transfers, is determined according to FOC for transfers, equation (45):

$$\lambda_{it} + \varphi_{it} h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^1_{it} r^1_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^2_{it} r^2_i(\mathbf{y}_t, \mathbf{y}_{t-1}) = \frac{\eta_t(\mathbf{y}_t)}{v'(y_{it} + \tau_{it}(\mathbf{y}_t))} \tag{90}$$

and the future promise according to to FOC for $u_{i,t+1}$, equation (39), which can be rearranged as:

$$\lambda_{it} + \varphi_{it} h_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^1_{it} r^1_i(\mathbf{y}_t, \mathbf{y}_{t-1}) + \psi^2_{it} r^2_i(\mathbf{y}_t, \mathbf{y}_{t-1}) = -\frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial u_{i,t+1}(\boldsymbol{y}_t)} \tag{91}$$

where again λ_{it} is the multiplier on the promise-keeping constraint, φ_{it} is the multiplier on the incentive-compatibility constraint, and ψ_{it}^1 and ψ_{it}^2 are the multipliers on the two threat-keeping constraints. So again,

$$-\frac{\partial u_N(\mathbf{u}_{t+1}(\mathbf{y}_t), \hat{\mathbf{u}}_{t+1}(\mathbf{y}_t), a_t(\mathbf{y}_t), \mathbf{y}_t)}{\partial u_{i,t+1}(\boldsymbol{y}_t)} = \frac{\eta_t(\mathbf{y}_t)}{v'(y_{it} + \tau_{it}(\mathbf{y}_t))} \tag{92}$$

and changes to time t consumption arising from a change in any components of time t income, $x_{i,t}^k$ will be proportional to the corresponding change in the time $t+1$ promise.

A.5.1 The case of individual heterogeneity

A change in income component x^k, Δx_{it}^k, will affect both transfers and future promised utility through its effects on the promising-keeping constraint multiplier (λ_{it}) and the respective incentive constraint multipliers (ϕ_{it} for limited commitment; $\varphi_{it}, \psi_{it}^1$ and ψ_{it}^2 for moral hazard).

Under either limited commitment or moral hazard, the marginal propensity to consume out of income component x_{it}^k at time t is proportional to the marginal propensity to consume out of income component x_{it}^j at time $t+1$, by equations (89) and (92), respectively. Therefore:

$$\begin{aligned} \pi_i^{k,MH} &= \pi_i^{j,MH} \\ \pi_i^{k,LC} &= \pi_i^{j,LC} \end{aligned} \tag{93}$$

because, after an innovation to income, the planner optimally updates the current and future utilities promised to the household proportionally. While the π may vary across households due to individual heterogeneity, the proportionality is common across income innovations.

A.5.2 Measurement error in consumption

The true marginal propensity to consume out of x is

$$c_{i,t} = \pi x_{i,t}^k + \varepsilon_{i,t} \tag{94}$$

The true π is unknown and must be estimated. First consider measurement error in the left-hand side variable: assume true consumption, c, is unobserved and an error-ridden measure, $\tilde{c} = c + v$ is observed. (The x are assumed for now to be observed without error.) The measurement error v may be correlated with c:

$$corr(c_{it}, v_{it}) \neq 0$$

The probability limit of π is:

$$p\lim \tilde{\pi}_i^k = \frac{\frac{1}{n}\sum\left(x_{i,t}^k\right)\left(\pi_i^k x_{i,t}^k + \varepsilon_{i,t} - v_{i,t}\right)}{\frac{1}{n}\sum\left(x_{i,t}^k\right)^2} = \pi_i^k \tag{95}$$

When the measurement error is in the left-hand side variable, it is absorbed into the error term, $\varepsilon_{i,t} - v_{i,t}$ (Greene 2003, Section 5.6). Thus, π_i^k is consistently estimated, though the error will exhibit heteroskedasticity when $corr(c_{it}, v_{it}) \neq 0$.■

Proposition 7 *Classical measurement error biases OLS results toward a rejection of mean-sufficiency of LIMU; instrumenting lagged consumption yields consistent estimates.*

