Risk Sharing, Private Information, and Fertilizer Use

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Abstract

I study a model of risk sharing in which households' choices of effort and agricultural inputs are private. I relate the level of risk sharing to the households' production decisions. Insurance leads to inefficiently low levels of effort, lowers the use of inputs complementing effort, and increases the use of inputs substituting effort. Moreover, I demonstrate that agricultural input subsidies may improve welfare. Empirically, I provide reduced-form evidence that is consistent with the main predictions of the model using the latest ICRISAT panel from rural India. Then, I structurally estimate the model to quantify the size of the productive inefficiency generated by risk sharing and the welfare gains from a fertilizer subsidy. I show that the impact of risk sharing on fertilizer use is quantitatively important: going from no sharing to full insurance, fertilizer use drops by almost 50%. Finally, I find that cutting the price of fertilizer in half would cause a 8% drop in risk sharing and generate a consumption-equivalent gain in welfare of 47%.

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1 Introduction

Rural households in low-income countries face severe fluctuations in income. These households manage to insure against idiosyncratic income shocks by relying on a variety of informal insurance (risk-sharing) arrangements, such as gift exchange or informal loans.[1] A main finding in the literature is that risk sharing does not generally achieve perfect consumption smoothing (Cochrane (1991), Mace (1991), and Townsend (1994)). There are different frictions that could impede full insurance. A leading explanation is that, when effort is imperfectly monitored, insurance can lead to free-riding (Ligon (1998)).[2] While there has been much interest in identifying the obstacles to full insurance, little work has looked at the interaction between these frictions and agricultural production decisions, such as the use of agricultural intermediates. Understanding this interaction can have profound implications for the design of agricultural policy.

In this paper, I explore the connection between risk-sharing arrangements under private information in production decisions and households' demand for agricultural inputs. I provide a theoretical framework that relates the efficient level of insurance to the demand of agricultural inputs through households' effort decisions. I show that insurance leads to inefficiently low levels of effort, thus affecting households' incentives to use different inputs, and that policies affecting the relative prices of inputs may improve welfare. Empirically, I structurally estimate the model, and quantify the effect of risk sharing on agricultural input use and the potential gains from such a policy.

The relation between informal risk-sharing and a household's demand for agricultural inputs rests on two basic premises. First, private effort has been shown to be a relevant barrier to risk sharing in many different contexts.[3] The intuition is that when effort is imperfectly monitored, informal insurance induces households to shirk. Second, rural households use effort in combination with several agricultural inputs, and agricultural input use is linked to effort supply through relations of complementarity and substitutability. For example, it is well-

[1] See Fafchamps (2011) for a review.

[2] Other possible frictions are limited commitment (Ligon et al. (2002)) and hidden income (Kinnan (2017)).

[3] See Ligon (1998) for evidence from rural India; Paulson et al. (2006) and Karaivanov and Townsend (2014) for evidence from rural and semi-urban Thailand; Kocherlakota and Pistaferri (2009) for evidence from Italy, the UK, and the USA; and Attanasio and Pavoni (2011) for evidence from the UK.

established that effort and fertilizer are complements.[4] Given that agricultural inputs have different degrees of complementarity and substitutability with effort, and since insurance has a discouraging effect on households' effort supply, I argue that risk sharing may be depress the use of inputs complementing effort, such as fertilizer.

I outline a simple model of risk sharing in which households insure themselves by sharing the profits of agricultural production. Each household can exert costly effort and purchase agricultural inputs to increase expected output. I characterize the constrained-efficient allocation of effort and agricultural inputs subject to a fixed level of insurance. Insurance reduces the private marginal benefit of effort, thereby inducing underprovision of effort. The current framework departs from standard models of insurance with private effort *à la* Ligon (1998) by (i) introducing household choices of agricultural input use besides effort supply, and (ii) recognizing that effort displays varying degrees of complementarity and substitutability with different agricultural inputs. This last feature allows insurance to have heterogeneous effects on the use of different agricultural inputs. In particular, as insurance is detrimental to effort provision, higher risk sharing lowers the use of inputs complementing effort and increases the use for inputs substituting effort. Then, I proceed to characterize the optimal level of risk sharing.

