# Formal and Informal Risk Sharing in LDCs Theory and Empirical Evidence

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**Abstract**

In village economies, limited commitment models have been proposed as theoretical alternatives to the complete markets hypothesis and have been shown to be empirically relevant. Yet, village institutions might be able to enforce some contracts. We construct a theoretical model which shows how households can insure through both formal and informal contracts when some verifiable production takes place in an environment of incomplete markets. This theoretical setting nests the case of complete markets when all risks can be insured by formal contracts (because all states of nature would be verifiable) and the case where only informal agreements are available (agreements specifying informal transfers that needs to be self-enforceable). We derive two equations of interest, the income equation which is partially determined by the formal contract and an Euler-type equation where consumption growth is affected by lagged consumption instead of being a martingale. Using semi-parametric specifications, we derive testable restrictions of our model. We estimate both equations using data of village economies in Pakistan. Empirical results are consistent with the model. The estimation and allows to show that the incentive constraints due to self-enforcement bind and that formal contracts are used to reduce the probability of binding the constraint.

**JEL Classification:** C14, D13, D91, L14

**Key Words:** Risk sharing, Contracts, Incomplete Markets, Informal Transfers

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# 1 Introduction[1]

Following the seminal paper of Townsend (1994), the empirical testing of whether or not markets are complete in village economies have proved to be a fertile and valuable line of research. It led to a better understanding of market failures and a better identification of households in the village who are most affected by these failures (Deaton, 1997, Morduch, 1999, Fafchamps, 2003). These results were paralleled by tests of complete markets in developed economies at the aggregate level (see Attanasio and Ríos-Rull, 2003) and the micro level (Cochrane, 1991, and Mace, 1991). In both literatures, most papers report rejections of the hypothesis of complete markets and much effort is now put on looking at alternative credible models of partially insured agents (see Blundell, Pistaferri and Preston, 2003). This is where the two literatures, the one on village economies and the other on developed economies, depart. Because village economies seem a priori to be less prone to imperfect information problems, the latter literature, highlights the problem of contract enforcement (Thomas and Worrall, 1988, Ligon, Thomas and Worrall, 2002). The rationale is that village economies lack institutions which would enable to enforce the whole set of contracts and would lead to perfect risk sharing. Villagers are bound to enter agreements that are informal. There are no written records for transfers which can take the form of loans, no proper institutions designed to make repayments imperative and repayments can be delayed or debts altogether canceled (Fafchamps, 1992, Udry, 1994). Informal transfers are nonetheless Pareto-improving because they permit risk sharing provided that they can be self-enforced (Coate and Ravallion, 1993, Fafchamps, 1992, Kimball, 1988). The latter requirement restricts the set of informal agreements which may not be rich enough to lead to complete risk sharing in the village. In particular, it depends on the impatience and risk aversion of every household. A few recent papers show the empirical relevance of such analyses (Ligon, Thomas and Worrall, 2002).

Although these self-enforcing transfers play their part in sharing risk within villages, within extended families (Foster and Rosenzweig, 2001) or within networks of households formed by kinship, ethnicity and so on, (Grimard, 1997, Fafchamps and Lund, 2003), some institutions may help enforce more easily some form of contracts. In particular, sharecropping and fixed rent formal contracts are commonly observed in villages of LDCs and their role in allocating risk

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have been repetitively emphasized. The enforcement of contracts depend on specific institutions within each village and the degree of enforcement is likely to be a continuum. To make things precise, we nonetheless consider a model where two types of agreements coexist, enforceable formal contracts on the one hand, informal agreements which need to be self-enforced on the other hand. Although we analyze the role of these instruments, we keep on working within the set-up of Deaton (1997) where we do not examine specific institutions in villages but the consequences they have on the behavior of households in terms of income and consumption only. In particular we do not take into account family relationships that may have strong bearings onto the question.

Risks that households face are of many kinds. We assume that some subset of the set of states of nature are observable and verifiable. Other states of nature however may not be contractible like those related to health contingencies or to returns to individual activities. Hence, formal contracts are allowed to be contingent on agricultural risk while other risks can only be shared through the use of implicit informal agreements that need to be self-enforced. Of course, informal transfers can also be contingent on verifiable risks. That informal agreements are designed given the formal agreements would explain why formal contracts are accompanied by informal transfers that can attenuate their effects in bad states of nature (Udry, 1994). Moreover, as formal contracts allow risk sharing, households use this instrument to smooth income as well as consumption (Morduch, 1995).

In this paper, we construct a theoretical setting which nests the case of complete markets when all risks can be insured by formal contracts (because all states of nature would be verifiable), the case where only one non contingent transfer is allowed as in Gauthier, Poitevin and Gonzalez (1997) and the case where only informal agreements are available (Ligon et al., 2002). The setting is a two-agent model where preferences are random and the income process is stochastic. In the leading case, one agent, who is interpreted afterwards as representing the "village" can commit while the other agent (the "household") cannot. Formal contracts are short-term and entail real costs. Because of formal contracts, the value function is not concave, yet we show that intrinsic randomization and random preferences make the problem convex. This theoretical model proves to be quite general and makes a new step in the modeling of incomplete risk sharing with enforceable and self-enforceable contractual instruments.

We derive two equations of interest, an Euler-type equation of consumption dynamics and the equation of determination of the formal contract. Our first prediction is that the formal contract is a monotonous function of the ratio of agents' marginal utilities last period which makes income endogenous. The second prediction is that the ratio of marginal utilities is a random walk with jumps as in Ligon et al. (2002) but where the occurrence and size of the jumps are not exogenous and depend on the ratio of marginal utilities last period. It explains why lagged consumption might enter the right hand side of the Euler equation.

By specifying more precisely preferences and income processes, we derive estimable equations, one for income the other for consumption growth. The econometric set-up is semi-parametric and the consumption growth equation takes the form of a partially linear double index equation that we estimate using penalized splines (Yu and Ruppert, 2002). We show under which conditions the model is semi-parametrically identified and that the theoretical model has testable implications.

We estimate the model using data from village economies in Pakistan using a survey done by IFPRI at the end of the 1980s. The sample of around 900 households is interviewed in 12 successive rounds and the information collected in the survey is roughly equivalent to the celebrated ICRISAT Indian dataset (see Townsend, 1994, for instance). It contains food and non-food expenditures, various sources of income, asset composition etc. Dubois (2000) already shows in a thorough analysis that full risk sharing is rejected and that sharecropping influences the sharing of residual risk. As theory predicts, lagged consumption indeed affects income and this result is robust to the presence of measurement errors and to some superior information that households have on future income shocks (compared to the econometrician). The same results hold for the consumption growth equation. The estimation of this equation enables us to identify, up to a scale given by relative risk aversion, the probability that a self-enforcing constraint binds. If relative risk aversion is equal to 1.5, this probability is roughly equal to 10%. These results show the empirical relevance of our approach since households use both formal transfers because of the significant lagged consumption effect, and informal agreements, because the probability of a binding constraint is positive. The overidentifying restrictions of independent preference shocks and classic measurement errors are checked by analyzing the serial correlation of the residuals.

In Section 2, we set-up the model, define formal contracts and the optimal allocations and derive their characterization. We specify the primitives of the model in Section 3 in order to derive the income and the consumption growth equation. A brief informal analysis of the data is presented in Section 4 as well as the first estimations of income and consumption growth equations. The semi-parametric identification of the consumption growth equation is realized in Section 5 and results of the complete estimation of the structural model are reported in Section

6. The last section concludes and proofs are in appendices.

# 2 A Theoretical Model of Risk Sharing with Formal and Informal Contracts

In this section, we set up the theory step by step. In the two-agent framework that we consider, we start by introducing the characteristics of the income processes of the agents and their preferences. We begin with a simple model where we assume full commitment by one agent and none by the other. The full extension is delayed until the end of the section. We continue by defining the characteristics of formal contracts. After exhibiting the timing of the decision process, we analyze the optimal allocations and show that the decision problem is convex. The main predictions about the Euler equation and the monotonicity of the contracts as a function of lagged marginal utility or lagged consumption are then derived. We finish this section by extending our results when no agents can commit and when general Markov processes for preferences and income processes are considered.

## 2.1 Income Process & Preferences

Consider an economy with two agents and states of nature denoted $z_t$ for date $t = 1, ..., \infty$. At each date the state of nature $z_t$ belongs to some finite set $Z$, and the distribution of $z_t$ is i.i.d. The extension to general Markov process is undertaken at the end of the section. We denote by $z$ a generic element of $Z$ and by $p_z$ the probability of state $z$. Assume that resources of agent $i$ are exogenous and denoted $\omega_z^i$ in state $z$. With the empirical application in mind, one might think of agent 1 as the household and agent 2 as the collectivity (the village) which provides some informal insurance to agent 1.

Agent 2 has a fixed Von-Neuman Morgenstern utility $u_2(.)$. To account for random preferences in the empirical analysis, we assume that the utility function of agent 1 follows some stochastic process: at date $t$, it is equal to $u_{1t}(.) = \eta_t u_1(.)$, where $\eta_1 = 1$. The ratio $\eta_t/\eta_{t-1}$ stands for random preference shocks and we follow the literature by assuming that is independently and identically distributed (i.i.d.) with mean 1 and positive variance and whose support is an interval of $R^+$. We assume that $\eta_t$ is observed by the two agents at the very beginning of date $t$ before endowment shocks $z_t$ that are observed only at the end of period $t$. The ex-ante utility of agent 1 is then $E\left[\sum_{t=1}^{\infty} \rho^{t-1}\eta_t u_1(c_t^1)\right]$, while it is $E\left[\sum_{t=1}^{\infty} \rho^{t-1} u_2(c_t^2)\right]$ for agent 2. As there are only two agents, we assume that the second agent has non-stochastic preferences. As we show below, what matters are ratios of marginal utilities and this assumption is therefore a simple normalization. Moreover, we assume that $u_i(0) = 0$ and $u_i'(0) = +\infty$.

Finally, by anticipation, we will allow for some randomization beyond the fundamentals because of convexity issues. The reason is that the value function may not be concave. We show below that randomization over utilities generate enough convexity to solve the program even with a non-concave value function. We assume that at every period, there is a public random variable, $\varepsilon_t$, the intrinsic shock, whose realization occurs at the beginning of date $t$.

In the benchmark case of complete markets when optimal insurance is achieved, consumption at date $t$ depends only on the realization of total resources. According to Borch rules, the ratio of marginal utilities is the same in all states of nature. Thus, under a full contracting setting, the stochastic dynamics of consumption would be given by

$$\frac{\eta_{t+1}}{\eta_t}\frac{u_1'(c_{t+1}^1)}{u_2'(c_{t+1}^2)} = \frac{u_1'(c_t^1)}{u_2'(c_t^2)}.$$

It is generally not the case if we introduce limitations on the possibility for agents to sign formal contracts. Those contracts are now defined.

## 2.2 Formal Contracts

Formal contracts are binding for both agents once signed, but they are restricted and incomplete. Incompleteness is modeled here by three characteristics:

1. Contracts are short term and they are signed at the beginning of the period for the on-going period. Thus, prior to the realization of the period shocks but after the realization of preference shocks, individuals can sign a contract on how resources will be shared. At this stage they are not allowed to formally contract on the sharing of income for the subsequent periods.[2]

2. Second, contracts cannot be contingent to all components of the states of nature $z_t$ but only to some sets of states of nature. There is a set of events $e \in E$, where $E$ is a partition of the set of states of nature $Z$ i.e. $E$ is a set of exclusive events which are subsets of $Z$. Event $e$ is interpreted as composed of random shocks $z$ affecting the realization of some (say "agricultural") production that is verifiable. We denote $p_e$ the probability of event $e$: $p_e = \sum_{z \in e} p_z$. The formal contracts specify a reallocation of resources between agent 2 and agent 1 which can be contingent only on $e$ in the current period.

[2] This first restriction is important only in the case where there is aggregate risk in the economy otherwise spot contracts are sufficient to provide full insurance.

3. Contracts entail a real allocation of resources so that they have real effects (while voluntary transfers are monetary and involve no distortions).

A contract is represented by a vector $T = (\tau_1, ..., \tau_E)$ of net transfers received by agent 1. We assume that $T$ belongs to some compact set $\mathcal{T} = \times_e[\underline{\tau}_e, \bar{\tau}_e]$, where $\underline{\tau}_e < 0 < \bar{\tau}_e$. A contract entails a cost $\varphi_z(\tau_e)$ in state $z$. Thus the agent 2 supports a cost $\tau_e + \varphi_z(\tau_e)$ in state $z \in e$. Total resources in state $z$ are then $\omega_z = \omega_z^1 + \omega_z^2 - \varphi_z(\tau_e)$. For simplicity we assume that all contracts are feasible: $\omega_z^1 + \tau_e > 0$ and $\omega_z^2 - \tau_e - \varphi_z(\tau_e) > 0$ for all $z$ and all contracts. We also assume that the cost $\varphi_z(\tau_e)$ is continuous, quasi-convex, and reaches a minimum at some $\tau_e^0$, for instance $\tau_e^0 = 0$.

Note first that when no contract is feasible ($E = \varnothing$), we obtain the standard model of informal risk sharing as in Thomas and Worrall (1988). In the polar case when $E$ is the set of all events comprising each individual state in $Z$, our formulation yields full risk sharing.

Second, the model extends Gauthier, Poitevin and Gonzalez (1997) by allowing for random preferences and formal contracting on verifiable production. In Gauthier, Poitevin and Gonzalez (1997), only one ex-ante transfer is allowed such that it corresponds to the case where a non contingent transfer only is allowed ($E = \{Z\}$ i.e. $card(E) = 1$) and one agent is risk neutral.

## 2.3 Timing of the Game & History Dependence

The precise timing of realization of the various events within period $t$, is the following.

- At $t$ : the random preference, $\eta_t$, and intrinsic public shock, $\varepsilon_t$, are realized and observed by both agents. A contract $T_t \in \mathcal{T}$ is signed and is valid for period $t$.

- At $t + 1/2$ : the income shock, state $z_t$, is realized and observed (and thus the event $e_t$ that contains $z_t$). The contract $T_t$ is enforced. However, the parties are free to complement it by voluntary transfers. Then consumptions take place.

To fix idea, one can assume that at date $t$, agent 2 makes a take-it or leave-it offer $T_t$ to agent 1. If the agent 1 rejects the offer then no contract is signed for the ongoing period.[3] With such a timing, current preferences are known when the contract is signed. The contract $T_t$ can thus be contingent on $\eta_t$. Moreover the random component $\varepsilon_t$ allows the contract to be a stochastic function of tastes. Finally, let a superscript $(t)$ denote the history until $t$ of a variable, i.e.

[3] For the analysis, the precise bargaining game is not important. An alternative would be to assume that there is a planner who proposes the agreement.

$\eta^{(t)} = (\eta_1, ., \eta_t)$, let $H_t = \left(z^{(t-1)}, \eta^{(t)}, \varepsilon^{(t)}\right)$ be the history of the states of nature, preference and intrinsic shocks up to $t$, and let $h_t = (H_t, z_t)$ the history up to $t + 1/2$.

## 2.4 Optimal Allocations

A full description of the agents' behavior at any point in time and for any history is a full contingent plan that specifies transfers and formal contracts for each date, state of nature and history of events and transfers up to this date. An allocation is a random profile of consumptions $c_t^i$ and contracts $T_t \in \mathcal{T}$ that are measurable with respect to history: $c_t^i = c^i(h_t)$ and $T_t = T(H_t)$. Denoting $\omega_t = \omega_t^1 + \omega_t^2 - \varphi_t$ the total resources available at date $t$ where $\varphi_t$ is the real cost attached to the formal contracts *i.e.* $\varphi_t = \varphi_{z_t}(\tau_{e_t})$. The allocation is feasible if in all states,

$$c_t^1 + c_t^2 = \omega_t. \tag{1}$$

The expected utility of the agents are then

$$v^1 = E\left[\sum_{t=1}^{\infty} \rho^{t-1} \eta_t u_1\left(c_t^1\right)\right], \quad v^2 = E\left[\sum_{t=1}^{\infty} \rho^{t-1} u_2\left(c_t^2\right)\right].$$

Because of the presence of the random taste parameter, our model is not truly a repeated game. Yet, it is stationary in the sense that the sub-game starting at date $t$ is identical to the game starting at date 1 up to a re-normalization of utilities. To see that, define the expected utility at the beginning of date $t$ normalized by $\eta_t$ as:

$$v_t^1 = E\left[\sum_{r=1}^{\infty} \rho^{r-1} \frac{\eta_{t+r-1}}{\eta_t} u_1(c_{t+r-1}^1) \mid H_t\right], \quad v_t^2 = E\left[\sum_{r=1}^{\infty} \rho^{r-1} u_2(c_{t+r-1}^2) \mid H_t\right]. \tag{2}$$

Notice that

$$v_t^1 = E\left[u_1\left(c_t^1\right) + \rho \frac{\eta_{t+1}}{\eta_t} v_{t+1}^1 \mid H_t\right], \quad v_t^2 = E\left[u_2\left(c_t^2\right) + \rho v_{t+1}^2 \mid H_t\right].$$

Now consider the subgame starting at date $t$ with $\eta_t$ known and expected utilities $v_t^i$. Denote $\hat{\eta}_r^t = \frac{\eta_{t+r-1}}{\eta_t}$. Given that $\left(\frac{\hat{\eta}_{r+1}^t}{\hat{\eta}_r^t}\right)$ is i.i.d., the distribution of $\left\{\hat{\eta}_r^t\right\}_{r\geq 1}$ is the same as the distribution of $\left\{\eta_r\right\}_{r\geq 1}$. Thus the subgame starting at date $t$ is identical to the initial game. This means that the sets of equilibria of the two games coincide. In other words, using normalized utilities $v_t^i$ we can solve the game using the same tools as for a repeated game.

In particular there are minimal and maximal expected utility levels of agent $i$, denoted $\underline{v}^i$ and $\bar{v}^i$, that can be supported in equilibrium (up to the normalization). By assumption, agent 2 can commit to transfer all her/his wealth to agent 1, $\underline{v}^2 = 0$. On the contrary agent 1 cannot commit and will refuse to enter into any agreement leading to a utility level below the autarky level:

$$\underline{v}^1 \geq v_a^1 = \frac{1}{1-\rho} \sum_z p_z u_1(\omega_z^1),$$

using $E(\eta_t) = 1,\ c_t^1 = \omega_{z_t}^1$ and the i.i.d. assumption. In order to prevent agent 1 from reneging on the agreement, it is optimal to coordinate in such a way that if agent 1 deviates, the equilibrium that follows is the worst equilibrium for agent 1. In other words one should apply an optimal penal code as defined by Abreu (1988). Clearly, agent 2 should optimally commit not to contract at all with the agent 1 if this latter doesn't abide to the initial agreement. Thus the minimal utility that a deviant agent 1 can obtain from date $t$ is the autarky level $\underline{v}^1 = v_a^1$. Even if it seems to be a severe punishment, any less severe punishment would sustain a smaller set of risk sharing arrangements and might be given way to renegotiation and thus incredible threats (see Fafchamps, 1992, for arguments along these lines).

Since the game is one with symmetric information, an allocation can be supported in equilibrium provided that at any point in time agent 1 prefers to abide to the informal agreement rather than to renege and be punished by receiving his minimal equilibrium expected utility. Thus at date $t$, agent 1 should be willing to sign the contract

$$v_t^1 \geq \underline{v}^1, \tag{3}$$

where $v_t^1$ are defined in equation (2). At date $t+1/2$, the agent must prefer to make the informal transfer rather than to enforce the formal contract only and continue in autarky next period:

$$u_1(c_t^1) + \rho E\left[\frac{\eta_{t+1}}{\eta_t} v_{t+1}^1 \mid h_t\right] \geq u_1(\omega_t^1 + \tau_t) + \rho \underline{v}^1. \tag{4}$$

Following the standard approach to the problem we derive the set of Pareto optimal equilibria. For a given expected utility $v_1^2 \equiv v$ of agent 2 at date 1, let $P(v)$ denote the maximal expected utility that the agent 1 can obtain in equilibrium. Then $P(v)$ solves

$$P(v) = \max_{c_t^1, c_t^2, T_t} E\left[\sum_{t=1}^{\infty} \rho^{t-1} \eta_t u_1\left(c_t^1\right)\right]$$

s.t.

$$E\left[\sum_{t=1}^{\infty} \rho^t u_2\left(c_t^2\right)\right] \geq v,\ (1)\,,\ (3)\,,\ (4)\,.$$

The argument used by Thomas and Worrall (1988) shows that the function $P(v)$ is decreasing and continuous. The optimal contract is such that conditional on $H_t$, agent 1 should receive the maximal expected utility given that agent 2 receives at least $v_t^2$. Notice that under our assumptions on the stochastic processes of $z_t$ and $\eta_t$, the problem of maximizing $v_t^1$ conditional on $H_t$ and $v_t^2$ is the same as the problem of maximizing the ex-ante utility of agent 1 subject to giving an ex-ante utility of at least $v_t^2$ to agent 2. Thus we must have $v_t^1 = P(v_t^2)$.

Then, the standard arguments apply and the allocation of consumption is solution to the program

$$P(v) = \max_{(c_z^1, c_z^2, T, v_{z\eta\varepsilon})} E\left[u_1\left(c_z^1\right) + \rho\eta P\left(v_{z\eta\varepsilon}\right)\right]$$

s.t.

$$\begin{aligned} E\left[u_2\left(c_z^2\right) + \rho v_{z\eta\varepsilon}\right] &\geq v \\ u_1(c_z^1) + E\left[\rho\eta P(v_{z\eta\varepsilon}) \mid z\right] &\geq u_1(\omega_z^1 + \tau_e) + \rho\underline{v}^1 \ \ \forall z \\ c_z^1 + c_z^2 &= \omega_z \ \ \forall z \\ v_{z\eta\varepsilon} &\in \left[\underline{v}^2, \bar{v}^2\right] \ \ \forall z, \eta, \varepsilon \end{aligned}$$

where equation (3) is implicitly translated by the last constraint.