Proof: Note that we want to estimate the part of consumption that is unexplained by LIMU and village-year effect:

$$\varepsilon_{ivt} = \ln c_{ivt} - \delta_{vt} - \gamma \ln c_{iv,t-1} \tag{96}$$

Assume an error-ridden measure of consumption is observed,

$$\tilde{c}_{iv,t-1} = c_{iv,t-1} \cdot \nu_{iv,t-1}$$

where the measurement error $\nu_{iv,t-1}$ is uncorrelated with true time $t-1$ consumption, $c_{iv,t-1}$, or true time t consumption, c_{ivt}. The estimated prediction error is constructed using observed lagged consumption $\tilde{c}_{iv,t-1}$, and the estimates of γ and δ:

$$\hat{\varepsilon}_{ivt} = \ln c_{ivt} - \hat{\delta}_{vt} - \hat{\gamma} \ln \tilde{c}_{iv,t-1}$$

Assume the true data-generating process is a model with sufficiency of LIMU, such as insurance constrained by limited commitment or moral hazard. Then, the forecast error (96) will be uncorrelated with lagged income:

$$\mathbb{E}\underbrace{(\ln c_{ivt} - \gamma \ln c_{iv,t-1} - \delta_{vt})}_{\text{“true” residual } \varepsilon_{ivt}} y_{iv,t-1} = 0 \tag{97}$$

However, if γ is estimated by OLS, the null hypothesis (97) may potentially be incorrectly rejected, because $\hat{\gamma}$ is biased downward:

$$p \lim \hat{\gamma} = \gamma \left(1 - \frac{\sigma_\nu^2}{\sigma_c^2 + \sigma_\nu^2}\right)$$

The estimated residual is then positively correlated with lagged income, because fraction $\frac{\sigma_\nu^2}{\sigma_c^2+\sigma_\nu^2}$ of current log consumption is incorrectly not projected onto lagged log consumption, and this term is correlated with lagged income (because under either limited commitment or moral hazard, contemporaneous income and consumption are positively correlated):

$$\begin{aligned}
\hat{\varepsilon}_{ivt} &= \ln c_{ivt} - \hat{\delta}_{vt} - \hat{\gamma} \ln \tilde{c}_{iv,t-1} \\
p \lim \hat{\varepsilon}_{ivt} &= \ln c_{ivt} - \hat{\delta}_{vt} - \gamma \left(1 - \frac{\sigma_\nu^2}{\sigma_c^2 + \sigma_\nu^2}\right) \ln \tilde{c}_{iv,t-1} \\
&= \underbrace{\ln c_{ivt} - \hat{\delta}_{vt} - \gamma \ln \tilde{c}_{iv,t-1}}_{\text{uncorrelated w/ } y_{iv,t-1}} + \underbrace{\frac{\sigma_\nu^2}{\sigma_c^2 + \sigma_\nu^2} \gamma \ln \tilde{c}_{iv,t-1}}_{\text{+ correlated w/ } y_{iv,t-1}}
\end{aligned}$$

That is, we may conclude wrongly that $corr(\hat{\varepsilon}_{ivt}, y_{iv,t-1}) > 0$, that is, that LIMU is not sufficient to predict current inverse marginal utility when consumption is measured with classical error, because lagged income is then in effect a second proxy for true LIMU.

However, for classical error, there is a straightforward solution. If γ is estimated using the second lag of consumption as an instrument for the first lag, we obtain a consistent estimate of γ:

$$\begin{aligned} p\lim \hat{\gamma}^{IV} &= \frac{cov(\ln \tilde{c}_{iv,t-2}, \ln \tilde{c}_{ivt})}{cov(\ln \tilde{c}_{iv,t-2}, \ln \tilde{c}_{iv,t-1})} \\ &= \gamma \left(1 - \underbrace{\frac{cov(\nu_{t-2}, \nu_{t-1})}{cov(\ln \tilde{c}_{iv,t-2}, \ln \tilde{c}_{iv,t-1})}}_{=0} \right) \end{aligned}$$