I test the model empirically using the latest (2009-2014) ICRISAT panel from rural India. First, I provide reduced-form evidence about the main predictions of the model. The key prediction of a model of risk sharing with private effort is that better insured household should be exerting less effort, other things being equal. I show that this prediction is borne out in the data, as insurance is negatively correlated with effort provision. More specifically, I find that, on average, households with a higher average effort supply over available time periods experience higher elasticity of consumption to idiosyncratic income shocks. I go on to provide evidence of the complementarity between effort and fertilizer by showing that effort provision and fertilizer use are strongly positively correlated after controlling for land area, unobserved household heterogeneity, and possible seasonalities in agricultural production. Finally, I find

[4]See Foster and Rosenzweig (2009), Foster and Rosenzweig (2010), and Foster and Rosenzweig (2011) for evidence from India; Beaman et al. (2013) for evidence from Mali; Ricker-Gilbert (2014) for evidence from Malawi; and Haider et al. (2018) for evidence from Burkina Faso.

that insurance is negatively correlated with fertilizer use, as indicated by the theory.

Finally, I structurally estimating the model. I do so by fitting the theoretical relationship between fertilizer used per hours worked on the one hand, and the price of fertilizer, the marginal disutility of effort, and the wedge between the private and social marginal benefit of effort on the other. A clear advantage of structural estimation is that it allows me to conduct counterfactuals and policy simulations. Moreover, it provides a joint test of (i) the relationship between risk sharing and fertilizer use, and (ii) the complementarity between effort and fertilizer. I retrieve the elasticity of substitution between effort and fertilizer, the marginal disutility of effort, and the wedge between the private and social marginal benefit of effort. I quantitatively assess the role of risk sharing in effort supply and fertilizer use, and simulate the effects of a fertilizer price subsidy on risk sharing and welfare. I find that the impact of risk sharing on effort supply and fertilizer use is quantitatively important: going from no sharing to full insurance, effort supply decreases by more than six times and fertilizer use drops by almost 50%. As for the fertilizer price subsidy, I show that cutting the price of fertilizer in half would cause a 8% drop in risk sharing and generate a consumption-equivalent gain in welfare of 47%. The reason why the subsidy gives rise to a welfare gain despite reducing risk sharing is that it induces households to use more fertilizer and also exert more effort, because of the complementarity between effort and fertilizer. In turn, increasing effort supply unequivocally increases welfare because of the initial underprovision of effort set up by risk sharing, thus moving the economy's input allocation closer to the full information benchmark.

Overall, my results suggest that when informal insurance arrangements are constrained by private information frictions in agricultural production decisions, risk sharing can have heterogeneous effects on the use of different agricultural inputs, and that the signs of these effects will be positive or negative depending on the substitutability or complementarity between effort and the agricultural inputs. On the positive side, these results show the importance of taking into account risk sharing when analyzing the determinants of agricultural input use. On the normative side, they demonstrate that it is critical to consider the endogenous response of risk sharing when designing agricultural input price subsidies.

Related literature

Time and again, development economists have placed insurance amongst the key factors explaining the process of economic development. While some have argued that a lack of insurance can hold households back from adopting high-risk and high-return technologies (Rosenzweig and Binswanger (1993) and Dercon and Christiaensen (2011)), others have pointed out that social pressure to share income with neighbors and relatives might reduce investment incentives (Jakiela and Ozier (2015)). This paper analyzes a new mechanism that relates informal insurance to different patters of agricultural input use through households' effort supply decisions. This mechanism allows insurance to have heterogeneous effects on the use of different inputs. Its novelty is that this heterogeneity is driven by the nature of the technological relationship between effort and the inputs: risk sharing is predicted to curtail the use of inputs that complement effort and boost the use of inputs that substitute effort.

First and foremost, this paper contributes to the understanding of agricultural input use in low-income countries and, in particular, of its relationship with risk sharing. Uncovering the determinants of agricultural input use is extremely important from both an academic and a policy perspective (Feder et al. (1985), Sunding and Zilberman (2001), Foster and Rosenzweig (2010), Udry (2010), and Jack (2013)). One need only consider that many agricultural policies for poverty reduction are based on fostering the use of agricultural inputs embodying technological improvements, such as new seed varieties, fertilizers, and other chemicals. The literature has argued before that it is critical to uncover the impact of risk-sharing arrangements on technology adoption and agricultural input use, as these arrangements are ubiquitous in village economies.[5] However, few papers have been written on this topic. The only exceptions (Giné and Yang (2009) and Dercon and Christiaensen (2011)) analyze the case of new technologies, the use of which is discouraged by their inherent uncertainty over benefits and costs. In this case, better insurance should be associated with higher take-up rates. This paper takes a very different approach. It does not speak to the issue of understanding of how insurance might boost the use of new and riskier technologies. Instead, it focuses on the discouraging effect of insurance on effort supply, and how this effect relates to the use of different agricultural inputs

[5] According to Udry (2010), understanding "how [...] imperfect insurance influence input choice and/or technology adoption in agriculture" is "a key research agenda" in agricultural and development economics.

through relations of complementarity and substitutability between effort and the agricultural inputs.