In this program, $v_{z\eta\varepsilon}$ is the agent 2 promised utility at date 2, conditional on the realization $z$ at date $1 + 1/2$, on the taste parameter $\eta$ at date 2 and on the random shock $\varepsilon$ at date 2. The expectation operator refers to the joint probability distribution of $z$, $\eta$ and $\varepsilon$. The optimal allocation can thus be described by consumption levels $c_z^i$ for each agent at date $1+1/2$, contract $T$ and continuation expected utility $v_{z\eta\varepsilon}^i$ at date 2 contingent on the realization of the shocks.

## 2.5 Convexity & Randomization

When there is no contract $T$, it is known (Thomas and Worrall) that the function $P$ is decreasing, concave and differentiable. However, when contracts $T$ are allowed, $P(.)$ needs not be concave although the problem is convex for a fixed contract $T$. Notice that if $P(.)$ is not concave, it is optimal for the agents to randomize between several date 2 utilities. Let us denote $v_{z\eta} = E\left[v_{z\eta\varepsilon} \mid z, \eta\right]$. Given $v_{z\eta}$, choosing $v_{z\eta\varepsilon}$ is equivalent to choosing a distribution of utility on $[\underline{v}^2, \bar{v}^2]$ that maximizes $E\left[P(v_{z\eta\varepsilon}) \mid z, \eta\right]$ subject to the agent 2 receiving $v_{z\eta}$. From Carathéodory's Theorem (see Rockafellar (1970), corollary 17.1.5), the optimum obtains with a two-point support distribution, say $\varepsilon \in \{1, 2\}$. Let the support be $\{v_{z\eta 1}, v_{z\eta 2}\}$ and write $v_{z\eta} = p v_{z\eta 1} + (1-p) v_{z\eta 2}$. Thus an optimal allocation is such that conditional on $z$ and $\eta$, the distribution of the future utility solves the program

$$\hat{P}(v_{z\eta}) = \max_{p\in[0,1], v_{z\eta 1}, v_{z\eta 2}} \left\{pP(v_{z\eta 1}) + (1-p)P(v_{z\eta 2})\right\} \ s.t. \ p v_{z\eta 1} + (1-p) v_{z\eta 2} = v_{z\eta}.$$

$\hat{P}(.)$ is the concave envelop of $P(.)$, thus a concave decreasing function. It is immediate that $P(v_{z\eta\varepsilon}) = \hat{P}(v_{z\eta\varepsilon})$ for $d = 1, 2$ at the optimal solution. Moreover

$$\hat{P}'(v_{z\eta}) = P'(v_{z\eta 1}) = P'(v_{z\eta 2}) \tag{5}$$

whenever $v_{z\eta\varepsilon} < \bar{v}^2$ (notice that $0 = \underline{v}_2 < v_{z\eta\varepsilon}$).

Consider now the choice of $v_{z\eta}$. Here again, given an expected utility $v_z = E[v_{z\eta} \mid z]$, it is optimal to choose $v_{z\eta}$ so as to maximize agent 1 utility. Define then

$$Q(v_z) = \max_{v_{z\eta} \in [\underline{v}_2, \bar{v}^2]} E\left[\eta \hat{P}(v_{z\eta}) \mid z\right] \; s.t. \; E[v_{z\eta}] \geq v_z.$$

The function $Q(.)$ is decreasing and strictly concave due to the continuity of the random effect (see Lemma 5 in appendix A).

$$Q'(v_z) = \eta \hat{P}'(v_{z\eta}) \text{ if } \frac{Q'(v_z)}{\hat{P}'(\bar{v}^2)} < \eta. \tag{6}$$

The value function $P(.)$ can then be written as the solution of:

$$P(v) = \max_{(c_z^1, c_z^2, T, v_z)} E\left[u_1\left(c_z^1\right) + \rho Q\left(v_z\right)\right] \tag{7}$$

s.t.

$$\begin{aligned} E\left[u_2\left(c_z^2\right) + \rho v_z\right] &\geq v && (8)\\ u_1\left(c_z^1\right) + \rho Q\left(v_z\right) &\geq u_1\left(\omega_z^1 + \tau_e\right) + \rho \underline{v}^1 \qquad \forall e \in E, \forall z \in e && (9)\\ c_z^1 + c_z^2 &= \omega_z \qquad \forall z && (10)\\ \underline{v}_2 &\leq v_z \leq \bar{v}^2 \qquad \forall z && (11) \end{aligned}$$

This shows that, for a fixed contract $T = \{\tau_1, ..., \tau_E\}$, the program is convex although $P(.)$ may not be concave. The argument developed in Gauthier, Poitevin and Gonzalez (1997) for the case where the contract is a fixed transfer can be used similarly in our case to show that $P(.)$ is continuously differentiable because we proved that $Q(.)$ is concave. This in turn implies that $Q(.)$ and $\hat{P}(.)$ are continuously differentiable.

Now, to describe the dynamics of the system, we don't need to describe the whole frontier $P$ but only those points that can occur in equilibrium. The set of such points is the union of the supports of the distributions $v_{z\eta\varepsilon}$ that solves $\hat{P}(.)$. From what is developed above this corresponds to the set of utility levels $v$ such that $P(v) = \hat{P}(v)$. But for these points, we can rely on duality theory despite the fact that $P(.)$ is not concave. Indeed we have $v \in \arg\max_x \left\{\hat{P}(x) - \hat{P}'(v)x\right\}$ since $\hat{P}(.)$ is concave. Using $\hat{P}(x) \geq P(x)$ and $P(v) = \hat{P}(v)$,we obtain $v \in \arg\max_x \left\{P(x) - \hat{P}'(v)x\right\}$.

Let $W$ be the set of solutions of the program

$$\Phi(\mu) = \max_{v \in [\underline{v}^2, \bar{v}^2]} P(v) + \mu v.$$

when the weight $\mu$ varies continuously between $-\hat{P}'(\underline{v}^2)$ and $-\hat{P}'(\bar{v}^2)$. Then $v_{z\eta\varepsilon} \in W$ with probability 1. It is thus sufficient to characterize the solutions at the optima of this program $\Phi(\mu)$ to derive the equilibrium. This amounts to solve

$$\begin{aligned} \Phi(\mu) &= \max_{(c_z^1, c_z^2, T, v_z)} E\left[u_1\left(c_z^1\right) + \rho Q\left(v_z\right)\right] + \mu E\left[u_2\left(c_z^2\right) + \rho v_z\right] \\ & \quad s.t\ (9)\,,\ (10)\,,\ (11)\,. \end{aligned}$$

To solve this program, notice that it is separable between events $e$. In other words

$$\Phi\left(\mu\right) = \max_{T=\{\tau_1,..,\tau_E\}} \sum_e p_e \Phi_e\left(\mu, \tau_e\right)$$

where $\Phi_e(\mu, \tau_e)$ is the solution for a fixed value of $\tau_e$ of the maximization of $E\left[u_1\left(c_z^1\right) + \rho Q\left(v_z\right) \mid e\right] + \mu E\left[u_2\left(c_z^2\right) + \rho v_z \mid e\right]$ subject to the constraints (9) to (11) for all states in event $e$. $\Phi_e\left(\mu, \tau_e\right)$ is a concave program and we show that due to the preference shock $\eta_t$, it is a strictly concave problem with a unique solution.

## 2.6 Characterization: Euler equation & Monotonicity

Working with this program we obtain the main result that will be used for estimation:

**Proposition 1** *Let's denote $\pi_z = \omega_z^1 + \tau_e$ agent 1's income in state $z$. There exists a function $\bar{\mu}\left(\omega, \pi\right)$ with values in $[-\hat{P}'(\underline{v}^2), -\hat{P}'(\bar{v}^2)]$, decreasing in $\pi$ whenever interior such that:*

$$\frac{u_1'\left(c_z^1\right)}{u_2'\left(c_z^2\right)} = -Q'\left(v_z\right) = \inf\left\{\mu, \bar{\mu}\left(\omega_z, \pi_z\right)\right\}$$

**Proof.** See Appendix A. ■

For a given formal contract $T$, this result is a generalization of Thomas and Worrall (1988) where one agent is risk neutral and no formal contract is allowed. Also, it extends the results of Gauthier, Poitevin and Gonzalez (1997) where one agent has a constant endowment and $T = \{\tau\}$ is a unidimensional unconditional transfer. The proposition thus defines the current and future ratios of marginal utilities as a function of the multiplier $\mu$ and ex-post resources (which depend on the contract $T$). Using this we can fully characterize the solution as a function of the contract $T$.

The second theoretical result is that the optimal contract $T$ is monotone in $\mu$. The problem is not concave in $T$ so that there may be multiple solutions for $T$. Multiple solutions arise when the frontier $P(v)$ is not concave or when no incentive constraint is binding in some event $e$. However intuition suggests that when $\mu$ increases, $T(\mu)$ should decrease as $v$ moves along the Pareto frontier toward higher utility for agent 2 (since $\mu$ is the slope of the frontier).

**Proposition 2** *The mapping $\bar{T}(\mu) : \mu \to \arg\max_T \sum_e p_e \Phi_e(\mu, \tau_e)$ is a monotone decreasing correspondence in $\mu$ (according to the strong order set).*

**Proof.** See Appendix A.2. ■

To summarize, as we move along the frontier $\hat{P}(v)$ toward higher absolute slopes (and thus higher $v$), the contract becomes uniformly more favorable to agent 2. Notice that the same holds true for the allocation of consumptions and future utilities $(c_z^2, v_z)$.[4]

Let us now turn to the implications of the results for the dynamics of consumption and contracts. For the estimation we assume that corner solutions never arise:

**Assumption:** $prob\{\underline{v}^2 < v_t^2 < \bar{v}^2\} = 1$.

The dynamics can be described by mean of the evolution of the weight $\mu_t = -P'(v_t^2)$ associated with the point in $W$ chosen after history $H_t$.

At this stage, agents sign a contract $T_t \in \bar{T}(\mu_t)$. At date $t + 1/2$ consumption is given as a function of $\mu_t$, the contract $T_t$ and the state of nature $z_t$ by Proposition 1. This also defines the slope $Q'(v^2(h_t))$ at this interim stage. Then at date $t+1$, $H_{t+1}$ is realized and thus $v_{t+1}^2$. This gives the new value of the weight $\mu_{t+1}$. The intertemporal link is provided by the relation $\frac{\eta_{t+1}}{\eta_t} P'(v_{t+1}^2) = \frac{\eta_{t+1}}{\eta_t} \hat{P}'(v_{t+1}^2) = Q'(v^2(h_t))$. The dynamics thus verifies

$$
\begin{aligned}
T_t &= \{\tau_{te}\}_e \in \bar{T}(\mu_t) && (12)\\
\pi_t &= \omega_t^1 + \tau_{te_t} && (13)\\
\frac{u_1'(c_t^1)}{u_2'(c_t^2)} &= \inf\{\mu_t, \bar{\mu}(\omega_t, \pi_t)\} && (14)\\
\mu_{t+1} &= \frac{\eta_t}{\eta_{t+1}} \frac{u_1'(c_t^1)}{u_2'(c_t^2)} && (15)
\end{aligned}
$$

Whenever the Pareto frontier is concave this defines exactly the whole dynamics because $\bar{T}(\mu)$ is single valued. If $P(.)$ is not concave $\bar{T}(\mu)$ can be multi-valued. Notice that it is single valued for

[4] This follows from the fact that at the solution of $\Phi_e(\mu, \tau_e)$, both $c_z^2$ and $v_z$ are non-decreasing with $\mu$ and non-increasing with $\tau_e$.

all values $\mu_t$ where $\Phi(\mu_t)$ has a unique solution. This corresponds to values where $-\hat{P}'(v_t) = \mu_t$ has a unique solution.[5] But we have shown in the proof of Proposition 1 (in Lemma 5) that this occurs with probability 1 due to the effect of the preference shock $\eta_t$. Thus in equilibrium $\bar{T}(\mu_t)$ is single valued with probability 1. We can thus ignore the issue of equilibrium randomization over utilities and contracts for estimation purpose.

## 2.7 Extensions

### 2.7.1 Additional sources of observed heterogeneity

In what preceded we assume time-invariant utility functions and a stationary resource process. Suppose now that the utility is $u_i(c^i; x_t^i)$ where $x_t^i$ follows a Markov process. Suppose also that resources depend on state $z_t$ and a state variable $q_t$ describing the information set for instance, where $q_t$ follows a Markov process. Let $x_t = (x_t^1, x_t^2)$ and suppose that $q_t$ and $x_t^i$ are revealed to the agent at the beginning of period $t$. Then the value function at date $t$ is a function $P(v; x_t, q_t)$. The interim value function is $Q(v; x_t, q_t)$ obtained by maximizing

$$E\left\{\frac{\eta_{t+1}}{\eta_t}\hat{P}(v(x_{t+1}, q_{t+1}, \frac{\eta_{t+1}}{\eta_t}); x_{t+1}, q_{t+1}) \mid x_t, q_t\right\}$$

subject to $E\left\{v(x_{t+1}, q_{t+1}, \frac{\eta_{t+1}}{\eta_t}) \mid x_t, q_t\right\} \geq v$. The value function $P(v; x_t, q_t)$ is then the solution of the maximization of

$$E\left[u_1\left(c^1(x_t, q_t, z_t); x_t\right) + \rho Q\left(v(x_t, q_t, z_t); x_t, q_t\right) \mid x_t, q_t\right]$$

subject to incentive and participation constraints. In this set-up all proofs generalize. Function $\bar{\mu}$ depends only on $\omega_t$, $\pi_t$ and $x_t, q_t$ (but not on $\eta_t$): $\bar{\mu}(\omega_t, \pi_t, x_t, q_t)$. The ratio of marginal utility $\frac{u_1'(c_t^1)}{u_2'(c_t^2)}$ has to be conditioned on $x_t^i$ only. We thus obtain

$$\frac{u_1'(c_t^1; x_t^1)}{u_2'(c_t^2; x_t^2)} = \inf\left\{\mu_t, \bar{\mu}\left(\omega_t, \pi_t, x_t, q_t\right)\right\}.$$

The contract $\bar{T}(\mu_t, x_t, q_t)$ depends on $\mu_t$ and $x_t, q_t$. But the dynamics of the multiplier $\mu_t$ is unchanged since $-\frac{\eta_{t+1}}{\eta_t}\hat{P}'(v_{t+1}; x_{t+1}, q_{t+1}) = -Q'(v(x_t, q_t, z_t); x_t, q_t) = \frac{u_1'(c_t^1; x_t^1)}{u_2'(c_t^2; x_t^2)}$ with probability 1 and $\mu_{t+1} = \hat{P}'(v_{t+1}; x_{t+1}, q_{t+1})$.

### 2.7.2 Two-sided limited commitment

Consider now that agent 2 cannot commit to the long run agreement, but only to a formal contract. Then the analysis is similar except that the informal agreement must as well satisfy at

[5] $\tau_e$ may still be undetermined if the probability that an incentive constraint binds in event $e$ is zero. But then $\mu_t < \bar{\mu}(\omega_t, \pi_t)$ with probability 1 in event $e$ so that the dynamics is unaffected.

each date an incentive compatibility condition for agent 2:

$$u_2(c_z^2) + E\left[\rho v_{z\eta\varepsilon} \mid z\right] \geq u_2(\omega_z^2 - \tau_e) + \rho \underline{v}^2 \ \ \forall z$$

This situation is analyzed in Dubois, Jullien and Magnac (2002). Since the agent cannot commit to an intertemporal utility level below the autarky level, the minimal utility $\underline{v}^2$ has to be redefined.[6] In this context a new threshold function $\underline{\mu}\left(\omega_z, \pi_z\right)$ appears. It is associated with the incentive compatibility condition of agent 2 and $\underline{\mu}\left(\omega_z, \pi_z\right) < \bar{\mu}\left(\omega_z, \pi_z\right)$. The optimal allocation then satisfies:

$$\begin{aligned}
\frac{u_1'\left(c_z^1\right)}{u_2'\left(c_z^2\right)} &= -Q'\left(v_z\right) = \bar{\mu}\left(\omega_z, \pi_z\right) \text{ if } \mu \geq \bar{\mu}\left(\omega_z, \pi_z\right) \\
\frac{u_1'\left(c_z^1\right)}{u_2'\left(c_z^2\right)} &= -Q'\left(v_z\right) = \underline{\mu}\left(\omega_z, \pi_z\right) \text{ if } \mu \leq \underline{\mu}\left(\omega_z, \pi_z\right) \\
\frac{u_1'\left(c_z^1\right)}{u_2'\left(c_z^2\right)} &= -Q'\left(v_z\right) = \mu \text{ if } \underline{\mu}\left(\omega_z, \pi_z\right) \leq \mu \leq \bar{\mu}\left(\omega_z, \pi_z\right)
\end{aligned}$$

The case $\mu \leq \underline{\mu}\left(\omega_z, \pi_z\right)$ corresponds to situations where maintaining the ratio of marginal utilities constant would require an excessively low consumption of agent 2 relative to that of agent 1, who would then renege on the agreement. Then his/her consumption is increased and the ratio of marginal utility is given by the agent 2's incentive compatibility condition and the resource constraint. Thus the analysis with bilateral limited commitment is the same except that there are two threshold levels for the ratio of marginal utilities. Moreover, we showed in Dubois, Jullien and Magnac (2002) that Proposition 2 extends to this case with bilateral limited commitment.

# 3 Model Specification

In this model, there are two main sources of stochastic shocks either through preferences or through incomes, and three endogenous variables, consumption, formal contracts and income. In contrast to usual consumption growth settings, the endogeneity of formal contracts makes non-labor income endogenous. In order to proceed with the estimation of the structural model developed in the previous section, we shall now specify more precisely the primitives that lead to estimable equations. We start with notations and then specify utility functions and income processes that lead to derive income and consumption growth equations.

[6] In this case, minimal equilibrium utility levels $\underline{v}^1, \underline{v}^2$ are endogeneous and may not coincide with the autarchy level for low discount factors. The reason is that the agent may not be able to commit not to sign a mutually advantageous short run contract.

For the sake of clarity, we shall adopt the following notations where "observable" or "non-observable" refers from now on to variables which the econometrician observes or does not observe.

Notations 3.1:

(i) Household $i$'s consumption at time $t$ is denoted $c_{it}$.

(ii) Household $i$'s income at time $t$ is denoted $\pi_{it}$. It consists of agricultural profits, net of input costs including non family labor costs, and of non-agricultural profits and other exogenous income.

(iii) Observable preference shifters (household demographics for instance) are denoted $x_{it}$. Unobserved preference shocks are denoted $\eta_{it}$. These variables are revealed to the agent at the beginning of period $t$.

(iv) Conditioning on the information set at the beginning of the period is equivalent to conditioning on the set of observable variables $(x_{it}, q_{it})$ where $x_{it}$ are preference shocks defined in (iii). Other variables $q_{it}$ help to predict future preferences and income processes. Such variables are assets, owned land, or variables that affect agricultural production and that are known when the contract is signed.

(v) Income shocks are revealed at the mid-period. Observable shocks[7] are denoted $z_{it}$ (days of illness for instance), unobservable shocks are denoted $\xi_{it}$. The set of all observables at mid-period is denoted $s_{it} = (x_{it}, q_{it}, z_{it})$.

One important issue is the adaptation of the two-agent framework to a village i.e. a multi-agent framework. We follow Ligon et al. (2002) by assuming that each household plays a two-person game with the rest of the village or with a pivot person in the village. In either case, the characteristics of the other agent are summarized by village-and period indicators. Yet, the main theoretical issue remains the unlikely aggregation of individual incentive constraints. It is a conjecture that in a sufficiently large village the quality of our approximation is correct but we leave that point for further research. We do not either model individual savings in contrast to Ligon et al. (2000). Those are assumed away while aggregate savings are implicitly modeled through village-and-period dummy variables. Finally, we refrain from using information on informal transfers as in Foster and Rosenzweig (1999) because it is difficult to draw the line between truly exogenous transfers and the informal transfers that we developed in the theoretical

[7] In the theoretical model, we should assume that $z_{it}$ and $(x_{it}, q_{it})$ are independent. If they are not, we would replace $z_{it}$ by the innovation in $z_{it}$ independent of $(x_{it}, q_{it})$.

section. Here also, we are more interested at looking at the ultimate effect of transfers on consumption than on the transfers themselves (Deaton, 1997).

In the following, consumption dynamics is studied first, the specification of the income process $\pi_{it}$ as a function of formal contracts comes in second. All specification assumptions are piled up into different items of Assumption 3.2. All parameters indexed by $vt$ control for village-and-period effects.

## 3.1 Consumption Dynamics

Following most papers in this literature (not all, see for instance Ogaki & Zhang, 2001 for HARA estimation and Dubois, 2000, for heterogenous CRRA functional forms) we assume that households have constant relative risk aversion:

Assumption 3.2(i): The ratio of marginal utility of consumption for household $i$, relatively to the marginal utility of the village, is written as

$$\eta_{it} \exp(\delta_{vt}) \exp(\sigma x_{it}\beta).c_{it}^{-\sigma} \tag{16}$$

where $\sigma > 0$ and where the log of the marginal utility of the village is captured by the village–and–period effect $\delta_{vt}$. We denote $\lambda_{it}(\beta) = \ln(c_{it}) - x_{it}\beta$.

Demographics $x_{it}$ are permitted to affect the slope of marginal utilities only. Note that we exclude leisure from this equation by assuming that it is exogenous or that it is additively separable from consumption (see Attanasio and Davis, 1996, for a discussion). We will test this assumption in the empirical section.