Then, the probability limit of the residual is

$$\begin{aligned} p\lim \hat{\varepsilon}^{IV}_{ivt} &= \ln \tilde{c}_{ivt} - \hat{\delta}_{vt} - \gamma \ln \tilde{c}_{iv,t-1} \\ &= \ln c_{ivt} + \ln \nu_{ivt} - \hat{\delta}_{vt} - \gamma \left(\ln c_{iv,t-1} + \ln \nu_{iv,t-1} \right) \end{aligned}$$

Rearranging,

$$p\lim \hat{\varepsilon}^{IV}_{ivt} = \underbrace{\ln c_{ivt} - \gamma \ln c_{iv,t-1} - \delta_{vt}}_{\text{“true” residual}} + \underbrace{\ln \nu_{ivt}}_{\text{meas. error in } c_{ivt}} - \gamma \underbrace{\ln \nu_{iv,t-1}}_{\text{meas. error in } c_{iv,t-1}}$$

Under the hypothesis that true lagged inverse marginal utility ($\ln c_{iv,t-1}$) is sufficient to predict true current inverse marginal utility, the “true” residual (96) is uncorrelated with lagged income. Moreover, if the measurement error in (log) consumption is classical, $\ln \nu_{ivt}$ and $\ln \nu_{iv,t-1}$ are also uncorrelated with lagged income:

$$corr(\ln \nu_{ivt}, y_{iv,t-1}) = corr(\ln \nu_{iv,t-1}, y_{iv,t-1}) = 0$$

Therefore, with classical measurement error and a true data-generating process of limited commitment or moral hazard, instrumenting the first lag of consumption with the second lag of consumption will lead to the correct conclusion:$p\lim \hat{\varepsilon}^{IV}_{ivt} y_{iv,t-1} = 0$.■

B Appendix: Additional Tables

Table A1: Summary statistics

		531-HH panel mean	Non-continuously observed HH difference	N
	Monthly income	8981.224	-2624.627	670
	Monthly expenditure	5213.472	-1108.721***	670
	Monthly income, resids	32.443	-163.756	670
	Monthly expenditure, resids	67.416	-570.84	670
	Household size	4.525	-0.663***	669
	Adult equivalents	3.786	-0.638***	669
	Adult men	1.382	-0.324***	669
	Adult women	1.552	-0.247***	669
Gifts given:	Gifts to orgs in village	33.714	-9.813	670
	Gifts to orgs not in village	53.749	-29.063**	670
	Gifts given for events in village	103.219	-35.550***	670
	Gifts given for events not in village	220.117	-140.576***	670
	Other gifts to HHs in village	147.317	-29.854	670
	Other gifts to HHs not in village	637.198	-96.868	670
Gifts received:	Gifts from orgs in village	36.105	-20.002**	670
	Gifts from orgs not in village	38.963	10.82	670
	Gifts rec'd for events in village	316.862	-213.653***	670
	Gifts rec'd for events not in village	80.068	9.976	670
	Other gifts from HHs in village	118.129	-20.575	670
	Other gifts from HHs not in village	1327.131	-253.376	670
Occupation (household head, baseline)				
	Rice farmer	0.355	0.116*	667
	Non-ag labor	0.119	0.033	667
	Corn farmer	0.098	-0.062*	667
	Livestock farmer	0.089	-0.082***	667
	Ag wage labor	0.051	0.007	667
	Other crop farmer	0.043	-0.036*	667
	Shrimp/fish farmer	0.036	-0.021	667
	Orchard farmer	0.017	0.005	667
	Construction	0.015	0.036*	667
	Other	0.074	0.013	667

Notes: All baht-denominated variables were converted to 2002 baht using the Thai Ministry of Trade's Rural Consumer Price Index for Thailand. In 2002, approximately 42 Thai baht were equal to US$1. Income and expenditure resids are residuals from regression on village, year, occupation and demographic variables.