The mechanism I propose to link risk sharing to agricultural input use relies on a private effort friction. Most of the literature on sharecropping also assumes that effort provision is private (Quibria and Rashid (1984), Singh (1991), and Sen (2016)). More importantly, private effort has been used to rationalize imperfect insurance in village economies (Ligon (1998)). While several papers have provided evidence for private effort by testing models of imperfect insurance against each other (Ligon (1998), Ábrahám and Pavoni (2005), Kaplan (2006), Attanasio and Pavoni (2011), and Karaivanov and Townsend (2014)), this friction has been considered hard to detect using observational data (Foster and Rosenzweig (2001)).[6] I contribute to this literature by providing a first *direct* evidence of a negative relationship between insurance and effort.[7] By doing so, I confirm the main implication of the private effort explanation to imperfect insurance.

According to Foster and Rosenzweig (2010), research on agricultural input use needs to take into account the complementarity and substitutability between inputs, and in particular between labor and agricultural intermediates. Indeed, empirical evidence (Dorfman (1996) and Hornbeck and Naidu (2014)) suggests that labor availability plays a key role in the decision to adopt different input baskets. By taking into account the complementarity and substitutability between effort and other inputs, my model directly speaks to this issue. In particular, the model explicitly recognizes that the profitability of an agricultural input (and hence its use) will ultimately depend on a household's willingness to allocate its time to farm labor (which is in turn affected by how insured it is).

Finally, this paper relates to a growing literature focusing on how informal insurance affects different aspects of the village economy. Important contributions to this literature are Munshi and Rosenzweig (2006), which studies how risk sharing shapes career choice by gender in Bombay; Munshi and Rosenzweig (2016), which analyzes how caste-based informal insurance

[6]Despite this shortcoming, there exists experimental evidence of the effect of private effort on risk sharing (Prachi (2016)).

[7]The literature on sharecropping has produced consistent evidence that better risk sharing (in the form of a lower fraction of the agricultural output going to the tenant) leads to lower efficiency and effort provision (Laffont and Matoussi (1995)). However, the same empirical evidence has not been provided by the literature on informal insurance.

affects incentives to migrate in India; Advani (2017), which studies how informal insurance with limited commitment impacts on investment in livestock in Bangladesh; and Morten (2017), which studies the joint determination of informal insurance and temporary migration in rural India when there is a limited commitment friction.

The rest of the paper is organized as follows. In Section 2, I outline a simple model of risk sharing which generates testable implications for the relationships between insurance, effort supply, and agricultural input use. In Section 3, I introduce the data, provide reduced-form evidence confirming the testable implications, and structurally estimate the model to conduct counterfactuals and policy simulations. Finally, Section 4 concludes and points to future research.

2 A Model of Risk Sharing

I study an economy in which households face productivity shocks, and insure themselves by pooling part of their incomes together and sharing them equally. Each household chooses how much effort to supply to its own agricultural business, and how much agricultural inputs to buy at given prices. In Subsection 2.1 I outline the setup of the model. In Subsection 2.2 I characterize the efficient allocation of effort and agricultural inputs as a function of the sharing contract, both when the the households' choices are private information and when they are publicly observable. In Subsection 2.3 I solve for the efficient sharing rule in both the private and full information regimes. Finally, in Subsection 2.4 I discuss the effect of agricultural input subsidies on welfare. All the proofs are contained in Appendix H.