Equations (15) and (16), define the multiplier $\mu_{it}$ as:

$$\ln \mu_{it} = -\Delta \ln \eta_{it} - \sigma\lambda_{it-1}(\beta) + \delta_{vt-1}, \tag{17}$$

where the first difference operator $\Delta$ is such that, $\Delta \ln \eta_{it} = \ln \eta_{it} - \ln \eta_{it-1}$. Using equations (14), and (17) we get the consumption dynamics in two regimes. Whether the incentive constraint facing household $i$ is binding or not defines the regimes:

$$-\sigma\lambda_{it}(\beta) + \delta_{vt} = -\Delta \ln \eta_{it} - \sigma\lambda_{it-1}(\beta) + \delta_{vt-1}$$
$$\text{if } -\Delta \ln \eta_{it} - \sigma\lambda_{it-1}(\beta) + \delta_{vt-1} < \ln \bar{\mu}_{vt}(\pi_{it}, x_{it}, q_{it})$$

$$-\sigma\lambda_{it}(\beta) + \delta_{vt} = \ln \bar{\mu}_{vt}(\pi_{it}, x_{it}, q_{it})$$
$$\text{if } -\Delta \ln \eta_{it} - \sigma\lambda_{it-1}(\beta) + \delta_{vt-1} > \ln \bar{\mu}_{vt}(\pi_{it}, x_{it}, q_{it})$$

where the notation $\bar{\mu}_{vt}$ uses Notations 3.1 to re-write equation (14). Aggregate resources are summarized by the village-and-period index.

The functional form of the bound, $\ln \bar{\mu}_{vt}(\pi_{it}, x_{it}, q_{it})$, will be specified later on. Yet, note readily that this function is deterministic. It could implicitly be made random if $(x_{it}, q_{it})$ was allowed to include some unobserved heterogeneity components. The structure of stochastic shocks however is already sufficiently rich because of the income variable $\pi_{it}$. As we allow for measurement errors in income, the absence of unobserved heterogeneity in $(x_{it}, q_{it})$ does not seem to be such a tight assumption in this model. A more difficult issue that we do not treat here, is the presence of unobserved household effects in $x_{it}, q_{it}$. Yet, individual effects are notoriously difficult to handle in non-linear dynamic settings although some advances could be made along the lines proposed by Cunha, Heckman and Navarro (2005).

Whether the incentive constraint is binding or not, is not an observable event and the two regimes giving consumption dynamics, are therefore not observable. As a consequence, the system of equations in the two regimes above is observationally equivalent to a single equation describing the dynamics of marginal utilities that is consumption dynamics:

$$\sigma \Delta \lambda_{it}(\beta) = \Delta \delta_{vt} + \phi_{it}.\mathbf{1}\{\phi_{it} \geq 0\} + \Delta \ln \eta_{it} \tag{18}$$

where:

$$\phi_{it} = \delta_{vt-1} - \sigma \lambda_{it-1}(\beta) - \Delta \ln \eta_{it} - \ln \bar{\mu}_{vt}(\pi_{it}, x_{it}, q_{it}). \tag{19}$$

Three remarks are in order. First, an interesting particular case of this model is the case of complete markets. It amounts to assume that the incentive constraints never bind, that is $\phi_{it} < 0$:

$$\Delta \ln c_{it} = \Delta x_{it} \beta + (\Delta \delta_{vt} + \Delta \ln \eta_{it})/\sigma$$

Event, $\phi_{it} < 0$, can have probability 1 only if all variables (including those that are unobserved) in the expression of $\phi_{it}$ are bounded. It does not favor the use of a full parametric test of the hypothesis of complete markets. This consequence agrees well however with the general prediction of a model with self-enforcing constraints. Dynamics is at times consistent with the hypothesis of complete markets and at times inconsistent.

Secondly, the second term in the right hand side of equation (18) is positive when it is not equal to zero and the incentive constraint is binding. In that case, consumption growth is more than what would be expected under full insurance. It is the "rent" to pay to keep the household in the self-enforced informal arrangement when an income shock which is "too" favorable for them occurs.

Third, the right hand side of equation (18) is a function of income $\pi_{it}$ through $\phi_{it}$ and $\mu_{vt}$ while the left hand side is not. If income were exogenous, the standard test of the hypothesis of complete markets would generally consist in looking at the significance of the correlation between the residuals (under the null hypothesis) and income. This procedure is correct provided that income be excluded from preferences or, more precisely, from the marginal utility of consumption. In the model presented here, income is endogenous by construction. It is correlated with preference shocks because it depends on formal contracts that depend themselves on preference shocks. A test of complete markets should then be constructed by looking for exogenous variables that affect income and are independent of random preference shocks and therefore of formal contracts[8]. The existence of such variables can be justified by the specification of the other equation determining the income process $\pi_{it}$ that we now detail.

## 3.2 Formal Contracts and the Income Process

A formal contract is described by Proposition 2 or equation (12). The vector of formal transfers (i.e. for any state $e$) is a function specified as:

$$\begin{aligned} T &= T(\ln \mu_{it}, x_{it}, q_{it}) \\ &= T(-\Delta \ln \eta_{it} - \sigma \lambda_{it-1}(\beta) + \delta_{vt-1}, x_{it}, q_{it}). \end{aligned}$$

where $\ln \mu_{it}$ comes from equation (17). It makes clear that formal contracts depend on variables belonging to the information set $(x_{it}, q_{it})$. These formal transfers $T$ can be supported by land-leasing contracts: instruments are sharecropping contracts and sharing rules or fixed-rent contracts at a fixed price, set at the village level. We freely consider that land-leasing can be in or out. We do not consider that labor contracts can be formal contracts since permanent labor contracts are generally seldom in village economies(see Bliss and Stern, 1982).

As household income comprises agricultural profits, it is necessarily a function of the characteristics of these contracts, as well as variables pertaining to the information set $(x_{it}, q_{it})$. Household income is also a function of variables $z_{it}$ which are revealed after the signature of the contracts (see Notations 3.1) and all other shocks $\xi_{it}$, which remain unobserved to the econome-

[8] In some papers, the issue of income endogeneity is indeed treated in a reduced-form setting (Jacoby and Skoufias, 1998, Jalan and Ravallion, 1999, Kochar, 1999).

trician so that agricultural income is (using $s_{it} = (x_{it}, q_{it}, z_{it})$):

$$\pi_{it}^a = \pi^a(-\Delta \ln \eta_{it} - \sigma\lambda_{it-1}(\beta) + \delta_{vt-1}, s_{it}, \xi_{it}).$$

Depending on available data, one could presumably estimate a production function and input demands including labor in order to derive this profit function. Given the complicated endogenous structure of land exploitation, results will not be robust to specification errors on the production side. This is why we model directly the dependence of profits on the marginal utility of consumption and the information variables. We therefore do not use the structural relationships between the quantities of land under sharecropping and fixed-rent contracts and marginal utility[9].

We adopt the semiparametric assumption that agricultural profits are a linear function of its arguments:

Assumption 3.2(ii):

$$\pi_{it}^a = \pi_{vt} + \pi_0(\Delta \ln \eta_{it} + \sigma\lambda_{it-1}(\beta)) + s_{it}\pi_s + \xi_{it}$$

where the village-and-period effect, $\pi_{vt}$, absorbs parameters $\delta_{vt-1}$.

First, Proposition 2 provides the first restriction of our model that parameter $\pi_0$ is positive. Second, risks, summarized by state $e$ in the theoretical model and that are insurable against by formal contracts, are assumed to be represented by the village-and-period effects, $\pi_{vt}$ and the household random shock, $\xi_{it}$. Other risks, summarized by state $z$ in the theoretical model and that are insurable against only through informal contracts, are described by the same random shock $\xi_{it}$ and are also described and determined by variables $z_{it}$, such as days of sickness and craft income for instance. For the empirical specification to be consistent with the theoretical model, the set of states of nature corresponding to some agricultural profits should be contractible. In other words, agricultural profits should be a risk which can be partially insured against through formal contracts. Observing sharecropping contracts provides such evidence of formal insurance. Other risks can only be insured against by using informal contracts.

Household net income $\pi_{it}$ is not only composed of agricultural profits but also of non-agricultural profits or other exogenous income, $\pi_{it}^e$. The latter stands for other non-labor income or exogenous transfers such as exogenous remittances from abroad. They exclude informal transfers from the extended families studied for instance by Foster and Rosenzweig (2001) because

[9] We shall however investigate in the empirical section whether these quantities are associated with marginal utilities.

these transfers are to be interpreted as resulting from some of the endogenous informal contracts that we model here.

By adding some measurement errors, $\varsigma_{it}$, we obtain measured income:

$$\tilde{\pi}_{it} \equiv \pi_{it}^{a} + \pi_{it}^{e} + \varsigma_{it}$$

For more generality, we include $\pi_{it}^{e}$ among the variables $z_{it}$ (Notation 3.1(v)) to take into account the fact that there could be some reallocation of labor between agriculture and other activities at the mid-period. The income equation is written as:

$$\begin{aligned} \tilde{\pi}_{it} &= \pi_{vt} + \pi_0(\Delta \ln \eta_{it} + \sigma\lambda_{it-1}(\beta)) + s_{it}\pi_s + \xi_{it} + \varsigma_{it} \\ &= \pi_{vt} + \pi_0\sigma\lambda_{it-1}(\beta) + s_{it}\pi_s + \pi_0\Delta \ln \eta_{it} + \xi_{it} + \varsigma_{it}. \end{aligned} \tag{20}$$

The structural form of the model therefore consists of equations describing consumption growth (18), and income (20). The specification of the consumption growth equation will be developed further on in Section 5. Yet, our theoretical setup already yields predictions that deviate from empirical tests of perfect risk sharing. This is why it is interesting to look first at various estimates and informal tests providing tentative evidence of the relevance of our model.

# 4 Exploratory Empirical Analysis

It is fruitful to first present the data constructed from a sample of rural households in Pakistan and then explore the question of risk sharing in this sample under the light of our theoretical model. In this section we informally investigate income dynamics and how households smooth consumption over time taking into account changes in demographics, exogenous shocks (like sickness) as well as information variables (like assets of these households) that determine contracting practices.

## 4.1 A Brief Description of the Data

The data come from a survey conducted by IFPRI (International Food Policy Research Institute) in Pakistan between 1986 and 1989 (see Alderman and Garcia, 1993, for a thorough presentation). The survey consists of a stratified random sample of around 900 households interviewed 12 times and coming from four districts in three regions (Attock and Faisalabad in Punjab, Badin in the Sind, and Dir in the North West Frontier Province). In each of the four districts, villages were randomly chosen from a comprehensive list of villages classified in three sets according to their distances to two markets (mandis). In each village, households were randomly drawn from a comprehensive list of village households. Some attrition is observed in the data (927 households at the beginning, 887 only at the end) that seems to stem from administrative and political problems rather than from self-selection of households (Alderman and Garcia, 1993). We shall assume that attrition is exogenous. These rich data set contains information on household demographics, incomes from various sources, individual labor supply, endowments and owned assets, agrarian structure, crops and productions, and finally land contracts such as sharecropping and fixed rent. Sources of income are wages, agricultural profits, rents from property rights, pensions and informal transfers (from relatives or others). More details are given in Appendix B and descriptive statistics are presented in Table 1.

In our model, variables are distinguished according to their types, preferences, $x$, other variables in the information set, $q$ or unanticipated shocks $z$. First, previous investigations using the same data showed that household size is the main preference shifter (Dubois, 2000). This is the only variable $x_{it}$ that we consider because other variables such as the number of children never proved to be significant. As for variables in the information set, various empirical analyses (see Jalan and Ravallion, 1999, for instance) report evidence that contrasting rich and poor households is the main relevant differenciation when the complete markets hypothesis is evaluated. As income is endogenous in our model, the quantity of owned land seems to be a good indicator of household's productive assets and therefore a good predictor of income. The quantity of owned irrigated land that is available in the survey (or the complement, rain-fed land) should give additional information about the quality and price of productive land. These two variables are included among variables, $q_{it}$, in the information set. Finally, income is affected by exogenous income shocks or by unexpected shocks due to illness of household members, shocks that are unlikely to be contractible. In conclusion, it means that mid-period income shocks (or at least the non-predictable part of it) do not affect formal contracts but do affect informal arrangements between households.

In order to examine the characteristics of random shocks affecting households, we present in Table 2, for all variables of interest $y_{it}$, the following variance decomposition:

$$y_{it} = \delta_{vt} + \delta_i + \varepsilon_{it}$$

where $\delta_{vt}$ is computed as usual and where $\delta_i = \frac{1}{\#\{i \text{ present at } t\}} \sum_{\{t\}} [y_{it} - \delta_{vt}]$. For each variable, we present variance estimates and the share of variance explained by the decomposition into village-and-period, household and residual effects.

Agricultural income shocks are left mostly unexplained by household and village-and-period effects, another evidence of the important idiosyncratic risks affecting these rural households. It is true also for all other sources of income: asset income, wages and exogenous income.

In contrast, 52.7% of the logarithm of food expenditures in level (logs) is explained by village-and-period effects and 23.7% by household effects. The first component refers to aggregate shocks, the second to the relative economic status of the household in the village i.e. its Pareto weight. We find the same pattern when looking at expenditures corrected by household size or for total expenditures. Yet, when looking at changes of the logarithm of food expenditures, one finds a different pattern with substantial though quite imperfect risk sharing since village-time effects explain only 24.1% of these changes. It is more understandable that household effects explain only 2.2% of food expenditure changes since household's economic status (at least in the complete market world) is constant. Of course, these descriptive statistics do not correspond to the true variance decomposition of marginal utility that depends not only on food expenditures but also on preference shifters. It is also well known that first differencing magnifies measurement errors. Finally, we did the same analysis at the district level and risk sharing in expenditures seems more effective at the village level rather than at the district level. Unsurprisingly, other variables such as demographics or assets follow a still different pattern with a large household specific component. It is more surprising that male illness days have a large village-and-period variance.

## 4.2 The Income Equation and Household Private Information

Turning to the analysis of the income equation (20), a first prediction of our model concerns the impact of the formal contracting behavior of households on income. Income, which comprises agricultural profits and other exogenous income, depends on formal contracting (e.g. sharecropping) which is determined by the level of lagged marginal utility. In turn, the latter depends on lagged consumption, preferences and other variables in the information set such as the amount of land. Different specifications of this equation have been investigated. explanatory variables are lagged consumption, lagged and current values of the preference shifter that is household size, land assets ($q_{it}$), shocks revealed after the signature of formal contracts ($z_{it}$) and exogenous income, $\pi_{it}^e$. Household preference shocks $x_{it}$ are well represented by (log) household size since other demographics like the number of children or age of the household head have never come out significantly.

Provided that all relevant information is included among explanatory variables, the significance of the coefficient of lagged consumption in the income equation yields evidence that households also smooth the income process (Morduch, 1995). Yet, if all relevant information is not included, it could also mean that lagged consumption is a good indicator of information that households have over future income shocks that we, as econometricians, do not observe. Note that both effects go into the same direction. On the one hand, Proposition 2 in the theoretical model yields the testable restriction that this coefficient $\pi_0$ is positive. On the other hand the presence of household superior information about larger future income shocks makes lagged consumption larger.

In order to deal with this problem, we use the insight that was developed in the seminal paper of Campbell (1987) by using another decision variable that reveals the superior information that households have on future income shocks. This decision should be taken at the same time that contracts are signed to be on par in terms of information. Cultivated land area is such a decision or equivalently as owned land is included as explanatory variables, the household decision about net rented-in area including both sharecropping and renting land at a fixed price. We estimate the determinants of net rented-in area using the same variables as in the income equation which are known at the beginning of the period by the household. We then interpret the residuals of this equation as the missing information variable known by the household when deciding how much formal contracting to use (sharecropping and fixed rent). Introducing these residuals in our main structural equations for income and consumption dynamics will then control for the presence of household superior information.

Table 3 reports the estimation of equation (20). As shown by the estimation results, the positive correlation of income and lagged consumption is not rejected by the data. We present three sets of results in Table 3. Column 1 reports the OLS estimates which are likely to be biased by the presence of measurement errors in the right hand side variables, in particular lagged consumption. We control for measurement errors by introducing residuals of the instrumental regression of lagged consumption on a further lag of consumption and other variables. The coefficient of those residuals in column 2 is indeed significant and actually triple the estimated coefficient of lagged consumption. We also tested for the presence of measurement errors in other variables using the lag structure but were unable to reject exogeneity of those variables.

Furthermore, information controls are indeed significant in column 3 as expected if private information is important. They decrease marginally the estimated coefficient of lagged consumption which remains largely significant and positive. How these residuals are computed can be seen from Table 4 where results of the auxiliary regression of rented-in land area are reported. Before analyzing those, let us return to Table 3 first and examine the estimates of the other coefficients.

Household demographics represented by the logarithm of lagged household size should partly compensate the effect of lagged consumption and it does though insignificantly. The quantity of owned land affects as expected household income. As the effect of rainfed land compensates the former effect, irrigated land only seems to matter. Effects of household size is not significant and this is also true for days of illness for males and females which nevertheless decrease income as expected. Informal transfers can take the form of additional labor from the village that compensate for the sickness of household members since it should be less costly to intervene at that stage than afterwards. Sickness would not affect household income in that case but our variable of income would be contaminated by informal transfers that are implicitly already smoothing it. Finally, exogenous income is positive and very significant.

Table 4 reports results of the estimation of the rented-in area equation which includes variables known at the beginning of the period only. It would be tempting to interpret this equation as the equation for formal contracts but rented-in area does not seem to be the right index for the prevalence of formal contracts and for formal transfers that the household benefits. We interpret this equation as providing information on what the household knows only. The regression is very well determined and lagged consumption, which is instrumented as before to account for measurement errors, negatively affects rented-in area. Lagged household size partly attenuates this effect as expected but again this is on the margin of significance. Land assets negatively affects rented-in land as expected.

Information controls in the income equation are the residuals of this last equation. They affect negatively household income as it can be seen in Table 3 which means that in anticipation of an adverse shock in income, the household tends to rent-in more land. It favors the argument that private information is mainly related to off-farm activities and not to on-farm future productivity shocks.

As a way of testing for misspecification, we also analyzed the autocorrelation of unobservables affecting income. The estimates of residual variances with their standard errors are reported graphically in Figure 1 and forward autocorrelations up to order 4 as functions of the round are reported in Figures 2. From Figure 1, one infers that the sample period is clearly cut into two subperiods, the first one with small variances (till round 7), the second one with a lot more variance. It is known that the sample period was a quite uncertain and troubled period for agricultural activities (Alderman and Garcia, 1993), yet it seems to be true above all for the second half of the sample period. Autocorrelations are as well quite diverse. Autocorrelation of order 1 is overall significant but its evolution over time shows a loss of significance from period 5 onwards. Autocorrelations of order 2 are not significant while the most intriguing result is the autocorrelation of order 3 which for no good reason we can think of, is increasing till round 7 and decreases afterwards to become insignificant.

This overall view does not indicate the presence of strong household specific effects. We also tried to first-difference the income equation but we lost all significance. The main question that remains is whether households are aware of the structure of autocorrelation because we use econometric restrictions that they do not. More prosaically, the presence of serial correlation might also modify standard errors of the estimates of the income equation. We did try to correct for serial correlation by assuming that it is unrestricted over time but constant across individuals. It indeed modified standard errors of coefficients differently but by a maximal factor of 50% without affecting any diagnostic of significance that was used using the robust to heteroskedasticity White correction (Table 3).

## 4.3 Consumption Growth

We choose food expenditures as our consumption variable because they represent the largest part of non-durable expenditures and are relatively well measured. It is closely in line with the literature in village economies (Townsend, 1994). We also tried to use total expenditures with quite similar results. First, under perfect risk sharing, consumption dynamics is governed by preferences and aggregate shocks only as marginal utility is. In many subsequent papers to the seminal paper of Townsend (1994), perfect risk sharing is tested by introducing additional household-specific shocks, e.g. income shocks, in the regression of consumption growth on preference shifters and by testing whether income shocks affect consumption growth. The complete markets hypothesis indeed provides overidentifying restrictions that can be tested and rejected using this dataset (Dubois, 2000).

Our model is more precise and predicts that departures from perfect risk sharing should be a function of the determinants of agricultural income as described in equation (19) and in particular a function of lagged marginal utility because formal contracts depend on these variables. Consumption growth is affected by lagged marginal utility, variables in the information set and unanticipated exogenous shocks like days of illness and not only by preference shifters.

Before estimating the non-linear structural equation in Section 6, one can first look at a linear approximation of the consumption growth equation. Second, we can also look at regressions of consumption growth on non-linear functions of lagged consumption, $\ln c_{it-1}$. Table 5 presents the results of such regressions. In column (1), OLS estimates are reported. As in the income equation, explanatory variables are lagged consumption, lagged and current values of the preference shifter that is household size, land assets ($q_{it}$), shocks revealed after the signature of formal contracts ($z_{it}$) and exogenous income, $\pi^e_{it}$. In columns (2) and (3), we used two stage least squares instrumenting $\ln c_{it-1}$ by $\ln c_{it-2}$ in order to take into account some possible measurement error in consumption. Measurement errors indeed affect both the dependent variable and lagged consumption and might explain the negative coefficient of lagged consumption. This coefficient indeed becomes much smaller in absolute value in column (2) with respect to column (1) yet it remains negative and significant. Not surprisingly, we strongly reject the exogeneity of $\ln c_{it-1}$ and column (1) is thus not valid. In column (3), consumption growth, $\Delta \ln c_{it}$, is assumed to be a non-linear function of $\ln c_{it-1}$. Non-linearity is modeled as a three-piecewise linear spline function but results are the same when five or more break points are used. It seems indeed that the effect of lagged consumption is non linear as it remains significantly negative in the central part of the distribution only. We did not add information controls in this section as we will show in Section 6 that it marginally affects results.

As for preference shifters, $x_{it}$ or $x_{it-1}$, we do not reject their exogeneity. The coefficients of lagged and current household size are roughly the same but opposite in sign. It would conform with the prediction that consumption growth is caused by the growth in household size and not by their levels. Estimated coefficients of asset levels are not significant and neither are exogenous shocks except days of illness for women.