Table A2: Testing the hidden income model, full sample

	(1)	(2)	(3)
Lagged consumption	0.290		
	(0.0440)		
Lagged IHS income	40.15	23.09	18.93
	(6.703)	(6.326)	(6.284)
Village-month fixed effect?	Yes	Yes	Yes
Village-month fixed effect$\times c_{t-1}$?	Yes	Yes	Yes
Estimation method	OLS	OLS	OLS
R-squared	0.102	0.369	0.380
Observations	44,073	44,073	44,073

Notes: Sample includes household-month observations with negative lagged net income. Standard errors clustered at the village quarter level in brackets. IHS is inverse hyperbolic sine (see text).
Model 1: $\rho = 1$, including village-month fixed effects (η'_{-it}) and $\eta'_{-it} \times c_{t-1}$.
Model 2: $\rho = 1$, including village-month fixed effects (η'_{-it}) and $\eta'_{-it} \times c_{t-1}$ and quadratic splines in lagged consumption.
Model 3: $\rho = 1$, including quadratic splines in estimated village-month effects (η'_{-it}) and quadratic splines in lagged consumption and lagged consumption$\times \eta'_{-it}$.

Table A3: Predicting income with rainfall

Occupation	R^2	N
Rice farmer	0.386	752
Construction	0.292	32
Orchard farmer	0.222	36
Shrimp/fish farmer	0.195	76
Agricultural wage labor	0.143	108
Livestock	0.142	188
Other crop farmer	0.120	92
Non-agricultural wage labor	0.116	252
Other	0.100	156
Corn farmer	0.088	208

Notes: R^2 is the R-squared of annual income on quarterly income deviations and squared deviations, plus province-fixed effects. N is the number of household-year observations.

B.1 Linearized tests of hidden income: insufficiency of LIMU and predictive power of lagged income

Under either limited commitment or moral hazard, all past information relevant to forecasting current inverse marginal utility is encoded in last period's inverse marginal utility and a village-year fixed effect. Thus:

$$\mathbb{E}_{t-1}\left[\frac{1}{v'(c_{it})}\right] = f\left(\frac{1}{v'(c_{it})}, \eta_t\right) \tag{98}$$

If (98) holds, the prediction errors:

$$\hat{\varepsilon}^*_{it} \equiv \frac{1}{v'(c_{it})} - \mathbb{E}\left(\frac{1}{v'(c_{it})} | \frac{1}{v'(c_{i,t-1})}, \eta_t\right) \tag{99}$$

should be uncorrelated with past income, a finding that contrasts with the prediction of the hidden income model. Under Lemma 4, prediction errors from forecasting current inverse marginal utility based on LIMU will be positively correlated with income in the previous period.

Table A4 tests this implication. Consistent with the hidden income prediction, when the prediction errors defined in equation (99) are regressed on lagged income (and lagged income and lagged income squared interacted with the aggregate shock measure η_t) the slope is positive and significant while the intercept is significantly negative (column 1). Since the dependent variable is a regression residual, which has mean zero by construction, the slope and intercept are not independent. The joint hypothesis that $\alpha = 0, \beta = 0$ is rejected at the .0001 level. Column 2 shows that instrumenting $\ln c_{iv,t-1}$ with $\ln c_{iv,t-2}$ does not overturn the finding that the prediction residuals are negative at low levels of lagged income: the null that the slope and the intercept in (99) are both 0 is rejected at the 1% level. This suggests that the rejection of sufficiency of LIMU is not driven by classical measurement error.

Table A4: Testing the hidden income model (CRRA utility, linear estimates)

LHS=Prediction residuals from a regression of $ln(c_t)$ on $ln(c_{t-1})$ and a village-year effect

	OLS	IV
	(1)	(2)
Constant (α)	-.4839	-.2123
	[.0694]	[.0576]
Lagged log income (β)	.0453	.0205
	[.0063]	[.0052]
Chi-square stat (α<0, β>0)	54.84	19.40
p value	(0.000)	(0.000)
Observations	2781	2322

Notes: Bootstrapped standard errors in brackets. Regressions include a village-year fixed effect. Chi-square stat is the statistic for the test that the slope$>$0, intercept$<$0. P-value in brackets.