2.1 Setup

There are n household-farms, each producing output y_i, $i \in N := \{1, \dots, n\}$. Output is uncertain, and depends on effort $e_i \in [0, \overline{e}_i]$ and quantities of agricultural inputs (intermediates) $\boldsymbol{z}_i \in \mathbb{R}^m_+$. Refer to $\boldsymbol{a}_i = (e_i, \boldsymbol{z}_i)$ as an action for household i. Let ε_i be a production shock with mean μ and variance η^2. I assume that

$$y_i := y(\boldsymbol{a}_i) + \varepsilon_i, \tag{1}$$

where y is jointly concave in $\boldsymbol{a}_i$, and strictly concave, strictly increasing, and twice-continuously differentiable in all arguments. Hence, supplying more effort or increasing the use of an agricultural input improves the expectation of output without making it riskier.[8] The shocks are independently distributed across households.[9] The effort used in i's agricultural business can only be supplied by household i (i.e., there is no market for effort). On the other hand, agricultural inputs are bought in the market, and households take their prices as given. Letting $\boldsymbol{p}$ be a vector of prices for the agricultural intermediates, household i's agricultural profit (income) is given by

$$\pi_i = y_i - \boldsymbol{p} \cdot \boldsymbol{z}_i. \tag{2}$$

Households share incomes[10] to smooth consumption risk. In particular, household i's consumption is given by

$$c_i(\alpha) = (1-\alpha)\pi_i + \alpha\overline{\pi}, \tag{3}$$

where $\alpha \in [0,1]$ is a coefficient that fully characterizes the extent of risk sharing and $\overline{\pi}$ is average income. The intuition is that each household consumes a fraction $1-\alpha$ of its agricultural profit, and contributes the rest to a common pool which is shared equally.[11] Risk sharing is assumed

[8] See Appendix B for a discussion of how the results here presented can be preserved in a model where effort and agricultural inputs have an impact on the variance of output. Intuitively, if the impact of intermediates on output volatility is not too big, and either effort makes production less risky or it does not increase volatility by too much, then my results are still valid.

[9] This assumption is without loss of generality as long as the shocks are not perfectly correlated across households. Indeed, one can assume that $\varepsilon_i = \upsilon + \theta_i$, where υ is an aggregate shock, which is common across households, and θ_i is idiosyncratic risk. In this case, it is optimal for the households to only share the idiosyncratic components of the shocks they experience.

[10] Given that income is defined as agricultural profit, households share both outputs and the monetary costs of agricultural inputs. This assumption plays an important role, as it implies that risk sharing only has a direct impact on effort choices. Of course, in equilibrium risk sharing does affect agricultural input use, but this effect only comes about through its impact on effort. While the informal insurance literature made it customary to think of households that only share outputs, this is mainly an artifact due to the fact that most models abstract away from the presence of inputs purchased in the market. In fact, the assumption that household income equals agricultural profit is consistent with the way in which farm household income is measured in practice (The Organisation for Economic Co-operation and Development (2003)).

[11] Equation (3) can be thought of as an implementation of the well-known contrast estimator (Suri (2011)) when the economy is closed and there are no saving technologies, as shown in Appendix C.

to be enforceable.

Household i's expected utility is given by[12]

$$U\left(c_{i}\left(\alpha\right), e_{i}\right) := \mathbb{E}\left(c_{i}\left(\alpha\right)\right) - \frac{\rho}{2}\mathbb{V}\text{ar}\left(c_{i}\left(\alpha\right)\right) - \kappa e_{i},$$

where ρ is the coefficient of absolute risk aversion and κ is the marginal disutility of effort. Expectations are taken with respect to the distribution of the production shocks.

For simplicity, price vector $\boldsymbol{p}$ can be thought of as a parameter, thus making this model a partial equilibrium model. Equivalently, one can assume that each agricultural input q is supplied by competitive manufacturers with a linear cost function $c^{q}z^{q}$, for some $c^{q} > 0$. In this case, profit maximization on the part of the manufactures implies that $p^{q} = c^{q}$, which pins down the equilibrium prices of agricultural intermediates. Since there are no markets for effort and consumption, these 'price equals marginal cost' conditions characterize the unique (general) equilibrium for this economy.

An allocation is a sharing rule α together with an action profile $\boldsymbol{a} := \left(\boldsymbol{a}_{i}\right)_{i \in N}$. There is a utilitarian social planner who chooses an allocation to maximize welfare. My aim is to characterize a welfare-maximizing allocation in two information regimes: the full information regime and the private information regime. A welfare-maximizing allocation under full information is said to be efficient, while a welfare-maximizing allocation under private information is said to be constrained-efficient. In order to solve the planner's problem, I proceed as follows. First, I find a welfare-maximizing action profile $\boldsymbol{a}^{*}$ for a given sharing rule α. Then, I find a welfare-maximizing sharing rule α^{*}.