In conclusion, the estimates exhibit a significant lagged consumption effect, another piece of evidence to add against perfect risk sharing in these villages. Yet, Table 5 reports results which can be very far from the results of the true structural consumption growth equation. Consumption growth in general is not an additive function of the variables in the RHS and results in Table 5 should be viewed with caution. The estimation of the structural form requires the estimation of a semi-parametric model that we now study with more detail.

# 5 The Structural Econometric Model

We now continue to specify the structure so as to derive the structural form of the consumption growth equation. We also state more rigorously identifying restrictions on stochastic shocks and specify the bound function appearing in equation (19). We then derive the estimable reduced form of the model, establish that structural parameters are identified and present the estimation method.

## 5.1 Identifying Restrictions and Reduced Forms

Notations 3.1 and equations (18) and (20) lead to the following list of covariates, $w_{it} = (\ln c_{it-1}$, $x_{it-1}$, $x_{it}$, $q_{it}$, $z_{it})$ respectively standing for lagged consumption, lagged and current preference shifters, information variables and exogenous shocks. Identifying restrictions on heterogeneity terms, measurement errors and predetermined variables are stated as:

**Assumption 3.2 (ct'd):** (iii) The vector of household heterogeneity terms describing preference and income shocks $(\Delta \ln \eta_{it}, \xi_{it})$ is independent of covariates $w_{it}$ and of measurement errors, $\varsigma_{it}$, and is identically distributed and independent across households and periods. It has an absolutely continuous distribution and its support is a compact set of $\mathbb{R}^2$.

(iv) Measurement error $\varsigma_{it}$ is mean-independent of covariates, $w_{it}$, and is independent across households and periods.

(v) Variables in $w_{it} = (\ln c_{it-1}, x_{it-1}, x_{it}, q_{it}, z_{it})$ have a compact support in $\mathbb{R}^r$. If $w_{vt} = E(w_{it} \mid v, t)$ denotes their expectations within a village-and-period, there is full within-variation of the covariates i.e.:

$$rank\left(E\left[(w_{it} - w_{vt})(w_{it} - w_{vt})'\right]\right) = r$$

The independence Assumption 3.2(iii) is slightly stronger than the ones generally used in linear dynamic models. It is a very usual assumption in non-linear dynamic models. Non-linearities, due here to the presence of a bound, require more than mean-independence assumptions. We could relax them somehow to get identification of some subsets of parameters but we did not thoroughly investigated this point. We also used the assumption of compact support in order to fit the econometric model into the setting of Ai and Chen (2003) where asymptotic properties can be rigorously proven. Assumption 3.2(iv) is weaker as it takes advantage of linearity. Both Assumptions 3.2 (iii&iv) make the covariate process $w_{it}$ weakly exogenous. Assumption 3.2 (v) implies that the distribution function of predetermined variables $w_{it}$ is not degenerate. It is not innocuous because variables, $q_{it}$, in the information set could include $x_{it}$ and $x_{it-1}$ only which would lead to a violation of this assumption. We thus need more than preference shifters to achieve identification and the presence of one asset variable, or any variable affecting the income process independently of preferences, at least is required . It provides exogenous variability that income cannot provide in our framework since it is endogenous.

To complete the specification of consumption dynamics, we now specify the bound $\phi_{it}$ appearing in equation (19). As the income process $\pi_{it}$ described in Assumption 3.1(ii) depends on marginal utility, $\Delta \ln \eta_{it} + \sigma\lambda_{it-1}(\beta) - \delta_{vt-1}$, on the index, $\pi_{vt} + s_{it}\pi_s + \xi_{it}$, and on other covariates $(x_{it}, q_{it})$, and village-and-period effects, the unobserved variable $\phi_{it}$ defined in equation (19) can be written as a function of the following arguments:

$$\begin{aligned}\phi_{it} &= \phi(\mu_{it}, \pi_{vt} + s_{it}\pi_s, x_{it}, q_{it}, \phi_{vt}) \\ &= \phi(\Delta \ln \eta_{it} + \sigma\lambda_{it-1}(\beta) - \delta_{vt-1}, \pi_{vt} + s_{it}\pi_s + \xi_{it}, x_{it}, q_{it}, \phi_{vt}),\end{aligned}$$

Using equation (19) and Proposition 1, $\phi_{it}$ is decreasing in its first argument and increasing in $\pi$, its second argument.[10] Thus, using Assumption 3.2 (iv&v), we can evaluate the expectation of the term in the RHS of equation (18) :

$$\begin{aligned}E(\phi_{it}\mathbf{1}\{\phi_{it} &\geq 0\} \mid \ln c_{it-1}, x_{it-1}, x_{it}, q_{it}, z_{it}) \equiv \\ &\qquad H(\sigma\lambda_{it-1}(\beta) - \delta_{vt-1}, \pi_{vt} + s_{it}\pi_s, x_{it}, q_{it}, \phi_{vt}),\end{aligned}$$

where $H$ is an unknown positive function derived from the joint distribution function of $(\Delta \ln \eta_{it}, \xi_{it})$. This function is decreasing in its first argument and increasing in its second argument.

Note first that as $s_{it} = (x_{it}, q_{it}, z_{it})$ the derivatives of $H$ with respect to its second, third and fourth arguments are not identified separately. The direct effect of variables $(x_{it}, q_{it})$ on the incentive constraint and the indirect effect through income cannot be separated except if one has access to a variable that affects punishment and therefore the incentive constraint. By the same token, the knowledge of coefficients $\pi_{vt}$ and $\pi_x, \pi_q$ that can be derived from the income equation does not imply any restriction in the consumption growth equation. Yet, variables $z_{it}$ appear only in the profit index and thus a restriction of our setting is that their effects in the consumption growth and in the income equation should be proportional. If there is more than

[10] **This result is not as straightforward as it seems because the multiplier appears directly in $\phi$ and indirectly through $\pi$. The intuition of the result though is that the ratio of marginal utilities tomorrow is necessarily an increasing function of the ratio of marginal utilities today by the strict concavity of $Q(.)$ (Lemma 5).**

one $z$ variable,

$$\frac{\partial H}{\partial z_{it}^{(j)}} / \frac{\partial H}{\partial z_{it}^{(1)}} = \pi_{z^{(j)}} / \pi_{z^{(1)}} \text{ for any } j > 1. \tag{21}$$

Returning to the specification of $\phi_{it}$, we did not follow the full non parametric route and chose to specify this function as a linear index:

Assumption 3.2 (ct'd): (vi) Departures from perfect risk sharing can be written as:

$$E(\phi_{it}\mathbf{1}\{\phi_{it} \geq 0\} \mid \ln c_{it-1}, x_{it-1}, x_{it}, q_{it}, z_{it}) = H(\lambda_{it-1}(\beta) + s_{it}\phi_s + \phi_{vt})$$

where $H(.)$ is an unknown positive and decreasing function

Note that parameter $\sigma$ has been absorbed in $H_0$. It is fair to note that a sufficient condition for such an assumption is the log linearity of the bound function $\bar{\mu}_{vt}(\pi_{it}, x_{it}, q_{it})$ in all its arguments. In that case, we also have that:

**Lemma 3** *If* $\ln \bar{\mu}_{vt}(\pi_{it}, x_{it}, q_{it})$ *is linear in all its arguments then* $H(.)$ *is decreasing and convex.*

**Proof.** As $\phi_{it}$ is linear in all its arguments, it can be written as $\phi_{it} = \phi_{it}^0 + \varepsilon_{it}^0$ where $\phi_{it}^0$ is proportional to the deterministic index. Using Assumption 3.2(iii) and some algebra, $E(\phi_{it}1\{\phi_{it} \geq 0\} \mid \phi_{it}^0)$ is increasing and convex in $\phi_{it}^0$ and because $\phi_{it}^0$ is a decreasing function of $\lambda_{it-1}(\beta)$, the conclusion follows. ■

Note also from this proof that:

$$\frac{\partial H}{\partial \ln c_{it}} = \frac{\partial H}{\partial \phi_{it}^0}\frac{\partial \phi_{it}^0}{\partial \ln c_{it}} = -\Pr(\phi_{it} > 0).\sigma \tag{22}$$

which makes the slope of function $H$ an estimator of the probability that an incentive constraint binds up to the unknown value of the relative risk aversion $\sigma$. The reduced form of the consumption equation (18) can finally be written as the moment condition:

$$E(\Delta\lambda_{it}(\beta) - \Delta\delta_{vt} \mid \ln c_{it-1}, x_{it-1}, x_{it}, q_{it}, z_{it}) = H(\lambda_{it-1}(\beta) + s_{it}\phi_s + \phi_{vt}). \tag{23}$$

Moreover, using equation (20) and orthogonality conditions (A2(iii)), the reduced form of the income process is given by the moment condition:

$$E(\tilde{\pi}_{it} \mid \ln c_{it-1}, x_{it-1}, x_{it}, q_{it}, z_{it}) = \pi_{vt} + \pi_0\sigma\lambda_{it-1}(\beta) + s_{it}\pi_s \tag{24}$$

The system of equations (23) and (24) defines the econometric model. We allow for correlation between these equations. This correlation is not informative about the parameters of interest appearing in these moment conditions. It depends on the joint distribution of random shocks which is unrestricted. Yet, this correlation is informative about the correct specification of the model. If there is a significant correlation across equations, it would be the sign that we are missing some important variables. Anticipating over the results, this is not the case.

### 5.2 Semi-Parametric Identification

We first investigate identification of the parameters of interest. The model depends on the following population parameters:

$$\theta = (\beta, \sigma, \pi_0, \pi_s, \phi_s) \in \Theta, \;\; \varrho = (\{\delta_{vt}, \pi_{vt}, \phi_{vt}\}_{vt}) \in \Xi$$

where $\theta$ is the parameter of interest and $\varrho$, summarizing village-and-period effects or "aggregate shocks", is treated as a nuisance parameter. The model also depends on the functional parameter $H(.) \in H$.

The identification analysis proceeds as follows. First, the parameters of the reduced form of the income equation (24), $\pi_{vt}$, $\pi_0\sigma$, $-\beta\pi_0\sigma$, $\pi_s$ are identified because of Assumption 3.2(v). As $\pi_0\sigma$ and $-\beta\pi_0\sigma$ are identified, $\beta$ is also identified. Identification of these parameters is the only information that one can get from the income equation.

Turning to the consumption equation, it is easy to show that $\sigma > 0$ is not identified. The transformation from the vector of parameters ($\sigma$, $\pi_0$, $\Delta\delta_{vt}$, $H(.)$) into (1, $\pi_0/\sigma$, $\Delta\delta_{vt}/\sigma$, $H(.)/\sigma$) (holding other parameters constant) and the random shocks $\Delta \ln \eta_{it}$ into $\Delta \ln \eta_{it}/\sigma$ is invariant for the two equations of interest. We shall therefore normalize $\sigma = 1$ without loss of generality and change the interpretation of other parameters accordingly. It is not a surprise since the relative risk aversion or intertemporal substitution parameter is not identified in an Euler equation when the interest rate is unknown.

Second, as the parameter of interest, $\beta$, is identified from the profit function, we can redefine the dependent variable in the consumption equation (18) as $\lambda_{it}(\beta) = \ln c_{it} - x_{it}\beta$. Using equation (23),

$$E(\Delta\lambda_{it}(\beta) \mid \lambda_{it-1}(\beta), s_{it}) = \Delta\delta_{vt} + H(\lambda_{it-1}(\beta) + s_{it}\phi_s + \phi_{vt}).$$

It is an index model and its identification is given for instance by assumptions stated in Ichimura & Lee (1991). We adapt these assumptions to our special case as $H$ is a positive and decreasing function (and convex if we impose additional structure, see above Lemma 3) and as all regressors are bounded.

The main problem we have to face is that constant terms in index models are identified at infinity only (Heckman, 1990). To see this, let us rewrite the equation of interest using simplified notations:

$$E(\Delta\lambda \mid \lambda_{-1}, s) = a_{0vt} + H(\lambda_{-1} + s\phi_s + a_{1vt}) \tag{25}$$

As function $H$ is positive, decreasing and convex and as its argument $u = \lambda_{-1} + s\phi_s + a_{1vt}$ is bounded, this moment condition is invariant to all transformations of $(a_{0vt}, a_{1vt}, H(u))$ into $(a_{0vt} + \varepsilon_0, a_{1vt} + \varepsilon_1, -\varepsilon_0 + H(u - \varepsilon_1))$ where $(\varepsilon_0, \varepsilon_1)$ are any pair of scalars such that $\varepsilon_0 < \inf H(u - \varepsilon_1)$. There are two consequences at the village-and-period level. First, $(\Delta\delta_{vt}, \phi_{vt}, H)$ is not identified. Second, we can adopt a normalization $(a_{0vt}, a_{1vt}, H_0)$ for the true $(\Delta\delta_{vt}, \phi_{vt}, H)$. It fixes the coordinates of the point at the origin so as to derive $a_{0vt}$ and $a_{1vt}$. We start by reasoning at the village-and-period level and we return to the general case at the end of this subsection.

Assumption 3.2 (ct'd):

(vii) At the true parameter value, the support of $\lambda_{-1} + s\phi_s + a_{1vt}$ is a bounded interval of $R$ denoted $S_I$. The distribution of the index $\lambda_{-1} + s\phi_s + a_{1vt}$ is such that:

$$Median(\lambda_{-1} + s\phi_s + a_{1vt}) = 0$$

(viii) $H_0$ is the set of bounded, decreasing and convex functions taking values on a compact set including $S_I$ and such that $H_0(0) = 0$.

Recall that by Assumption 3.2(v), the variable $\lambda_{-1}$ is absolutely continuous and $(\lambda_{-1}, s)$ are bounded so that $\lambda_{-1} + s\phi_s + a_{1vt}$ is a bounded index which distribution is continuous. For simplicity, Assumption 3.2 (vii) avoids supports that are unconnected though the generalization is straightforward. An assumption about a quantile such as the median is made here because the problem is non linear. Both assumptions imply that 0 is an interior point of $S_I$. Assumption 3.2 (viii) then posits that, at that value 0, $H_0$ takes value 0. As a result, function $H_0$ is not positive but as it is bounded, a positive function $H(.)$ can be easily derived from $H_0$ as shown below. We first state the identification result where it is implicit that the argument runs at the village-and-period level.

**Proposition 4** *Under Assumption 3.2 (i-viii), $(\theta_0, H_0)$ is identified, the latter on $S_I$.*

**Proof.** Because function $H$ is bounded, decreasing and convex, and takes values in a compact set, it has bounded derivatives up to the second order. As the index is continuous on $S_I$ and as

$H_0$ is decreasing, $E(\Delta\lambda \mid \lambda_{-1}, s)$ necessarily continuously decreases from $c_H$ to $c_L$ (say) where $c_L < 0 < c_H$ because 0 is an interior point of $S_I$.

Conversely, for any $c \in [c_L, c_H]$, the set $S_0 = \{(\lambda_{-1}, s)$ such that $E(\Delta\lambda \mid \lambda_{-1}, s) = c\}$ is defined and equal to a linear manifold $\lambda_{-1}+s\phi_s = b$. Therefore $\phi_s$ is identified. By normalization 3.2(vii), $a_{1vt} = -Median(\lambda_{-1}+s\phi_s)$. Denote $S_0$ the set of values of $(\lambda_{-1}, s)$, such that $\lambda_{-1}+s\phi_s+a_{1vt} = 0$. Then, $a_{0vt} = E(\Delta\lambda \mid (\lambda_{-1}, s) \in S_0)$ is identified. For any value $b = (\lambda_{-1} + s\phi_s + a_{1vt})$ in support $S_I$, we can then construct function $H_0$ as the function of $b$ such as:

$$H_0(b) = E(\Delta\lambda \mid \lambda_{-1} + s\phi_s + a_{1vt} = b) - a_{0vt}$$

and $H_0$ is identified in $S_I$. ■

The degree of underidentification of $H$ can now be stated. Given $(a_{0vt}, a_{1vt}, H_0)$ and for any pair of scalars $(\varepsilon_0, \varepsilon_1)$, such that $\varepsilon_0 \geq 0$, $(a_{0vt} - \varepsilon_0, a_{1vt} + \varepsilon_1, H_0(u - \varepsilon_1) - \inf_{u \in S_I} H_0(u) + \varepsilon_0)$ is a solution to the moment condition (25).

Additional identifying power could come from village-and-period effects in the original problem and that we assumed away until now. Such results on identification are not robust however, if Assumption 3.2 (vi) is relaxed so that function $H()$ depends on village-and-period effects. We can then rephrase Assumption 3.2 (vii-viii) as applying to any village-and-period.

## 5.3 Estimation using Penalized Splines

The moment condition (23) explaining consumption growth can be written as a partially linear function:

$$E(\Delta\lambda_{it}(\beta) \mid \lambda_{it-1}(\beta), s_{it}, v, t) = \Delta\delta_{vt} + H_0(\lambda_{it-1}(\beta) + s_{it}\phi_s + \phi_{vt})$$

where $\Delta\lambda_{it}(\beta)$ is consumption growth adjusted for household size, $s_{it}$, household characteristics, $\lambda_{it-1}(\beta)$ is lagged log-consumption adjusted for household size which is a continuously distributed variable. Because parameter $\phi_{vt}$ is identified thanks to the normalization written as Assumption A2 (vii) only, variables $\lambda_{it-1}(\beta)$ and $s_{it}$ can be centered without loss of generality with respect to their village-and-period medians so that Assumption A2 (vii) implies that $\phi_{vt} = 0$. Deriving $\Delta\delta_{vt}$ is more intricate since it depends on the estimate of $\phi_s$ and $H(.)$.

We follow the method of estimation proposed by Yu and Ruppert (2002), using penalized spline regression. Letting $u = \lambda_{it-1}(\beta) + s_{it}\phi_s$, we choose function $H_0(.)$ in the following set:

$$H_0(u; \gamma) = \gamma_1 u + ... + \gamma_p u^p + \sum_{k=1}^{K-1} \gamma_{p+k} S_p(u - \kappa_k)$$

where

$$S_p(u-\kappa_k) = \begin{cases} (u-\kappa_k)^p \mathbf{1}\{u > \kappa_k\} \text{ for } k > p/2 \\ (\kappa_k - u)^p \mathbf{1}\{u < \kappa_k\} \text{ for } k \leq p/2 \end{cases}$$

where $1\{A\}$ is the indicator function of $A$. By construction $H_0(0) = 0$.

Parameters to estimate are $(\beta, \phi_s, \{\Delta\delta_{vt}\}, \gamma)$ where $\{\Delta\delta_{vt}\}$ is the collection of village-and-period effects and where $\gamma$ are the parameters of the spline. The number of knots $K-1$ is considered as fixed (see Ruppert, 2002, for a procedure of selection) and the locations of the knots $\kappa_k$ are supposed to be given by the $1/K$-quantiles of $u$. What makes the problem continuous instead of discrete is the penalization that we impose on coefficient $\gamma$.

The method of estimation consists in finding the global minimum of:

$$Q(\beta, \phi_s, \{\delta_{vt}\}, \gamma) = \sum_{i,t} (\Delta\lambda_{it}(\beta) - \Delta\delta_{vt} - H_0(\lambda_{it-1}(\beta) + s_{it}\phi_s; \gamma))^2 + \nu.\gamma' G\gamma$$

where $\nu$ is a penalty weight. We chose to penalize equally the elements $\gamma_{p+1}$ to $\gamma_{p+K-1}$ writing:

$$\gamma' G\gamma = \sum_{k=1}^{K-1} \gamma_{p+k}^2$$

Other details of the estimation procedure are presented in Appendix C.

# 6 Results

We shall now examine the empirical relevance of the testable restrictions implied by our model and Assumption 3.2 (i-viii) that we summarize:

$C1$ : $\pi_0 \geq 0$ (monotonicity of the contract from proposition 2)

$C2$ : The coefficients of $x_{it-1}$ in the income equation, and in both the linear and the non-linear index of the consumption growth equation, are all equal to $\beta$.

$C3^a$ : $H$ is decreasing. $C3^b$ : $H$ is convex.

In Table 6, we report the estimates of the consumption growth equation. The number of knots is small and equal to 8 and the penalization parameter is optimally chosen for the specification corresponding to column 4 by Generalized Cross Validation (see below for an evaluation). In this Table, various assumptions are made on the exogeneity of lagged consumption and on the correlation between the income and consumption equations. In the first column, lagged (log-)consumption is supposed to be exogenous. As shown in the previous empirical section, this assumption is rejected in the linearized case. We follow a control function approach in non-linear models (see Blundell and Powell, 2003) and we introduce, as an explanatory variable, the residual of the regression of lagged consumption on its second lag and all other variables.

Comparing results in the first and second columns, exogeneity of consumption is rejected very strongly indeed. The Student statistic associated with the coefficient of the residual of lagged consumption is very large in the consumption equation (column 2). We then estimate the system of income and consumption growth equations by allowing for some correlation between equations and results are reported in the third column. Correlation between equations is insignificant in magnitude (0.001) and statistically (the likelihood ratio contrasting columns 2 and 3 is equal to 0.4 and has one degree of freedom). It shows that even if residual shocks in income could affect bounds and thus the non linear index, their influence is small relative to measurement errors in both equations and preference shocks in consumption dynamics. We do not report the estimates of the income equation because they are very similar to what is reported in Table 3. Finally, in column 4 we introduce the residual of the net rented-in area equation (Table 4) as a control for superior information. It is very significant (the likelihood ratio statistic is around 60 and has two degrees of freedom) though it does not affect the estimation of the other coefficients.

We now consider testing the structure (C1-C3). First, in Table 3, the coefficient of lagged consumption in the income equation is positive at a 1% level and restriction (C1) is thus accepted. Second, the hypothesis that the coefficients of preference variables in the consumption and income equations are equal (C2) cannot be rejected. The likelihood ratio statistic is equal to 1.4 in column 4. It presumably has two degrees of freedom although we should account for the fact that we were unable to estimate precisely separately the coefficients of lagged household size in the linear and non linear indices because function $H()$ is too close to a linear function (see below). Even if the statistic has one degree of freedom only, we cannot reject restriction (C2) at any reasonable level of confidence. Finally, Figures 3 and 4 report estimates of function $H(.)$ in two cases, first with some undersmoothing, second with optimal smoothing. Although it should not be taken as a formal test (see Ruppert, Caroll and Wand, 2003), it is decreasing and almost linear, therefore the shape is not in contradiction with hypothesis (C3).

Overall, we consider that results of Table 6, Column 4 are the most complete results. We analyze them starting with parameters in the linear index of the equation of consumption dynamics. As expected, household size has a positive and significant effect on the marginal utility of consumption in a way that is comparable to what was obtained in a more usual setting (Dubois, 2000). The negative and very significant coefficient of the residual of lagged consumption denotes the presence of large measurement errors in consumption.

It is more difficult to analyze the effects of variables in the non-linear index of function $H(.)$ in the consumption growth equation. Remember that the larger this index is, the smaller is the probability that the incentive constraint not to renege the informal contract, binds. Positive coefficients indicate that we are moving away from the constraint. It is only the case for variables such as male days of illness but the effect is insignificant for information controls that we have seen to be correlated negatively to income (Table 3). It is negative for household size, land assets, female days of illness and exogenous income. Intuitively, we should expect that beneficial income shocks should increase the probability that the incentive constraint binds. Overall, theory does not completely comfort these insights because there could be compensating effects due to information transmitting these effects through the contracting behavior of the household. It is what happens however for all variables except for female days of illness which is an intriguing result.

Finally, the slope of $H(.)$ is related to the probability that an incentive constraint is binding. Recall from equation (22) that it is the product of this probability times the risk aversion parameter $\sigma$. Thus, as an informal guess, if we fix the risk aversion to 1 following Attanasio and Ríos-Rull (2003) the probability that a constraint binds is equal to the rough estimate of the slope which is roughly equal to 0.15. Such a risk aversion might be more reasonable in developed countries. Yet, doubling the risk aversion parameter to 2 yields a probability that a constraint binds equal to 7.5%.

## 6.1 Evaluation of the Estimation Method

We now analyze the robustness of the results with respect to variations in the penalization parameter, the number of knots and the order of the spline. We only report results relative to the consumption equation since the income equation is not affected by these variations as correlation between equations is virtually equal to zero.

In Table 7, we make the penalization parameter vary between one tenth of its optimal value and ten times its optimal value. There is no noticeable differences between the values of the estimated coefficients across columns. Yet, there are large differences in the estimated standard errors for some coefficients. It can vary by a very large factor for female illness for instance, nevertheless in a column (Optimal/2) which seems an outlier in this table. This point shall be investigated further on. Nevertheless, there is no clear pattern emerging from these results and the only thing we can say is that the asymptotic approximation of the variance-covariance matrix seems to be sensitive to the choice of these parameters. As we tested restrictions above by using likelihood ratio statistics, those tests are more robust than Wald tests would be. In Table 8, we do the same kind of experiment by varying the number of knots and in Table 9, the order of the splines. In all cases, the central results of this paper remain the same though standard errors seem affected by those auxiliary parameters. We also report in Figures 5 and 6, the estimates of function $H()$ when the order of the spline varies. As expected, it is much smoother using quadratic and cubic splines even though the estimation of a linear spline does not contradict our main empirical conclusions.

## 6.2 Evaluation of Economic & Econometric Assumptions

We first split the sample into two periods conforming with the scheme of residual variances in income that were described in Figure 1. Results are very stable across sub-samples although standard errors are again quite affected and increase a lot. Results are reported in Table 10. Many variables that were significant in the complete sample now lose their significance. Overall there are no contradiction between these results and our central points. In Table 11, we tested the separability of consumption and leisure by regressing the residuals of the consumption growth equation on male and female labor supply variables. None are significant and we do not reject separability.

We also computed the residual variances of the consumption growth equation along with their autocorrelations. They are reported in Figures 7 and 8. In contrast to income residuals, there is no clear time pattern for consumption residual variance with two peaks at rounds 6 and 9. They might be attributed to measurement errors since the length of the period is somehow variable across rounds even though we considered weekly income and consumptions. The pattern of autocorrelations is more surprising since they vary at order 1 between -0.2 and 0.05, at order 2 between -0.17 and 0, at order 3 between 0 and 0.10 and at order 4 between 0.05 and 0.15. In the case where the function $H(.)$ is linear, we develop in the appendix a model with i.i.d. preference shocks and classic measurement errors that we can calibrate using the slope of function $H(.)$, using the coefficient of the residual of lagged consumption in the consumption growth equation and its residual variance. We obtain that the first and second order autocorrelation coefficients are negative while the higher order are positive. Namely, their calibrated values are respectively

-0.04, -0.11, 0.06 and 0.045. They are thus broadly in line with what can be seen in Figures 8 and thus do not invalidate the econometric overidentifying restrictions that we made that is: i.i.d. preference shocks and classic measurement errors. The calibration also shows that the magnitude of preference shocks and measurement errors are roughly equal in the residuals of consumption growth. We left for further research the precise estimation of a model where measurement errors are allowed to have time varying variances as can be guessed from Figure 7.

Finally, we also estimated auxiliary regressions of cross-products of income and consumption growth residuals within a village on the difference of explanatory variables such as land assets or household size. They are reported in Table 12. Interestingly this correlation is always a negative function of the difference in characteristics between households. Furthermore, while land assets have a strong influence on the correlation between residual income, they lose their strength in the consumption growth equation. This is not the case for the difference in household size. This is thus tempting to interpret these results as risk sharing between households with different asset levels but none across households with different demographic shifters as we would expect.

# 7 Conclusion

In conclusion, we can underline the importance of the structural modelling of alternative assumptions about risk sharing mechanisms. Since, the complete markets hypothesis is generally rejected, the modelling of risk sharing and contracting mechanisms is now necessary to better understand the household behavior in an environment of incomplete markets. Here, we have elaborated a theoretical setting which nests the case of complete markets when all risks can be insured by formal contracts (because all states of nature would be verifiable) and the case where only informal agreements are available. This theoretical model provides two important structural equations of interest, an Euler-type equation of consumption dynamics and the equation of determination of the formal contract governing the income dynamics. We show that the model is semi-parametrically identified and estimate it. Estimating both equations using data of village economies in Pakistan, we found consistent results with the theoretical model developed. In particular, structural restrictions are satisfied and the empirical results show that formal contracts pay a role in risk sharing in this economy but do not provide full insurance.

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# A Proofs in Section 2

## A.1 Proof of Proposition 1

First we show that the problem is strictly concave because of the preference shock.

**Lemma 5** *$Q(.)$ is strictly concave.*

**Proof.** First notice that $\hat{P}(0) = P(0) = \frac{1}{1-\rho}\sum_z p_z u_1(\omega_z^1 + \omega_z^2 - \varphi_z(\tau_e^0))$ and no incentive constraint is binding. Given that $u_2'(0) = +\infty$, we immediately obtain $\hat{P}'(\underline{v}^2) = \hat{P}'(0) = 0 > \hat{P}'(\bar{v}^2)$. Consider the set $B \subset \left[\hat{P}'(\bar{v}_2), \hat{P}'(\underline{v}_2)\right]$ of slopes $b$ such that $b = -\hat{P}'(v)$ occurs for more than one value $v$. The solution of $Q(v)$ is a continuous function $v_\eta$ of $\eta$ with

$$\begin{aligned} \eta\hat{P}'(v_\eta) &= Q'(v) \text{ if } \underline{v}^2 < v_\eta < \bar{v}^2, \\ v_\eta &= \bar{v}^2 \text{ if } \eta \leq \frac{Q'(v)}{\hat{P}'(\bar{v}^2)}. \end{aligned}$$

This defines completely $v_\eta$ as a function of $Q'(v)$ except at those points where $\frac{Q'(v)}{\eta} \in B$. But $prob\{\frac{Q'(v)}{\eta} \in B\} = 0$ because $B$ is a countable set and $\eta$ is a continuous random variable. Consider now $v' > v$ with a solution $v_\eta'$. It is impossible that $Q'(v') = Q'(v)$ because this would imply $v_\eta' = v_\eta$ with probability one and thus contradicts $E\left\{v_\eta'\right\} = v' > v$. Thus $Q'(.)$ must be decreasing. ■

The program for given $\mu > 0$ and $T$, in the event $e$, is then:

$$\Phi_e(\mu, \tau_e) = \max_{(c_z^1, c_z^2, v_z)} E\left[u_1\left(c_z^1\right) + \rho Q\left(v_z\right) \mid e\right] + \mu E\left[u_2\left(c_z^2\right) + \rho v_z \mid e\right]$$

s.t.

$$\left(\frac{p_z}{p_e}\lambda_z^1\right) \qquad u_1\left(c_z^1\right) + \rho Q\left(v_z\right) \geq u_1\left(\pi_z\right) + \rho\underline{v}^1 \qquad \forall z \in e \tag{26}$$

$$\left(\frac{p_z}{p_e}\psi_z\right) \qquad c_z^1 + c_z^2 \leq \omega_z \qquad \forall z \in e \tag{27}$$

$$\left(\frac{p_z}{p_e}\rho\bar{\gamma}_z\right) \qquad v_z \leq \bar{v}^2 \tag{28}$$

$$\left(\frac{p_z}{p_e}\rho\underline{\gamma}_z\right) \qquad \underline{v}^2 \leq v_z \tag{29}$$

The terms in brackets are Lagrange multipliers. The Lagrangian of the program is:

$$\sum_{z\in e}\frac{p_z}{p_e}\left\{u_1\left(c_z^1\right) + \rho Q\left(v_z\right) + \mu\left[u_2\left(c_z^2\right) + \rho v_z\right] + \lambda_z^1\left[u_1\left(c_z^1\right) + \rho Q\left(v_z\right)\right] - \psi_z\left[c_z^1 + c_z^2\right] + (\underline{\gamma}_z - \bar{\gamma}_z)\rho v_z\right\}$$

As the program is strictly concave, the first order conditions of this program are necessary and sufficient for optimality. After elimination of $\psi_z$, $\underline{\gamma}_z$, $\bar{\gamma}_z$, they reduce to:

$$
\begin{aligned}
\frac{u_1'\left(c_z^1\right)}{u_2'\left(c_z^2\right)} &= \frac{\mu}{1+\lambda_z^1} \\
-Q'\left(v_z\right) &= \frac{\mu}{1+\lambda_z^1} \text{ if } v_z < \bar{v}^2 \\
-Q'\left(\bar{v}^2\right) &\leq \frac{\mu}{1+\lambda_z^1} \text{ if } v_z = \bar{v}^2 \\
v_z &> 0 \\
\psi_z &= \mu u_2'(c_z^2) = u_1'\left(c_z^1\right)\left(1+\lambda_z^1\right)
\end{aligned}
$$

along with complementary slackness conditions.

Let $\phi(.)$ be the inverse function of $-Q'(.)$ (which is increasing). Notice that $\underline{v}^2 = \phi(\underline{v}^2)$, $\bar{v}^2 = \phi(\bar{v}^2)$, and $\underline{v}^2 < \phi(\mu) < \bar{v}^2$ if $-\hat{P}'(\underline{v}^2) < \mu < -\hat{P}'(\bar{v}^2)$. Define $\psi^i(\omega,\mu)$ as the solution of

$$
\begin{aligned}
\frac{u_1'\left(\psi^1\right)}{u_2'\left(\psi^2\right)} &= \mu, \\
\psi^1+\psi^2 &= \omega.
\end{aligned}
$$

The solution coincide with $c_z^i = \psi^i(\omega_z,\mu)$ and $v_z = \phi(\mu)$ in all states where the incentive constraint is not binding:

$$
u_1\left(\psi^1\left(\omega_z,\mu\right)\right) + \rho Q(\phi(\mu)) \geq u_1\left(\pi_z\right) + \rho \underline{v}_1. \tag{30}
$$

The LHS of the condition decreases with $\mu$. Define $\bar{\mu}\left(\omega,\pi\right)$ as the solution of $u_1\left(\psi^1\left(\omega,\bar{\mu}\right)\right) + \rho Q(\phi(\bar{\mu})) \geq u_1\left(\pi\right) + \rho\underline{v}_1$. Then $\bar{\mu}(\omega,\pi)$ decreases with $\pi$, and the incentive constraint is not binding whenever $\mu \leq \bar{\mu}\left(\omega_z,\pi_z\right)$.

Now suppose that $\mu \geq \bar{\mu}\left(\omega_z,\omega_z^1+\tau_e\right)$. Then $\frac{u_1'\left(c_z^1\right)}{u_2'(c_z^2)} = -Q'(v_z) = \bar{\mu}\left(\omega_z,\pi_z\right) = \frac{\mu}{1+\lambda_z^1}$ verifies the first order conditions and thus is the solution.

## A.2 Proof of Proposition 2

First notice that we can restrict attention to the subset $\tau_e \leq \tau_e^0$ where $\frac{\partial\varphi_z}{\partial\tau_e} \leq 0$. Given the separability in $\tau_e$, we optimize events by events. The result follows from Milgrom and Shannon (1994), Theorem 4. Given the separability in $\tau_e$, $\Phi_e(\mu,\tau_e)$ is quasi-supermodular in $T$. The following lemma shows that it also verifies the single crossing condition in $(T;\mu)$.

**Lemma 6** *For a.e. $\tau_e$ such that $\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e} \leq 0$, $\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e}$ is decreasing with $\mu$.*

**Proof.** >From the envelop theorem,

$$
\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e} = -E\left\{\psi_z\frac{\partial\varphi_z}{\partial\tau_e} + \lambda_z^1 u_1'\left(\omega_z^1+\tau_e\right) \mid e\right\}.
$$

Denote by $\psi_z(\mu)$ the solution of

$$\begin{aligned}\psi_z &= u_1'\left(c_z^1\right) = \mu u_2'(c_z) \\ \omega_z &= c_z^1 + c_z^2\end{aligned}$$

When $\mu > \bar{\mu}$, then $\lambda_z^1 = \frac{\mu}{\bar{\mu}(\omega_z,\pi_z)} - 1$ and $\psi_z = \frac{\mu}{\bar{\mu}}\psi_z(\bar{\mu})$.
When $\mu < \bar{\mu}$,then $\lambda_z^1 = 0$ and $\psi_z = \psi_z(\mu)$.
The condition $\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e} = 0$ writes as

$$\begin{aligned}\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e} &= \\ -E\left\{\psi_z(\mu)\frac{\partial\varphi_z}{\partial\tau_e} \mid \mu < \bar{\mu}, e\right\} prob(\mu &< \bar{\mu} \mid e) \\ -E\left\{\frac{\mu}{\bar{\mu}}\psi_z(\bar{\mu})\frac{\partial\varphi_z}{\partial\tau_e} + \left(\frac{\mu}{\bar{\mu}} - 1\right) u_1'\left(\omega_z^1 + \tau_e\right) \mid \mu > \bar{\mu}, e\right\} prob(\mu &> \bar{\mu} \mid e)\end{aligned}$$

Remark: if $\mu = \bar{\mu}$ with some probability we will have to distinguish the right and left derivative in $\tau_e$.

$$\begin{aligned}\mu\frac{\partial}{\partial\mu}\left(\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e}\right) &= \\ -E\left\{\mu\psi_z'(\mu)\frac{\partial\varphi_z}{\partial\tau_e} \mid \mu < \bar{\mu}, e\right\} prob(\mu &< \bar{\mu} \mid e) \\ -E\left\{\frac{\mu}{\bar{\mu}}\psi_z(\bar{\mu})\frac{\partial\varphi_z}{\partial\tau_e} + \frac{\mu}{\bar{\mu}} u_1'\left(\omega_z^1 + \tau_e\right) \mid \mu > \bar{\mu}, e\right\} prob(\mu &> \bar{\mu} \mid e)\end{aligned}$$

$$\begin{aligned}\mu\frac{\partial}{\partial\mu}\left(\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e}\right) &= \\ \frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e} + E\left\{\left(\psi_z(\mu) - \mu\psi_z'(\mu)\right)\frac{\partial\varphi_z}{\partial\tau_e} \mid \mu < \bar{\mu}, e\right\} prob(\mu &< \bar{\mu} \mid e) \\ -E\left\{u_1'\left(\omega_z^1 + \tau_e\right) \mid \mu > \bar{\mu}, e\right\} prob(\mu &> \bar{\mu} \mid e)\end{aligned}$$

But

$$\psi_z(\mu) - \mu\psi_z'(\mu) = \mu u_2'\left(1 - \frac{u_1''}{u_1'' + \mu u_2''}\right) > 0$$

We thus have

$$\mu\frac{\partial}{\partial\mu}\left(\frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e}\right) < \frac{\partial\Phi_e(\mu,\tau_e)}{\partial\tau_e}.$$

■

Now assume that the correspondance $\arg\max_\tau \Phi_e(\mu,\tau_e)$ is interior to the set $T$, then the correspondance is increasing since the cross derivative is negative at any optimal $\tau_e$.

# B Data Appendix

The data provided by IFPRI consist of a sample of 927 households (in first round) interviewed 12 times between 1986 and 1989. We constructed some of the variables of interest from different data files that were available. Moreover, the 12 rounds of survey are in fact unequally spaced between July 1986 and September 1989, with time intervals varying between a minimum of 2 months and a maximum of 5 months, and survey questionnaires do not use always the same period of reference. We thus harmonized the period of reference to the week for all variables related to questions about consumption of income.

In the survey, household demographics are directly available. Household food consumption is initially reported by food item, in quantity and value, or quantity and price. It comprises meals at home including home-produced goods, and meals taken outside for all household members except meals that were the result of invitation or rewards in kind as the information on those items was not available. The non durable non food expenditures correspond mainly to heating expenditures. Other expenditures are travel expenditures, education, entertainment (very few), health, hygiene, clothes and tobacco, electricity and gas which were missing in the sample for several periods. We classified all these expenditures among durable goods.

Household agricultural income consists of cash income from staples, milk products, animal poultry and livestock production, net of total input expenditures including non-family wage costs, feeding costs of productive animals, fertilizers and pesticides. Other sources of income can also be easily recovered such as household's handicraft income. Allocating these different sources of income in the various theoretical constructs entails assumptions. We consider that household agricultural profits is included in income as well as asset income and non agricultural labor income as exogenous income. Household wage income in off-farm agricultural tasks are considered as one of the support of informal transfers. Asset income is constructed using property rents, fixed pensions regularly received from the government and rentals of different productive assets. Transfers correspond to transfers received from relatives, friends and from solidarity funds of local mosques (zakat).

At last, we also cleaned the data by removing observations where some of the key variables (consumption, household size, land ownership, agricultural income) were missing or presented very extreme values implying a sample size reduction from the initial sample of household of 10%.

# C The Application of Penalized Spline Estimation

We adopt the same notations than in the text.

## C.1 Concentration

The function to minimize is:

$$Q(\beta, \phi_s, \{\delta_{vt}\}, \gamma) = \sum_{i,t} (\Delta\lambda_{it}(\beta) - \Delta\delta_{vt} - H_0(\lambda_{it-1}(\beta) + s_{it}\phi_s; \gamma))^2 + \nu.\gamma' G\gamma$$

We concentrate function $Q(.)$ with respect to $\{\Delta\delta_{vt}\}$ and $\gamma$. We first set-up the spline basis.

Let the index:

$$u_{it} = \lambda_{it-1}(\beta) + s_{it}\phi_s$$

and any power of the index till $k = p$ to:

$$u_{it}^{(k)} = (u_{it})^k$$

For any $k = p+1, ., p+K-1$, if $K$ is the number of knots placed at the $K-$quantiles $\kappa_k$:

$$u_{it}^{(k)} = (u_{it}^{(p)} - \kappa_k^{(p)})(1\{u_{it} > \kappa_k, k > p/2\} - 1\{u_{it} < \kappa_k, k \leq p/2\})$$

Denote $\upsilon_{it} = (u_{it}^{(1)}, ., u_{it}^{(K+p)})$. Then minimizing $Q$ holding $\phi_s$ constant consists in minimizing:

$$\sum_{i,t}(\Delta\lambda_{it} - \Delta\delta_{vt} - \upsilon_{it}\gamma)^2 + \nu.\gamma' G\gamma$$

where $G$ is a diagonal matrix whose first $p-$elements are equal to zero while the $K-1$-last elements are equal to one. Parameter $\nu$ is a penalty. Substract cluster (village and periods) averages to $\upsilon_{it}$ to get $\upsilon_{it}^* = \upsilon_{it} - \upsilon_{vt}$. Then the criterion is equal to:

$$\sum_{i,t}(\Delta\lambda_{it} - \Delta\lambda_{vt} - \upsilon_{it}^*\gamma)^2 + \sum_{i,t}(\lambda_{vt} - \Delta\delta_{vt} - \upsilon_{vt}\gamma)^2 + \nu.\gamma' G\gamma$$

Concentration w.r.t. $\Delta\delta_{vt}$ yields:

$$\hat{\Delta\delta}_{vt} = \Delta\lambda_{vt} - \upsilon_{vt}\gamma$$

and the minimization becomes:

$$(\Delta\Lambda - U\gamma)' W(\Lambda - U\gamma) + \nu\gamma' G\gamma$$

where $\Delta\Lambda$ is the vector of elements $\Delta\lambda_{it}$ and $W$ is the usual within projection matrix. Note also that function $H_0$ is now replaced by the matrix $U$ whose elements are $\upsilon_{it}$. Minimization yields:

$$\hat{\gamma} = (U'WU + \nu G)^{-1}U'W(\Delta\Lambda)$$

and therefore:

$$Q^*(\beta, \phi_s) = (\Delta\Lambda)'(\Delta\Lambda) - (\Delta\Lambda)' WU(U'WU + \nu G)^{-1}U'U(\Delta\Lambda)$$

where $U$ only is an implicit function of $\phi_s$.