[12] The assumption that expected utility is separable in consumption and effort is standard in the moral hazard literature. I make use of a mean-variance expected utility of consumption because it greatly simplifies strategic interactions between households: given some α, i's choices of effort and intermediates do not depend on other households' choices. See Appendix A.1 for a more detailed discussion. Also notice that the disutility of effort is assumed to be linear in effort, so that the marginal disutility of effort can be interpreted as another price. This modeling strategy allows for the application of standard results in producer theory in what follows. The same strategy has been widely used in papers dealing with sharecropping (Arcand et al. (2007)) and general agency problems (Conlon (2009)).

2.2 Optimal Action Profile

Full information. Assume that $\boldsymbol{a}$ is observed by the planner. The problem of finding a welfare-maximizing action profile for a given α is

$$\max_{\boldsymbol{a}} \sum_{i \in N} U\left(c_i\left(\alpha\right), e_i\right), \tag{4}$$

subject to Equations (3), (2), and (1). Notice that there are no participation constraints. This is without loss of generality, as the planner is benevolent and each household's Pareto weight is 1. Let $\boldsymbol{a}^{\diamond}\left(\alpha\right)$ be a solution to Problem (4). The following claim nails down the welfare-maximizing action profile.

Claim 1 (Efficient action profile)**.** *Under full information, and for given α, the welfare-maximizing action profile is characterized by*

$$y_e\left(\boldsymbol{a}_i^{\diamond}\left(\alpha\right)\right) = \kappa,$$
$$y_{\boldsymbol{z}}\left(\boldsymbol{a}_i^{\diamond}\left(\alpha\right)\right) = \boldsymbol{p}.$$

The intuition behind this claim is straightforward: under full information risk sharing does generate externalities; hence, the optimal action profile commands to equate the marginal product of effort to its marginal utility cost, and the marginal product of each agricultural input to its price.

Private information. Next, assume that household i's action is private to i. In this case, to find a welfare-maximizing action profile for given α the planner has to solve

$$\begin{aligned} &\max_{\boldsymbol{a}} \sum_{i \in N} U\left(c_i\left(\alpha\right), e_i\right), \\ &\text{subject to } \boldsymbol{a}_i \in \arg\max_{\widehat{a}_i} U\left(c_i\left(\alpha\right), \widehat{e}_i\right), \ \forall i \in N, \end{aligned} \tag{5}$$

and Equations (3), (2), and (1). The difference between Problem (4) and (5) is that in the private information regime an optimal action profile has to satisfy n incentive-compatibility (IC) constraints, which say that the action chosen by the planner for household i coincides with what the household would do on its own; otherwise, the household would have an incentive to deviate to another action. Let $\boldsymbol{a}^*(\alpha)$ be a solution to Problem (5). The following claim characterizes the solution to Problem (5), which is pinned down by the IC constraints alone.

Claim 2 (Constrained-efficient action profile)**.** *Under private information, and for given α, the welfare-maximizing action profile is characterized by*

$$y_e\left(\boldsymbol{a}_i^*(\alpha)\right) = \frac{\kappa}{\left(1 - \frac{n-1}{n}\alpha\right)} =: p_e(\alpha),$$
$$y_{\boldsymbol{z}}\left(\boldsymbol{a}_i^*(\alpha)\right) = \boldsymbol{p},$$

for each $i \in N$.

Refer to $p_e(\alpha)$ as the 'effective price' of effort. Claim 2 shows that risk sharing induces a direct negative externality on effort provision, as it increases the 'effective price' of effort. On the other hand, risk sharing has no direct impact on agricultural input use, because it does not affect neither their marginal benefits nor their marginal costs. This asymmetry between effort and agricultural inputs is generated by the assumptions that (i) households share profits, so that they share the revenues as much as the monetary costs of the factors of production, and (ii) effort does not enter the monetary costs of the factors of production, as there is no market for effort (i.e., each household can only supply effort to its own agricultural business). Hence, the impact of the sharing contract on the private marginal benefit of an agricultural input cancels out with its impact on its private marginal cost. This is not true for effort, for which the sharing contract decreases private marginal benefits while leaving unaltered private marginal costs. The next theorem shows how effort supply and the use of agricultural inputs change when the sharing coefficient moves.