## C.2 Selecting Smoothing Parameters

As in Yu and Ruppert (2002), generalized cross validation is the residual sum of squares divided by the degrees of freedom of the fit:

$$GCV(\nu) = \frac{n^{-1}Q^*(\hat{\beta}, \hat{\phi}_s)}{(1 - n^{-1}\text{Tr}(A(\nu))^2}$$

where $\hat{\beta}, \hat{\phi}_s$ are the NLS estimates and $A(\nu)$ is the smoothing or hat matrix such that:

$$\hat{\Delta\Lambda} = A(\nu)\Delta\Lambda$$

Write the predictor:

$$\hat{\Delta\Lambda} = U(\hat{\beta}, \hat{\phi}_s)\hat{\gamma} + D\hat{\delta}$$

where $D\hat{\delta}$ is the average within each cluster. It is equal to $B(\Delta\Lambda - U\hat{\delta})$ where $B$ is the between projection matrix. We get:

$$\hat{\Delta\Lambda} = WU(\hat{\beta}, \hat{\phi}_s)\hat{\gamma} + B\Delta\Lambda$$

Replacing by the expression of $\hat{\gamma} = (U'WU + \nu G)^{-1}U'W\Delta\Lambda$, we get:

$$\hat{\Delta\Lambda} = (WU(U'WU + \nu G)^{-1}U'W + B)\Delta\Lambda = A(\nu)\Delta\Lambda$$

Thus:

$$\mathrm{Tr}(A(\nu)) = \mathrm{Tr}(B) + \mathrm{Tr}((U'WU + \nu G)^{-1}U'WU)$$

There is an interesting accelerating procedure based on the decomposition of this hat matrix into its Demmler-Reinsch basis (Cummins and Nychka, 1996, Ruppert, 2002). Let $\Gamma^{-1}$ be the Choleski factor of $U'WU$ (i.e. $\Gamma^{-1}(\Gamma^{-1})' = U'WU$). Let $M$ an orthogonal matrix and $C$, a diagonal matrix, be the results of the diagonalization of $\Gamma G\Gamma' = MCM'$. Then:

$$\begin{aligned}
U'WU + \nu G &= \Gamma^{-1}(\Gamma^{-1})' + \nu G \\
&= \Gamma^{-1}(I + \nu\Gamma G\Gamma')(\Gamma^{-1})' \\
&= \Gamma^{-1}(I + \nu MCM')(\Gamma^{-1})' \\
&= \Gamma^{-1}M(I + \nu C)M'(\Gamma^{-1})'
\end{aligned}$$

since $MM' = I$. Then:

$$(U'WU + \nu G)^{-1} = \Gamma' M(I + \nu C)^{-1}M'\Gamma$$

where we have used that $M' = M^{-1}$. Thus:

$$\begin{aligned}
\mathrm{Tr}((U'WU + \nu G)^{-1}U'WU) &= \mathrm{Tr}(\Gamma' M(I + \nu C)^{-1}M'(\Gamma^{-1})') \\
&= \mathrm{Tr}((I + \nu C)^{-1}) \\
&= \sum_i \frac{1}{1 + \nu c_i}
\end{aligned}$$

which can be computed very quickly for any $\nu$.

Also, as:

$$(U'WU + \nu G)\hat{\gamma} = U'W\Delta\Lambda$$

we have:

$$\Gamma^{-1}M(I + \nu C)(\Gamma^{-1}M)'\hat{\gamma} = U'W\Delta\Lambda$$

and thus:

$$(I + \nu C)(\Gamma^{-1}M)'\hat{\gamma} = (M'\Gamma)(U'W\Delta\Lambda)$$

Therefore:

$$\hat{\gamma} = (\Gamma' M)(I + \nu C)^{-1}(M'\Gamma)(U'W\Delta\Lambda)$$

where $I + \nu C$ is a simple diagonal matrix and which is the only object which depends on $\nu$.

Finally, we could also impose other constraints on $H_0(u; \gamma)$ such as concavity or convexity, yet this is more demanding. When $p = 1$, a strict application of the constraint would require that the collection of $\gamma_k$ for $k \geq 2$ is positive though the minimization program becomes non linear in $\gamma$. Another route that we could investigate is to try to penalize vectors of $\gamma$ which are "far" from totally positive vectors. For instance, let $e$ the constant vector and let $G_0$ a symmetric semi-definite positive matrix such that $G_0 e = 0$. For instance, $G_0$ is the matrix with 1s on the diagonal and $-1/K$ off-diagonal. As:

$$(\gamma_p - e)' G_0 (\gamma_p - e) = \gamma_p' G_0 \gamma_p$$

a distance such as $\nu\gamma_p'(I + \nu_0 G_0)\gamma_p$ represents the matrix for penalization for convexity and jumps in the first derivative. In that case however, the previous method using Demmler and Reinsch basis becomes untractable. The algorithm takes a lot more time.

## C.3 Algorithm

It is written as a non linear least square estimation. Initial values for $\beta$ are obtained using the income equation, initial values for $\phi_s$ are obtained by regressing $\Delta\lambda_{it}(\hat{\beta})$ on $\lambda_{it-1}(\hat{\beta}) + s\phi_s$. When $\nu$ is fixed, minimization is a standard non-linear least squares problem. When $\nu$ is data driven, we follow the following approach:

Step 1: Construct $U(\beta, \phi_s)$ compute $\Gamma$, $M$, $C$ and $U'W\Delta\Lambda$ and keep $C, M'\Gamma$ and $U'W\Delta\Lambda$.

Step 2: For any $\nu$ over a grid, compute $\mathrm{Tr}(A(\nu))$ and GCV.

Step 3: Minimize $\nu$ and compute the non linear least squares criterion as a function of $\beta$ and $\phi_s$.

## C.4 Other Regularity Parameters

When estimating this model, it has proved useful for the stability of the algorithm to smooth the computation of the $1/K$-quantiles. Instead of inverting the empirical distribution function, we invert:

$$F_n^{(h)}(x) = \frac{1}{n}\sum_{i=1}^{n} K\left(\frac{(\lambda_{it-1} + s_{it}\hat{\phi}_s) - x}{h\hat{\sigma}_r}\right)$$

where $K$ is a distribution function (here the normal df) and $\hat{\sigma}_r$ is the standard error of $(\lambda_{it-1} + s_{it}\hat{\phi}_s)$. The algorithm is much more stable.

## C.5 Asymptotic Variance-Covariance Matrix

We use the Yu and Ruppert (2002) sandwich formula. Let $\theta = (\beta, \phi_s, \gamma, \Delta\delta_{vt})$ the parameters to be estimated and let:

$$\Psi_{it}(\theta;\nu) = \frac{1}{2}\frac{\partial}{\partial\theta}\left[(\Delta\lambda_{it} - \Delta\delta_{vt} - H_0(\lambda_{it-1} + s_{it}\phi_s;\gamma))^2 + \nu\gamma' G\gamma\right]$$

Under i.i.d. conditions, $\theta(\nu)$ solves the moment condition for any $\nu$,:

$$E(\Psi_{it}(\theta(\nu);\nu)) = 0$$

and $\hat{\theta}(\nu)$ is consistent for $\theta(\nu)$. The sandwich formula yields the asymptotic distribution:

$$\sqrt{n}(\hat{\theta}(\nu) - \theta(\nu)) \underset{n\to\infty}{\rightsquigarrow} N(0, J^{-1}IJ^{-1})$$

where:

$$\begin{aligned} J &= E(\frac{\partial}{\partial\theta'}\Psi_{it}(\theta;\nu)) \\ I &= E(\Psi_{it}(\theta;\nu).\Psi_{it}(\theta;\nu)') \end{aligned}$$

# D Autocorrelation of Consumption Growth Residuals

Assume that:

$$\Delta y^*_{it} = \alpha y^*_{it-1} + \Delta\eta_{it}$$

where $\Delta\eta_{it}$ is an innovation orthogonal to the past, $\eta_{it-1}$.

Variables are measured with error:

$$y_{it} = y^*_{it} + \varepsilon_{it}$$

where $\varepsilon_{it}$ is some noise independent across time and of any true signals, $y^*$ and $\eta$. Replacing we get:

$$\Delta y_{it} = \alpha y_{it-1} - \alpha\varepsilon_{it-1} + \Delta\varepsilon_{it} + \Delta\eta_{it}$$

As usual, this equation should be instrumented as $y_{it-1}$ and $\varepsilon_{it-1}$ are correlated. The second lag $y_{it-2}$ is an obvious candidate since the structural equation leads to:

$$y^*_{it-1} = (1+\alpha)y^*_{it-2} + \Delta\eta_{it-1}$$

thus:

$$y_{it-1} = (1+\alpha)y_{it-2} - (1+\alpha)\varepsilon_{it-2} + \varepsilon_{it-1} + \Delta\eta_{it-1}.$$

The OLS regression will deliver a consistent estimate of (everything has mean zero):

$$\frac{E(y_{it-1}y_{it-2})}{Vy_{it-2}} = (1+\alpha)(1 - \frac{V\varepsilon_{it-2}}{Vy_{it-2}})$$

and thus the OLS residual will deliver a consistent estimate of:

$$u_{it} = (1+\alpha)\frac{V\varepsilon_{it-2}}{Vy_{it-2}}y_{it-2} - (1+\alpha)\varepsilon_{it-2} + \varepsilon_{it-1} + \Delta\eta_{it-1}$$

which can be written as the sum of independent terms:

$$u_{it} = \lambda y^*_{it-2} - (1+\alpha-\lambda)\varepsilon_{it-2} + \varepsilon_{it-1} + \Delta\eta_{it-1}$$

where $\lambda = (1+\alpha)\frac{V\varepsilon_{it-2}}{Vy_{it-2}} < (1+\alpha)$.

If we now introduce this residual into the estimated equation we get:

$$\begin{aligned}
\Delta y_{it} &= \alpha y_{it-1} + \rho u_{it} + (-\alpha\varepsilon_{it-1} + \Delta\varepsilon_{it} + \Delta\eta_{it} - \rho u_{it}) \\
&= \alpha y_{it-1} + \rho u_{it} + v_{it}.
\end{aligned}$$

where $\rho$ is the coefficient of the linear regression of $-\alpha\varepsilon_{it-1} + \Delta\varepsilon_{it} + \Delta\eta_{it}$ on $u_{it}$ :

$$\begin{aligned}
\rho &= \frac{Cov(-\alpha\varepsilon_{it-1} + \Delta\varepsilon_{it} + \Delta\eta_{it}, u_{it})}{Vu_{it}} \\
&= \frac{-(1+\alpha)V\varepsilon_{it-1}}{\lambda^2 Vy^*_{it-2} + (1+\alpha-\lambda)^2 V\varepsilon_{it-2} + V\varepsilon_{it-1} + V\Delta\eta_{it}}.
\end{aligned}$$

Thus:

$$v_{it} = \varepsilon_{it} + (1-\rho)\Delta\eta_{it} - (1+\alpha+\rho)\varepsilon_{it-1} - \rho(\lambda y^*_{it-2} - (1+\alpha-\lambda)\varepsilon_{it-2})$$

It thus gives rise to a MA(2) structure in $\varepsilon_{it}$ and an infinite lag structure through $y^*_{it-2}$.

## Table 1: Descriptive statistics[11]

| Descriptive statistics (all periods, 8053 observations) | | |
|---|---|---|
| Variable | Average | Std. Err. |
| Food consumption | 176.29 | 103.21 |
| Other non durable expenditures (heating, ..) | 43.66 | 188.98 |
| Total owned land area (acres) | 9.42 | 21.81 |
| Land owner (0:landless, 1:owner) | 0.60 | 0.48 |
| Total Land Owned in Village (acres) | 6.66 | 13.2 |
| Irrigated land (acres) | 3.32 | 8.94 |
| Non irrigated land (acres) | 1.79 | 4.76 |
| Household size | 7.73 | 2.73 |
| Number of children ($\leq$15years) | 4.56 | 2.21 |
| Number of days of illness per week (male) | 0.52 | 1.75 |
| Number of days of illness per week (female) | 0.25 | 0.90 |
| Pensions | 18.76 | 199 |
| Agricultural profits | -169.0 | 656.7 |
| Transfers | 87.03 | 408.2 |
| Exogenous income | 154.1 | 628.3 |
| Total income (without transfers) | 151.19 | 840.7 |
| Sharecropping dummy variable (renting in) | 0.35 | 0.47 |
| Fixed rent dummy variable (renting in) | 0.08 | 0.26 |
| Total area under sharecropping (renting in), (acres) | 2.65 | 4.96 |
| Total area under fixed rent (renting in), (acres) | 0.47 | 3.39 |
| Total area under sharecropping (renting out), (acres) | 2.55 | 9.84 |
| Total area under fixed rent (renting out), (acres) | 0.35 | 3.80 |

[11] All income and expenditure variables are in Rupees per week.

## Table 2: Variance decomposition: village and period effects[12]

| Variance Decomposition (unit of $y_{it}$ if not 1) | Total $var(y_{it})$ | Time $var(\delta_t)$ | Village $var(\delta_v)$ | Village $\times$Time $var(\delta_{vt})$ | Household $var(\delta_i)$ | Resid. $var(\varepsilon_{it})$ |
|---|---|---|---|---|---|---|
| Total Income (/100) | 706892 | 6731 | 24814 | 57365 | 163165 | 443159 |
| Explained share | | | | 14.8% | 23.1% | 62.7% |
| Ag. profit (/10000) | 0.431 | 0.019 | 0.0167 | 0.041 | 0.0951 | 0.243 |
| Explained share | | | | **22.7%** | **22.1%** | **56.3%** |
| Wage (/10) | 232929 | 360 | 2423 | 12303 | 30637 | 184610 |
| Explained share | | | | 7.6% | 13.2% | 79.3% |
| Property rents (/10) | 124233 | 201 | 4364 | 5323 | 44369 | 69003 |
| Explained share | | | | 9.05% | 35.7% | 55.5% |
| Exog. income (/1000) | 0.395 | 0.00046 | 0.0123 | 0.0197 | 0.108 | 0.253 |
| Explained share | | | | 9.11% | 27.4% | 64.1% |
| Food expend.: $\ln c_{it}$ | | | | | | |
| Explained share | 0.34 | 0.018 | 0.0136 | 0.011 | 0.0747 | 0.086 |
| Food expend. | | | | **53.8%** | **22%** | **25.3%** |
| changes: $\Delta \ln c_{it}$ | 0.234 | 0.0161 | 0.000593 | 0.0227 | 0.0103 | 0.171 |
| Explained share | | | | **24.3%** | **4.4%** | **73.2%** |
| Food expenditures per person | 0.33 | 0.0162 | 0.0135 | 0.0111 | 0.0878 | 0.0885 |
| Explained share | | | | 48% | 26.6% | 26.8% |
| Total expenditures | 0.466 | 0.00986 | 0.0146 | 0.0211 | 0.0833 | 0.135 |
| Explained share | | | | 54% | 17.9% | 29% |
| Other expenditures | 1.6 | 0.265 | 0.0517 | 0.0894 | 0.32 | 0.724 |
| Explained share | | | | 36.4% | 20% | 45.3% |
| log-Household size | 0.149 | 0.000119 | 0.0135 | 0.00133 | 0.114 | 0.0108 |
| Explained share | | | | 17.3% | 76.4% | 7.26% |
| Land owned (acres/10) | 1.75 | 0.000107 | 0.381 | 0.0133 | 1.23 | 0.0745 |
| Explained share | | | | 25.9% | 70.6% | 4.26% |
| Rainfed land (acres/10) | 0.227 | 0.0000722 | 0.0181 | 0.00174 | 0.154 | 0.0113 |
| Explained share | | | | 27.8% | 67.7% | 4.98% |
| Female illness days | 0.795 | 0.0587 | 0.00944 | 0.0513 | 0.0893 | 0.529 |
| Explained share | | | | 23% | 11.2% | 66.5% |
| Male illness days | 3.09 | 0.414 | 0.0409 | 0.194 | 0.265 | 1.16 |
| Explained share | | | | 57.3% | 8.58% | 37.7% |

[12] **8053 observations. See text for the definition of the variance decomposition. Note that the percentage of village-time effects represents the percentage of total village and time effects that is of** $var(\delta_t) + var(\delta_v) + var(\delta_{vt})$ over the total variance.

**Table 3: Income Equation**[13]

| Dependent variable: $\tilde{\pi}_{it}$ | (OLS) | (2SLS) | (2SLS) |
|---|---|---|---|
| $\pi_0$ | | | |
| | 0.060 | 0.194 | 0.177 |
| | (0.017) | (0.060) | (0.062) |
| $-\pi_0\beta$ | | | |
| lagged (log) household size | -0.014 | 0.032 | 0.035 |
| | (0.072) | (0.079) | (0.079) |
| $\pi_q$ | | | |
| total land in village | 0.137 | 0.149 | 0.150 |
| | (0.015) | (0.016) | (0.016) |
| rainfed land in village | -0.164 | -0.195 | -0.193 |
| | (0.029) | (0.031) | (0.031) |
| $\pi_x$ | | | |
| (log) household size | -0.044 | -0.129 | -0.125 |
| | (0.073) | (0.079) | (0.080) |
| $\pi_z$ | | | |
| female illness days | -0.011 | -0.004 | -0.005 |
| | (0.010) | (0.011) | (0.011) |
| male illness days | -0.004 | -0.008 | -0.008 |
| | (0.006) | (0.005) | (0.005) |
| exogenous income shocks | 0.158 | 0.159 | 0.157 |
| | (0.035) | (0.038) | (0.036) |
| Consumption Residuals | | -0.135 | -0.116 |
| (for $\ln c_{t-1}$ equation in lags) | | (0.064) | (0.065) |
| Information controls | | | -0.005 |
| (from rented-in land equation) | | | (0.002) |
| R-squared | 0.30 | | |
| Observations | 8053 | 7133 | 7133 |

[13] Robust standard errors in parentheses. All village-time effects not shown.

**Table 4 : Rented-in land area**[14]

| | OLS | 2SLS |
|---|---|---|
| Net rented-in area | (1) | (2) |
| $\ln c_{t-1}$ | -1.807 | -5.323 |
| | (0.275) | (0.851) |
| $q_{it}$ : land owned | | |
| total land in village | -5.192 | -5.054 |
| | (0.237) | (0.249) |
| rainfed land in village | -5.152 | -4.875 |
| | (0.785) | (0.837) |
| $x_{it}$: (log) household size | 1.318 | 1.915 |
| | (1.241) | (1.340) |
| $x_{it-1}$: lag (log) household size | 1.735 | 2.523 |
| | (1.256) | (1.327) |
| Constant | 5.815 | 19.666 |
| | (1.598) | (3.754) |
| Observations | 8053 | 7133 |
| R-squared | 0.53 | |

[14] Robust standard errors in parentheses. All village-and-period effects (46 villages, 11 rounds) not shown. In the case of 2SLS estimates, $\ln c_{it-1}$ is instrumented by $\ln c_{it-2}$ and all other variables.

**Table 5: Determinants of Consumption Growth**[15]

| | OLS | 2SLS | Control Function |
|---|---|---|---|
| Dependent variable: $\Delta \ln c_{it}$ | (1) | (2) | (3) |
| $\ln c_{it-1}$ | -0.478 | -0.164 | |
| | (0.027) | (0.040) | |
| Continuous spline function on $\ln c_{it-1}$ | | | |
| $1^{st}$ tercile | | | -0.060 |
| | | | (0.087) |
| $2^{nd}$ tercile | | | -0.356 |
| | | | (0.150) |
| $3^{rd}$ tercile | | | -0.114 |
| | | | (0.117) |
| $x_{it-1}$: lag (log) household size | -0.028 | -0.215 | -0.210 |
| | (0.055) | (0.054) | (0.054) |
| $x_{it}$: (log) household size | 0.323 | 0.283 | 0.279 |
| | (0.056) | (0.053) | (0.053) |
| $q_{it}$ : land owned | | | |
| total land in village | 0.016 | 0.005 | 0.004 |
| | (0.005) | (0.006) | (0.007) |
| rainfed land in village | 0.007 | 0.005 | 0.007 |
| | (0.012) | (0.014) | (0.014) |
| $z_{it}$ | | | |
| female illness days | 0.018 | 0.019 | 0.020 |
| | (0.006) | (0.006) | (0.006) |
| male illness days | -0.002 | 0.002 | 0.003 |
| | (0.004) | (0.005) | (0.005) |
| exogenous income shocks | 0.013 | 0.003 | 0.005 |
| | (0.008) | (0.008) | (0.008) |
| Observations | 8053 | 7133 | 7133 |
| R-squared | 0.44 | | |

[15] Robust standard errors in parentheses. All village-and-period effects not shown. In the case of 2SLS estimates and the control function approach, we include the residuals of the instrumental regression of $\ln c_{it-1}$ on lagged twice consumption and other variables.

**Table 6: Structural Equations: Consumption Growth & Income** [16]

| | No instrum. | Single eq. | System | System |
|---|---|---|---|---|
| *Consumption Growth* | | | | |
| *Linear index* | | | | |
| $\Delta \ln(hh\_size)_t : \beta$ | 0.066 | 0.251 | 0.248 | 0.249 |
| | (0.0158) | (0.0368) | (0.0754) | (0.0352) |
| Residual ($\ln c_{it-1}$) | | -0.572 | -0.571 | -0.565 |
| | | (0.0251) | (0.0246) | (0.0245) |
| *Non-Linear index* | | | | |
| $\ln(hh\_size)_t$ | -0.421 | -0.466 | -0.466 | -0.458 |
| | (0.0179) | (0.1469) | (0.0831) | (0.1543) |
| Owned Land | -0.041 | -0.020 | -0.020 | -0.015 |
| | (0.0043) | (0.0107) | (0.0056) | (0.0029) |
| Rainfed Land | -0.011 | -0.042 | -0.041 | -0.052 |
| | (0.0014) | (0.0096) | (0.0144) | (0.0264) |
| Female illness | -0.030 | -0.232 | -0.231 | -0.220 |
| | (0.0052) | (0.0227) | (0.0659) | (0.0623) |
| Male illness | 0.003 | 0.008 | 0.008 | 0.004 |
| | (0.0003) | (0.0044) | (0.0011) | (0.0085) |
| Exogenous income | -0.033 | -0.182 | -0.181 | -0.197 |
| | (0.0084) | (0.1126) | (0.1367) | (0.1426) |
| Information Control | | | | 0.011 |
| | | | | (0.0016) |
| Likelihood | -1149.4 | -850.2 | -850.0 | -829.6 |
| Observations | 8053 | 7133 | 7133 | 7133 |

[16] Quadratic splines. 8 knots. Penalization parameter =1.69. Robust standard errors below estimates in parenthesis. In columns 1 and 2, equations are estimated independently while in columns 3 and 4, correlation is allowed.