Theorem 1 (Effort, intermediates, and risk sharing)**.** *Let $\boldsymbol{a}^*(\alpha)$ be the constrained-efficient action profile. Then,*

$$\frac{\partial e_i^*(\alpha)}{\partial \alpha} < 0.$$

Moreover, suppose that e_i *and* z_i^q *are complements at* $(p_e, \boldsymbol{p})$*; i.e.,*

$$\frac{\partial z_i^{q*}(\alpha)}{\partial p_e} < 0.$$

Then,

$$\frac{\partial z_i^{q*}(\alpha)}{\partial \alpha} < 0.$$

The signs of the latter two inequalities are reversed if e_i *and* z_i^q *are substitutes at* $(p_e, \boldsymbol{p})$*.*

Theorem 1 shows that if risk sharing increases, then households exert less effort, increase the use of agricultural intermediates that complement effort, and decrease the use agricultural intermediates that substitute effort.[13] The intuition is as follows. Since effort has a direct negative externality on effort provision, more insurance induces households to shirk. This reduction in effort induces the households to decrease their use of inputs that complement effort, as they become less profitable. The opposite happens for inputs that substitute effort, which are more profitable the less effort is used.

2.3 Optimal Sharing Rule

In this model sharing contracts are assumed to be linear.[14] Nevertheless, the results obtained in this section carry through to more complex environments in which the linearity assumption is dropped, as shown in Appendix A.

Full information. Next, consider the problem of finding a welfare-maximizing sharing contract under full information; i.e.:

$$\max_{\alpha} \sum_{i \in N} U\left(c_i\left(\alpha\right), e_i\right),$$

[13]See Appendix D for a discussion on the definition of complementarity and substitutability used in Theorem 1, as well as Theorem 2 in Section A, and other possible definitions of complementarity and substitutability (and additional assumptions on the production function) under which these theorems would still hold.

[14]In general, linear contracts are not optimal when choices of effort and agricultural inputs are private. Yet, linearity simplifies the analysis considerably. Moreover, linear contracts can be motivated by empirical evidence, as in Dutta and Prasad (2002). In fact, explaining why linear contracts are so common is a longstanding problem in contract theory, since most models predict more complicated functional forms (Holmström and Milgrom (1987) and Carroll (2015)).

subject to Equations (3), (2), (1), and $\boldsymbol{a} = \boldsymbol{a}^{\diamond}(\alpha)$, where $\boldsymbol{a}^{\diamond}(\alpha)$ is the solution to Problem 4. The following claim shows that, under full information, risk sharing is perfect.

Claim 3 (Efficient sharing)**.** *Under full information, the welfare-maximizing sharing contract is full insurance.*

This result is entirely standard: since under full information risk sharing does not generate externalities, the planner maximizes welfare by insuring the households as much as possible.

Private information. Finally, assume that the households' choices are private. In this case, the problem of finding a welfare-maximizing sharing contract is given by

$$\max_{\alpha} \sum_{i \in N} U\left(c_i\left(\alpha\right), e_i\right),$$

subject to Equations (3), (2), (1), and $\boldsymbol{a} = \boldsymbol{a}^{*}(\alpha)$, where $\boldsymbol{a}^{*}(\alpha)$ is the solution to Problem 5. Let $W(\alpha)$ denote social welfare evaluated at $\boldsymbol{a}^{*}(\alpha)$. The next claim characterizes the welfare-maximizing sharing contract under private information, and highlights that, under this information regime, a marginal increase in α generates a trade-off between decreasing consumption volatility and decreasing aggregate consumption.

Claim 4 (Constrained-efficient sharing)**.** *Let α^* be an optimal sharing rule under private information. Notice that*

$$\frac{\partial W\left(\alpha\right)}{\partial \alpha} = \underbrace{\sum_{i \in N} \left(\kappa \left(\frac{1}{1 - \frac{n-1}{n}\alpha} - 1 \right) \frac{\partial e_i^*\left(\alpha\right)}{\partial \alpha} \right)}_{(-)} \underbrace{- \frac{n\rho}{2} \frac{\partial \mathbb{V}\text{ar}\left(c_i\left(\alpha\right)\right)}{\partial \alpha}}_{(+)}. \tag{6}$$

Moreover, it must be the case that

$$\begin{aligned} \tfrac{\partial W(\alpha^*)}{\partial \alpha} &= 0 \quad \text{if } \alpha^* \in (0,1), \\ \tfrac{\partial W(\alpha^*)}{\partial \alpha} &\leq 0 \quad \text{if } \alpha^* = 0, \\ \tfrac{\partial W(\alpha^*)}{\partial \alpha} &\geq 0 \quad \text{if } \alpha^* = 1. \end{aligned}$$

The first term of Equation (6), which is negative, is the loss in aggregate production generated by a marginal increase in the negative externality caused by sharing. The second term, which is positive, is the gain associated with a marginal reduction in consumption volatility. Hence, in general, one should not expect to observe $\alpha = 1$, as under full information.

2.4 Agricultural Input Subsidy

Next, I analyze the effect of an agricultural input subsidy on welfare. Such a policy can impact welfare along several different channels. First, an agricultural input subsidy has a direct beneficial effect on welfare, as it increases profits by mechanically reducing production costs. I call this the price effect. Second, an input price chance affects effort supply through complementarity and substitutability: a marginal decrease in the price of an effort complement induces households to exert more effort, while a marginal decrease in the price of an effort substitute induces households to exert less effort. Under private information, risk sharing leads to inefficiently low levels of effort. Hence, subsidizing the use of an effort complement pushes the effort allocation closer to the full information benchmark, while subsidizing the use of an effort substitute drives this allocation away from the benchmark. I call this the effort effect. Finally, when insurance is endogenous, the optimal sharing rule will also react to an input price change. I call this the insurance effect. This last effect is only relevant under private information, as under full information the optimal sharing rule is always full sharing.

To analyze the combination of these effects, notice that welfare can be written as

$$\sum_{i \in N} \left[y\left(\boldsymbol{a}_i\right) - \boldsymbol{p} \cdot \boldsymbol{z}_i - \kappa_i - \frac{\rho}{2} \left((1-\alpha)^2 + \frac{\alpha^2}{n} + \frac{2\alpha\,(1-\alpha)}{n} \right) \eta^2 \right].$$

Exogenous sharing rule. First, assume that α is fixed. By the envelope theorem, the effect of a marginal increase in the price of agricultural input q on welfare under full information is given by

$$-\sum_{i \in N} z_i^{q\diamond}\left(\alpha\right).$$

Thus, under full information, the only effect that matters is the price effect. This implies that it would be optimal to subsidize input q as much as possible. On the other hand, under private information, the effect of a marginal increase in the price of input q on welfare is

$$\sum_{i\in N}\left[\left(y_e\left(\boldsymbol{a}_i^*\right)-\kappa\right)\frac{\partial e_i^*\left(\alpha\right)}{\partial p^q}-z_i^{q*}\left(\alpha\right)\right].$$

Thus, under private information, the effort effect adds to the price effect. To determine the sign of the effort effect, recall that $y_e\left(\boldsymbol{a}_i^*\right)-\kappa<0$ (see Claim 2). When input q and effort are complements (i.e., $\partial e_i^*\left(\alpha\right)/\partial p^q>0$), the effort effect is negative; when they are substitutes ($\partial e_i^*\left(\alpha\right)/\partial p^q<0$), the effect is positive. This is intuitive: under private information, effort is underprovided. Subsidizing the price of an input complementing effort induces households to exert more effort, thus shrinking the negative externality generated by risk sharing. Conversely, subsidizing the price of an input substituting effort makes the households even less willing to exert effort, thus moving the effort allocation even further away from the full information benchmark. This implies that it, if input q and effort are complements, then it is optimal to subsidize the input as much as possible; on the other hand, if input q and effort are substitutes, then the effect of the subsidy is ambiguous, and depends on the trade-off between the welfare-improving price effect and the welfare-decreasing effort effect.

Endogenous sharing rule. Under full information, the welfare-maximizing sharing rule is full insurance independently of the agricultural input prices. Hence, even with endogenous insurance, the only relevant effect under full information is the price effect. On the other hand, when the sharing rule is endogenously chosen to maximize welfare under private information, insurance will respond to changes in the prices of agricultural inputs. This is because, by affecting effort provision, the subsidy will affect the marginal cost of risk sharing; i.e., the reduction in effort supply given rise by a marginal increase in insurance. Assuming an interior solution, the insurance effect is given by

$$\sum_{i\in N}\left[\rho\eta^2\left(1-\frac{1}{n}\right)\left(1-\alpha^*\right)\frac{\partial\alpha^*}{\partial p^q}\right].$$