**Table 7: The Impact of Smoothing: Penalization parameter**[17]

| $\Delta \ln c_{it}$ | **Optimal/10** | **Optimal/2** | **Optimal** | **Optimal*2** | **Optimal*10** |
|---|---|---|---|---|---|
| *Linear index* | | | | | |
| $\Delta \ln(hh\_size)_t$ | 0.249 | 0.248 | 0.249 | 0.249 | 0.249 |
| | (0.1068) | (1.3459) | (0.0352) | (0.0768) | (0.0453) |
| Res. ($\ln c_{it-1}$) | -0.562 | -0.564 | -0.565 | -0.567 | -0.574 |
| | (0.0245) | (0.1723) | (0.0245) | (0.0288) | (0.0042) |
| *Non-Lin. index* | | | | | |
| $\ln(hh\_size)_t$ | -0.475 | -0.462 | -0.458 | -0.454 | -0.441 |
| | (0.0906) | (1.8416) | (0.1543) | (0.2315) | (0.0075) |
| Owned Land | -0.002 | -0.014 | -0.015 | -0.016 | -0.015 |
| | (0.0024) | (0.0441) | (0.0029) | (0.0024) | (0.0089) |
| Rainfed Land | -0.052 | -0.051 | -0.052 | -0.055 | -0.069 |
| | (0.0161) | (0.0865) | (0.0264) | (0.0173) | (0.0660) |
| Female illness | -0.208 | -0.216 | -0.220 | -0.225 | -0.245 |
| | (0.0251) | (0.7525) | (0.0623) | (0.0715) | (0.0176) |
| Male illness | 0.009 | 0.005 | 0.004 | 0.004 | 0.004 |
| | (0.0015) | (0.0005) | (0.0085) | (0.0019) | (0.0172) |
| Exog. income | -0.184 | -0.194 | -0.197 | -0.202 | -0.223 |
| | (0.0313) | (0.4669) | (0.1426) | (0.1153) | (0.1036) |
| Information | 0.010 | 0.011 | 0.011 | 0.011 | 0.012 |
| | (0.0027) | (0.0508) | (0.0016) | (0.0031) | (0.0158) |
| Likelihood | -829.6 | -829.6 | -829.6 | -830.9 | -832.6 |

[17] Quadratic splines. 8 knots. The optimal penalization, according to Generalized Cross Validation, corresponds to $\nu = 1.69$. Observations =7133. Robust standard errors below estimates in parenthesis.

**Table 8: The Impact of Smoothing: Number of knots**[18]

| $\Delta \ln c_{it}$ | **4 Knots** | **8 Knots** | **16 Knots** | **32 Knots** |
|---|---|---|---|---|
| *Linear index* | | | | |
| $\Delta \ln(hh\_size)_t : \beta$ | 0.248 | 0.249 | 0.250 | 0.252 |
| | (0.3130) | (0.0352) | (0.4161) | (0.0543) |
| Residual ($\ln c_{it-1}$) | -0.569 | -0.565 | -0.562 | -0.580 |
| | (0.3555) | (0.0245) | (0.1129) | (0.0330) |
| *Non-Linear index* | | | | |
| $\ln(hh\_size)_t$ | -0.452 | -0.458 | -0.455 | -0.435 |
| | (0.0158) | (0.1543) | (1.9246) | (0.2315) |
| Owned Land | -0.018 | -0.015 | -0.014 | -0.024 |
| | (0.0051) | (0.0029) | (0.0621) | (0.0080) |
| Rainfed Land | -0.061 | -0.052 | -0.049 | -0.076 |
| | (0.0068) | (0.0264) | (0.1486) | (0.0319) |
| Female illness | -0.233 | -0.220 | -0.212 | -0.262 |
| | (0.0313) | (0.0623) | (0.3198) | (0.1144) |
| Male illness | 0.003 | 0.004 | 0.007 | 0.007 |
| | (0.0205) | (0.0085) | (0.0173) | (0.0100) |
| Exogenous income | -0.215 | -0.197 | -0.190 | -0.288 |
| | (0.0393) | (0.1426) | (0.5896) | (0.2814) |
| Information Control | 0.011 | 0.011 | 0.010 | 0.013 |
| | (0.0317) | (0.0016) | (0.0214) | (0.0080) |
| Likelihood | -831.7 | -829.6 | -830.1 | -829.4 |
| Observations | 7133 | 7133 | 7133 | 7133 |

[18] See Table 6.

**Table 9: The Impact of Smoothing: Order of the spline**[19]

| $\Delta \ln c_{it}$ | **1** | **2** | **3** |
|---|---|---|---|
| *Linear index* | | | |
| $\Delta \ln(hh\_size)_t : \beta$ | 0.249 | 0.249 | 0.251 |
| | (0.0225) | (0.0352) | (0.0663) |
| Residual ($\ln c_{it-1}$) | -0.593 | -0.565 | -0.583 |
| | (0.0324) | (0.0245) | (0.0230) |
| *Non-Linear index* | | | |
| $\ln(hh\_size)_t$ | -0.469 | -0.458 | -0.451 |
| | (0.1922) | (0.1543) | (0.3861) |
| Owned Land | -0.030 | -0.015 | -0.016 |
| | (0.0148) | (0.0029) | (0.0138) |
| Rainfed Land | -0.059 | -0.052 | -0.083 |
| | (0.0069) | (0.0264) | (0.0740) |
| Female illness | -0.317 | -0.220 | -0.251 |
| | (0.0184) | (0.0623) | (0.0475) |
| Male illness | -0.008 | 0.004 | 0.016 |
| | (0.0094) | (0.0085) | (0.0124) |
| Exogenous income | -0.198 | -0.197 | -0.376 |
| | (0.0118) | (0.1426) | (0.0881) |
| Information Control | 0.014 | 0.011 | 0.012 |
| | (0.0194) | (0.0016) | (0.0024) |
| Penalization | 1.69 | 1.69 | 1.69 |
| Number of knots | 8 | 8 | 8 |
| Likelihood | -842.0 | -829.6 | -829.5 |
| Observations | 7133 | 7133 | 7133 |

[19] Robust standard errors below estimates in parenthesis.

**Table 10: Splitting the sample by periods**[20]

| $\Delta \ln c_{it}$ | **Round <= 7** | **Round >= 8** |
|---|---|---|
| *Linear index* | | |
| $\Delta \ln(hh\_size)_t : \beta$ | 0.212 | 0.267 |
| | (0.6063) | (0.3440) |
| Residual ($\ln c_{it-1}$) | -0.652 | -0.505 |
| | (0.0759) | (0.0400) |
| *Non-Linear index* | | |
| $\ln(hh\_size)_t$ | -0.332 | -0.435 |
| | (0.4646) | (0.1686) |
| Owned Land | -0.032 | 0.005 |
| | (0.0157) | (0.0067) |
| Rainfed Land | 0.448 | -0.173 |
| | (0.3837) | (0.3071) |
| Female illness | -0.193 | -0.203 |
| | (0.4101) | (0.0701) |
| Male illness | 0.013 | -0.038 |
| | (0.0057) | (0.0480) |
| Exogenous income | -0.311 | -0.168 |
| | (0.6563) | (0.0249) |
| Information Control | 0.034 | 0.007 |
| | (0.0166) | (0.0031) |
| Penalization | 1.69 | 1.69 |
| Number of knots | 8 | 8 |
| Likelihood | 204.8 | -809.8 |
| Observations | 3704 | 3429 |

[20] Robust standard errors below estimates in parenthesis.

**Table 11: Consumption & Leisure Separability**

| Dependent Variable | Consumption-growth residuals | |
|---|---|---|
| Explanatory Variables | Coeff. | Std. Error |
| Male labor (days) | -0.0009 | (0.0010) |
| Female labor (days) | -0.0045 | (0.0024) |
| Observations | 7133 | |
| R-squared | 0.0007 | |

**Table 12a: Within-village Income Correlations**[21]

| Dependent Variable | Cross-product of residuals $(i, j)$ | |
|---|---|---|
| Explanatory Variables | Coeff. | Std. Error |
| $x_{it} - x_{jt}$ | | |
| total land in village | -0.140 | (0.0035) |
| rainfed land in village | -0.061 | (0.010) |
| (log) household size | -0.19 | (0.012) |
| Observations | 137561 | |
| R-squared | 0.024 | |

**Table 12b: Within-village Consumption Growth Correlations**[22]

| Dependent Variable | Cross-product of residuals $(i, j)$ | |
|---|---|---|
| Explanatory Variables | Coeff. | Std. Error |
| $x_{it} - x_{jt}$ | | |
| total land in village | -0.030 | (0.0030) |
| rainfed land in village | -0.023 | (0.0084) |
| (log) household size | -0.21 | (0.0095) |
| Observations | 137561 | |
| R-squared | 0.0056 | |

[21] This is the regression of all cross-products of residuals of the income equation within each village and each period on the difference of explanatory variables including village-and-period dummies. No correction for first stage estimation. Village-and-period effects are not shown.

[22] This is the regression of all cross-products of residuals of the consumption growth equation within each village and each period on the difference of explanatory variables including village-and-period dummies. No correction for first stage estimation. Village-and-period effects are not shown.

**Figure 1: Residual Variances in the Income Equation**

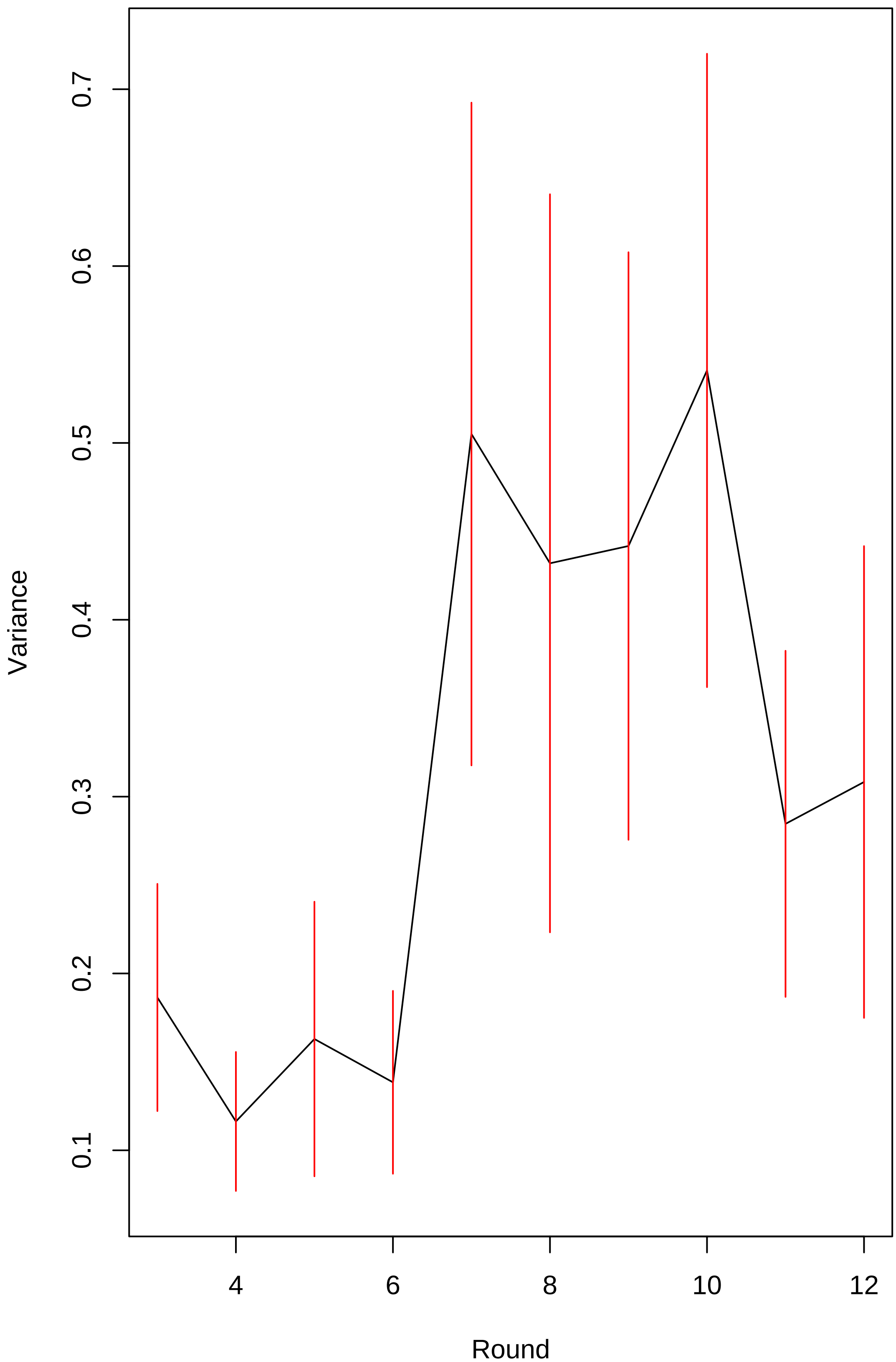


**Figure 2(1): Income Equation Residual Autocorrelations, Order 1**

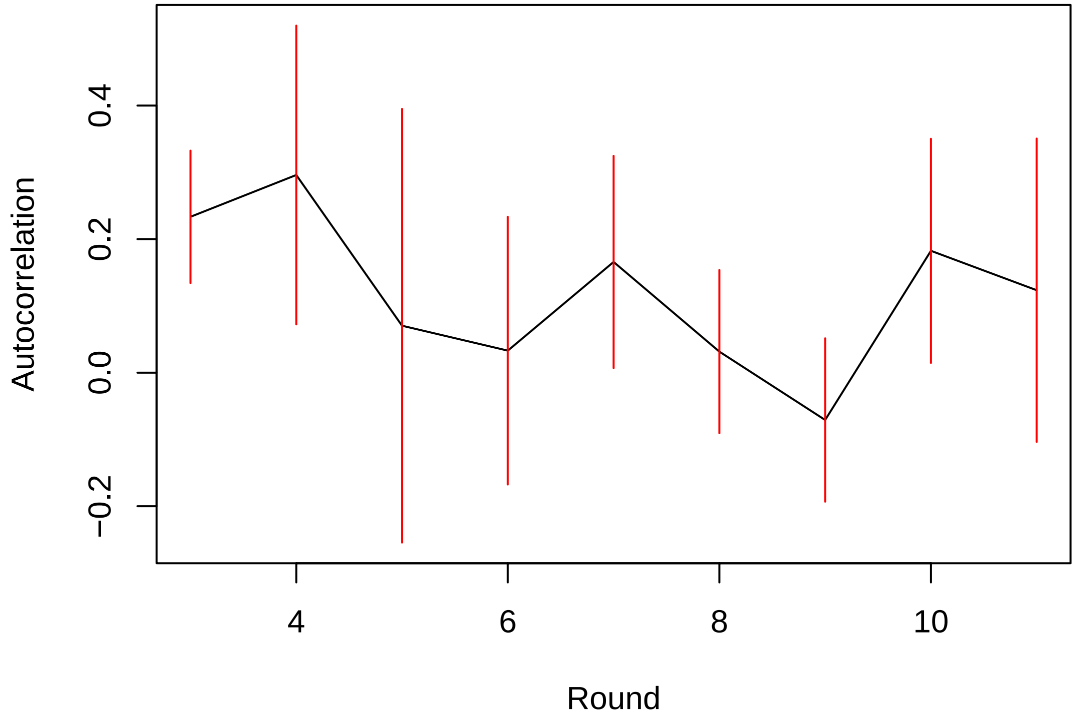



**Figure 2(2): Income Equation Residual Autocorrelations, Order 2**

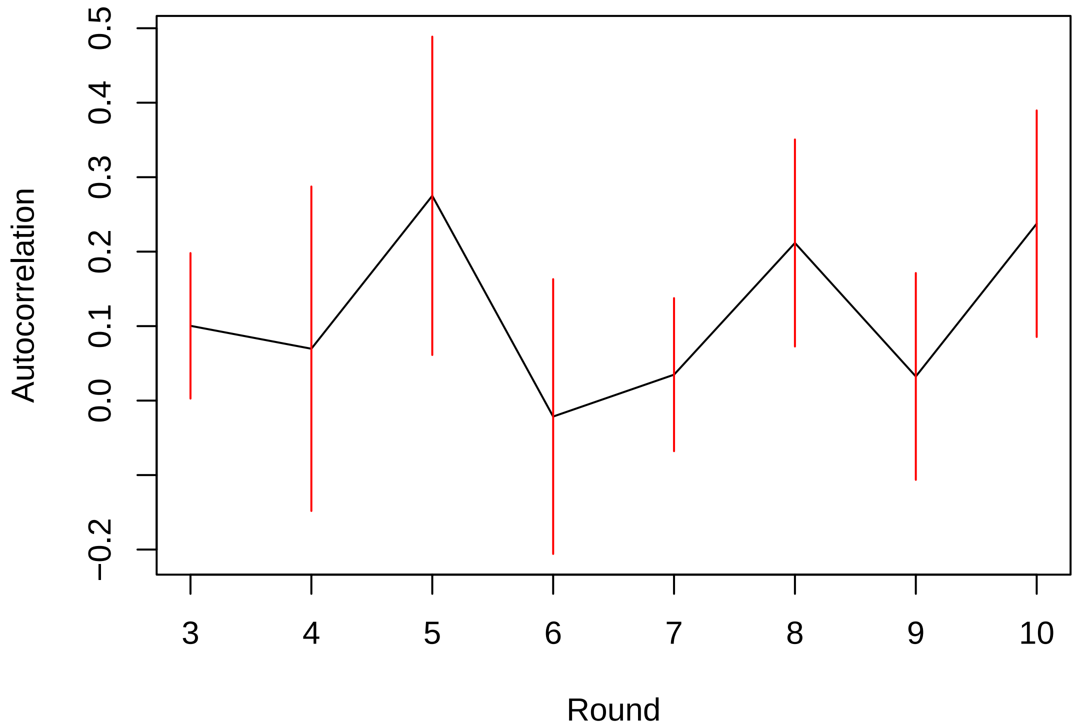


**Figure 2(3): Income Equation Residual Autocorrelations, Order 3**

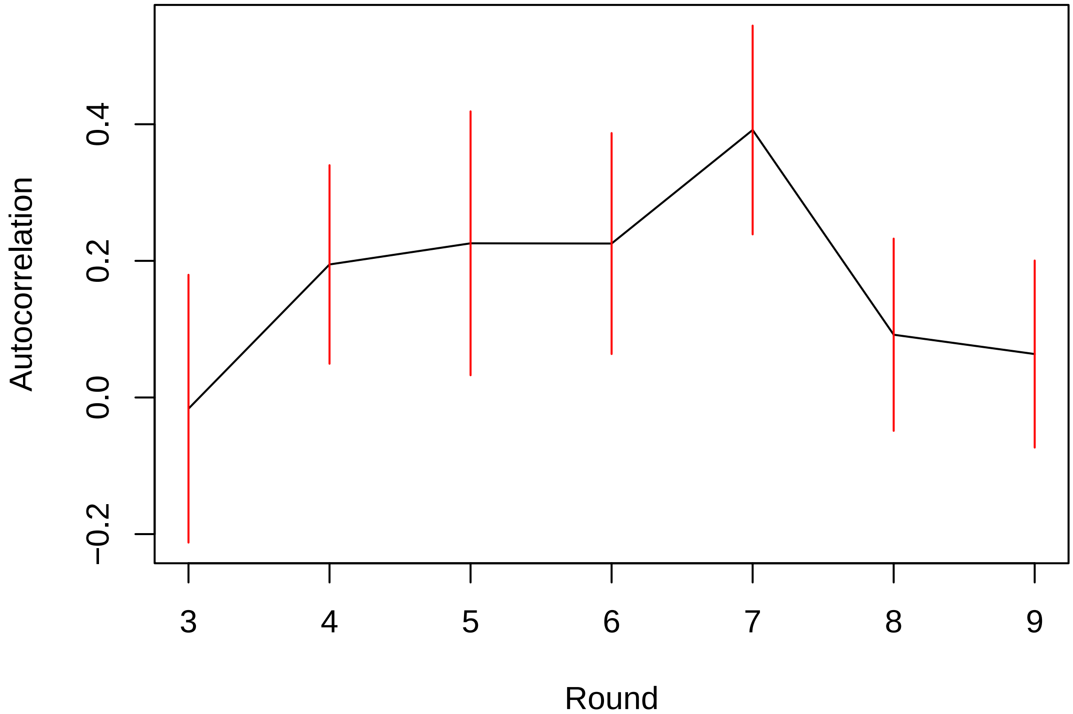
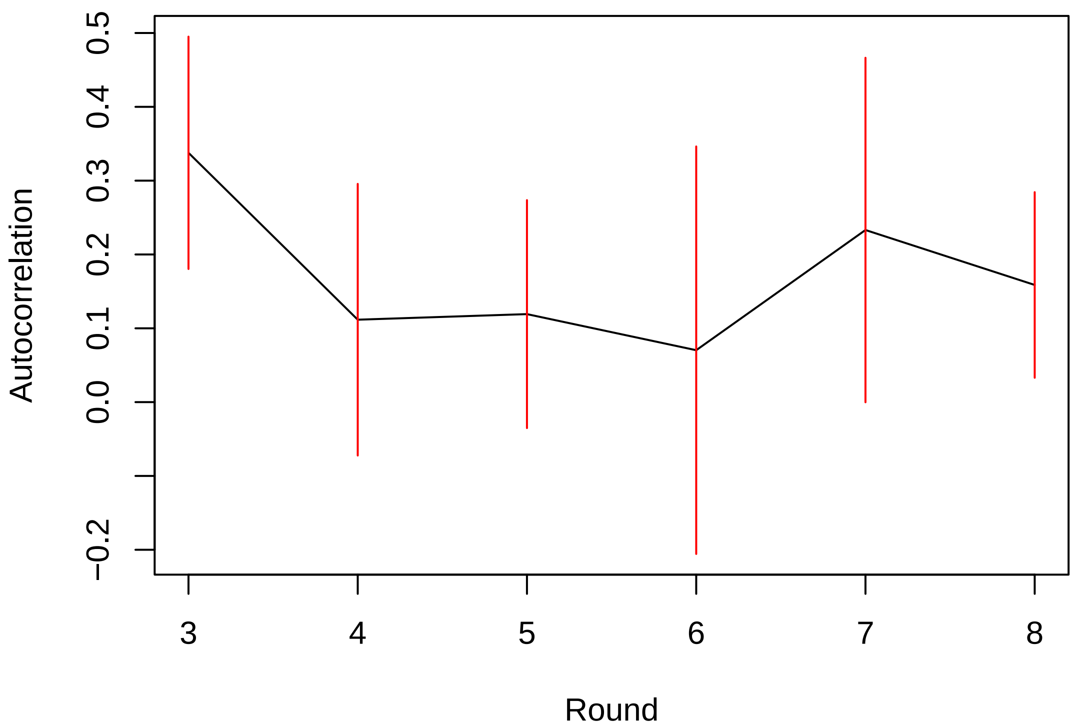



**Figure 2(4): Income Equation Residual Autocorrelations, Order 4**



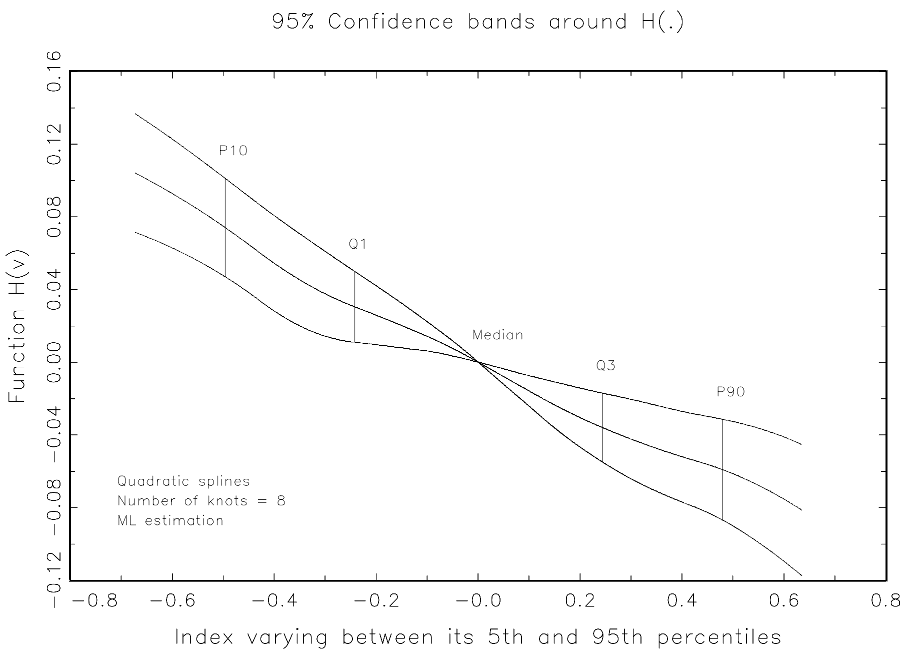



Figure 3 : Quadratic Splines : Undersmoothed Case

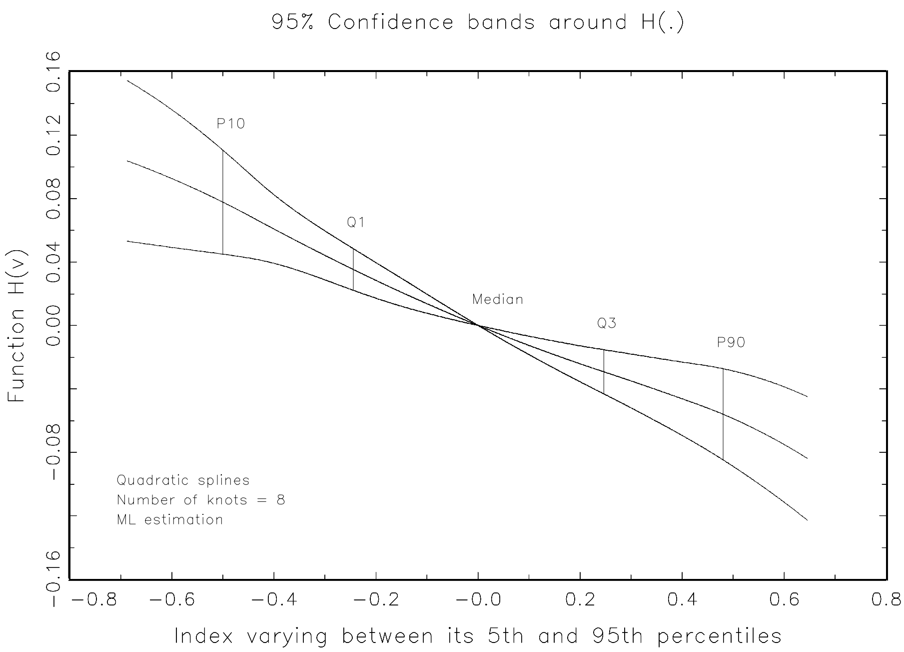



Figure 4 : Quadratic Splines : Optimal smoothing

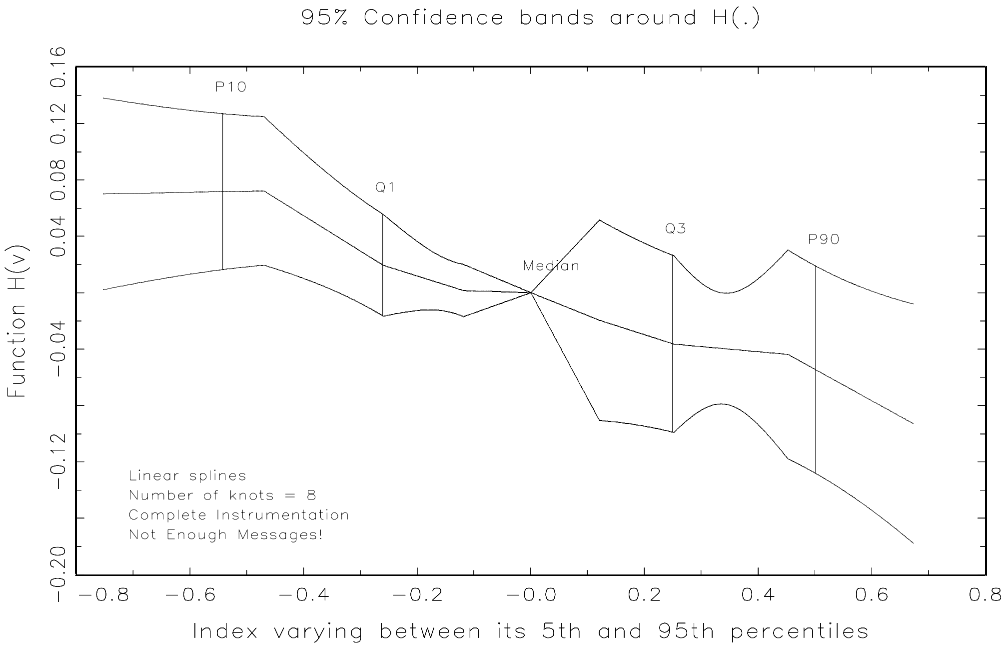



Figure 5 : Linear Splines

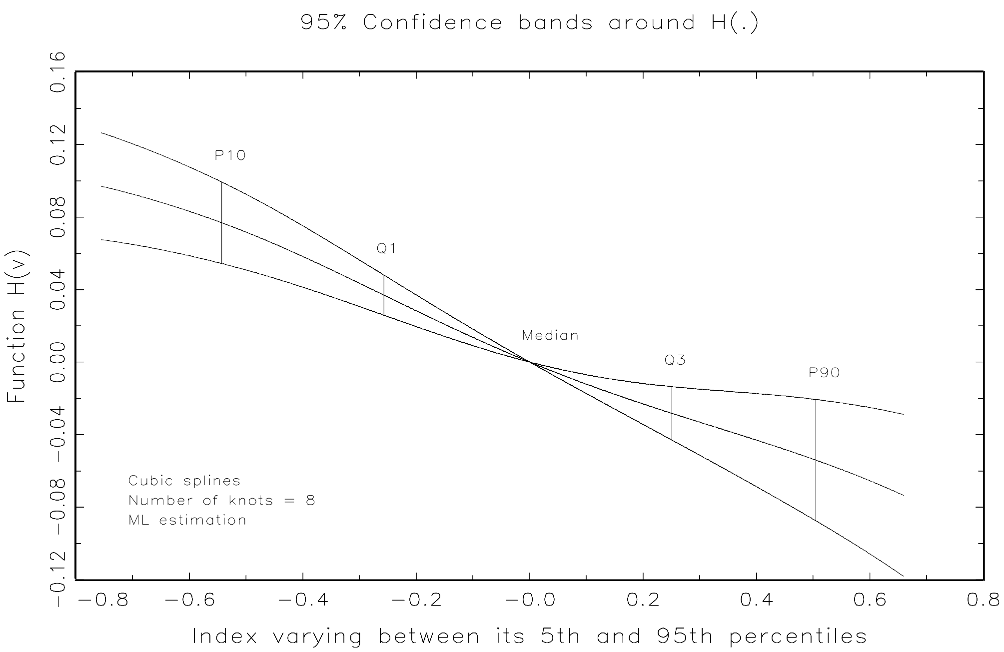
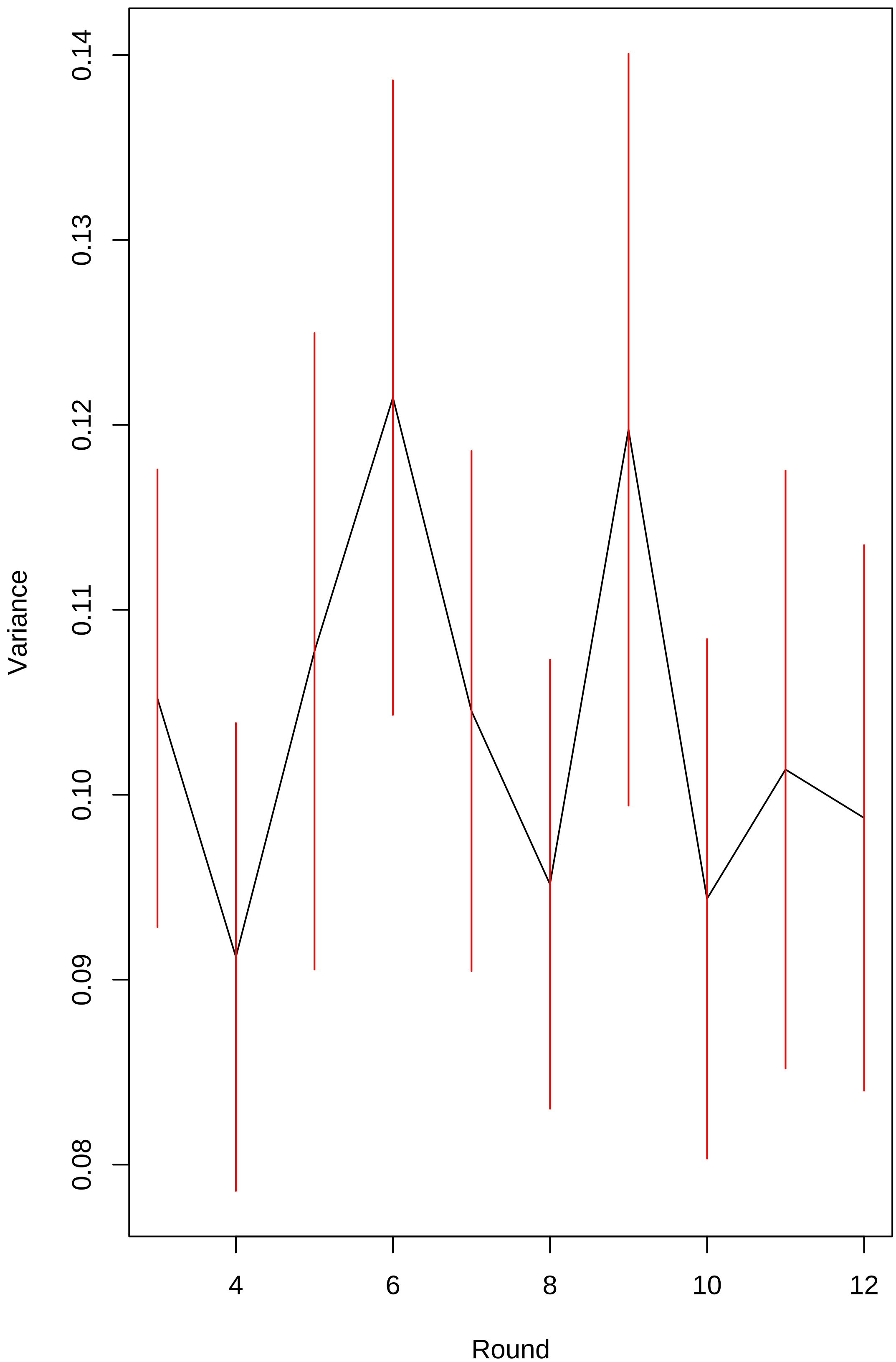
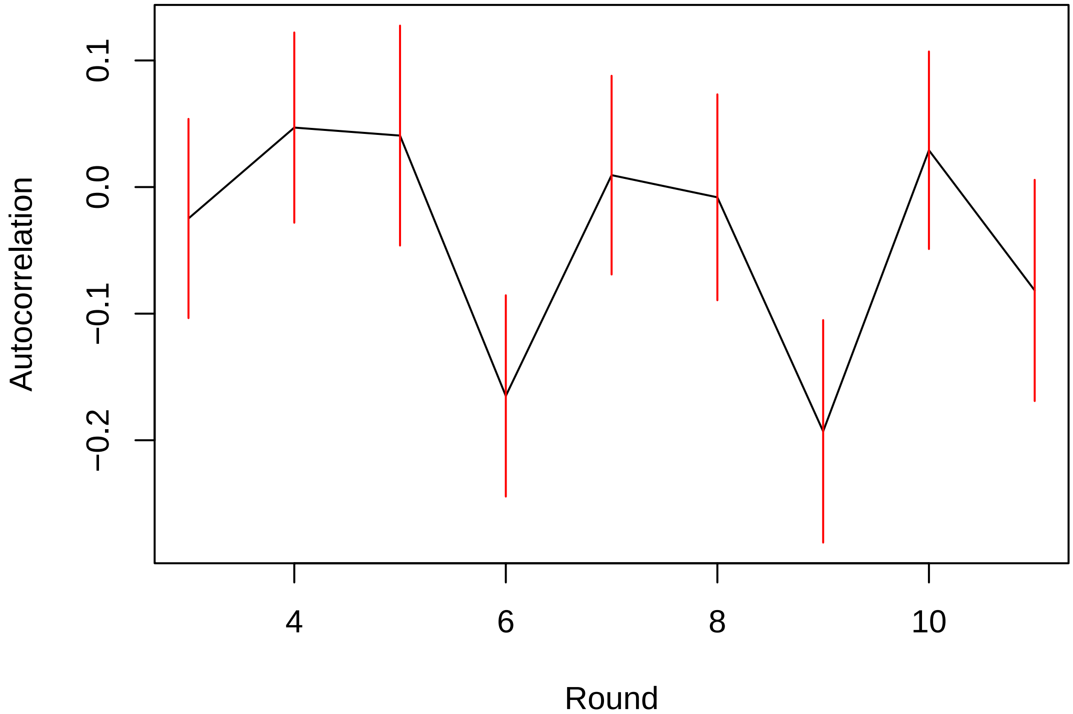



Figure 6 : Cubic Splines

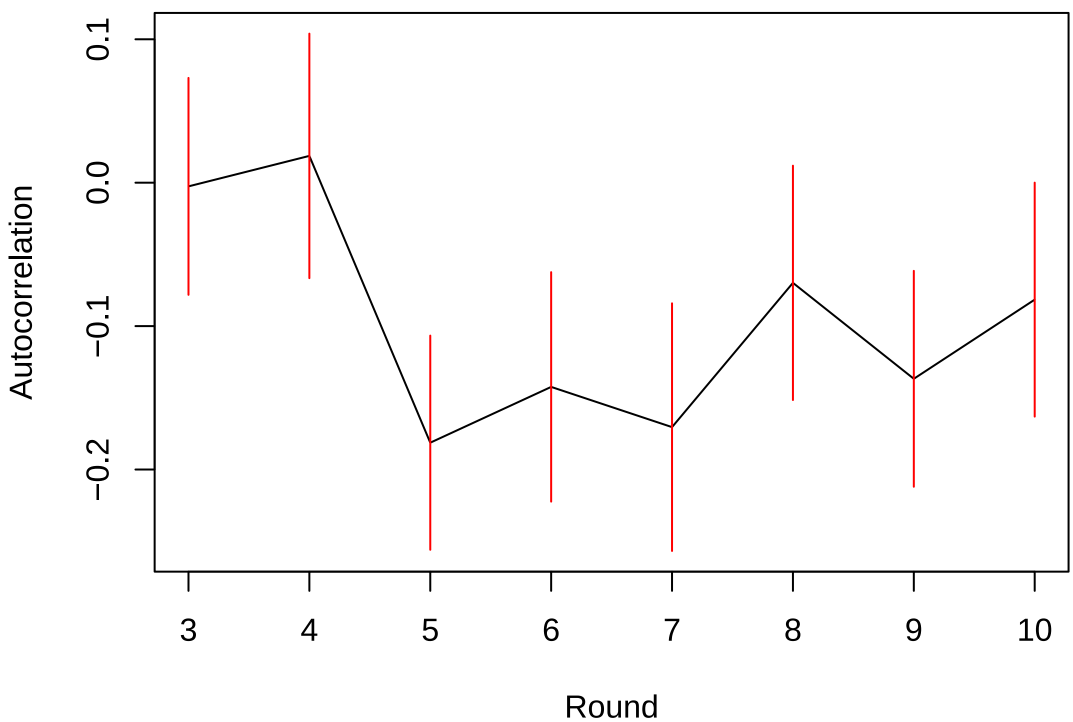
Figure 7: Consumption Growth Residual Variances



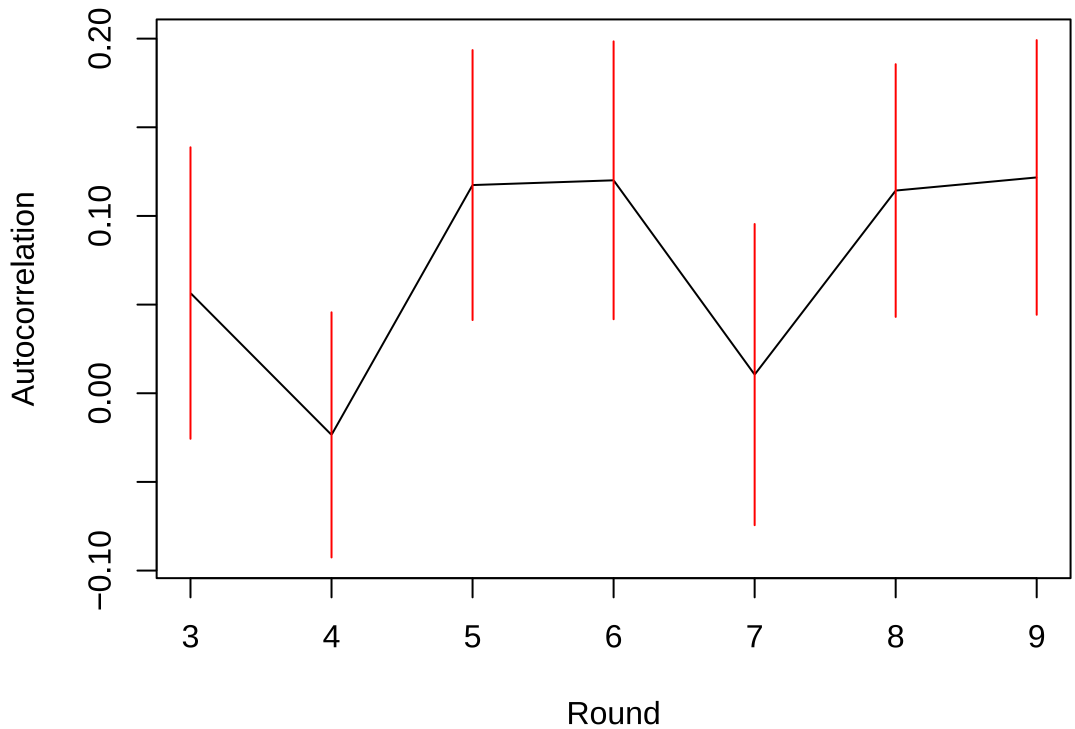
## Figure 8(1): Consumption Residual Autocorrelations, Order 1




## Figure 8(2): Consumption Residual Autocorrelations, Order 2



## Figure 8(3): Consumption Residual Autocorrelations, Order 3




## Figure 8(4): Consumption Residual Autocorrelations, Order 4