Notice from Equation (6) that

$$-\frac{n\rho}{2}\frac{\partial \mathbb{V}\text{ar}\left(c_i\left(\alpha\right)\right)}{\partial \alpha}=\rho\eta^2\left(1-\frac{1}{n}\right)\left(1-\alpha^*\right), \tag{7}$$

the marginal benefit of insurance. Hence, the insurance effect is simply the change in insurance generated by a marginal change in the price of input q, multiplied by the marginal benefit of insurance. This effect is positive as long as insurance is increasing in p^q; i.e., $\partial\alpha^*/\partial p^q > 0$. To see when this condition holds, notice that Claim 6 implies that an optimal sharing rule is implicitly defined by

$$\frac{\partial W\left(\alpha^*\right)}{\partial \alpha}=0.$$

By the implicit function theorem, the effect of a marginal increase in the price of agricultural input q on optimal insurance is given by

$$\frac{\partial \alpha^*}{\partial p^q}=-\frac{\frac{\partial^2 W\left(\alpha^*\right)}{\partial \alpha^*\partial p^q}}{\frac{\partial^2 W\left(\alpha^*\right)}{\partial \alpha^{*2}}}.$$

Notice that local optimality implies that $\partial^2 W\left(\alpha^*\right)/\partial\alpha^{*2}<0$. Moreover,

$$\frac{\partial^2 W\left(\alpha^*\right)}{\partial \alpha^*\partial p^q}=\sum_{i\in N}\left[\kappa\left(\frac{1}{1-\frac{n-1}{n}\alpha}-1\right)\frac{\partial^2 e_i^*\left(\alpha^*\right)}{\partial\alpha\partial p^q}\right].$$

Hence, insurance is increasing in the price of input q as long as $\partial^2 e_i^*\left(\alpha^*\right)/\partial\alpha\partial p^q>0$. To gain intuition, notice that $\partial e_i^*\left(\alpha^*\right)/\partial\alpha<0$ is the decrease in effort supply associated to a marginal increase in the sharing rule, and recall from Equation (6) that this decrease is the main driver of the marginal cost of insurance. Also, Equation (7) makes it clear that the marginal benefit of insurance is independent of agricultural input prices. If $\partial^2 e_i^*\left(\alpha^*\right)/\partial\alpha\partial p^q>0$ then the marginal cost of insurance is smaller when the price of input q is higher, while the marginal benefit of insurance is independent of this price. Because of the concavity of the welfare function around α^*, when p^q increases marginally, a marginal increase in α is needed to reestablish the equality between the marginal benefit and the marginal cost of risk sharing.

3 Empirical Evidence

This section presents a description of the data used, reduced-form evidence confirming the main theoretical predictions linking risk sharing and agricultural production, and a structural estimation of the model outlined above. All tables and figures are reported in Appendix I.

3.1 Background and Data

I use data collected under the Village Dynamics in South Asia (VDSA) project by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT). This data is a household-level panel covering more than 700 households in 18 villages in the Indian semi-arid tropics. The data comes from survey interviews conducted at an approximately monthly frequency from 2009 to 2014. For each village, 40 households were randomly selected stratifying by own landholding classes: 10 from landless laborers, 10 from small farmers, 10 from medium farmers, and 10 from large farmers. I chose this data firstly because it provides detailed information on farming activity, expenditure, and income. Moreover, this data has been widely used to test risk sharing models; hence, my results can be compared with the findings of previous papers. I refer to Townsend (1994), Mazzocco and Saini (2012), and Morten (2017) for more detailed descriptions of the data.

There are three problems with the data: (i) the frequency of the interviews varies, (ii) the interview dates differ across households, and (iii) recall periods vary across interviews. Fortunately, from 2010 onwards, information is provided on the month and year to which a given interview refers to. Since recall periods can be longer than a month, it is impossible to determine to which month an interview refers to if this information is not provided. Therefore, I drop the observations from 2009.

For the estimation, I need information on demographic characteristics, consumption, income, agricultural intermediates, a proxy for effort, and prices of agricultural intermediates. In the following, I discuss how variables are constructed. Money values are converted in 1975 rupees for comparability with Townsend (1994).

Following Mazzocco and Saini (2012), I use the data coming from the General Endowment

Schedule to construct a set of observable household heterogeneity variables, which I use to build the age-sex weight proposed in Townsend (1994).

Monthly household consumption is calculated using the Transaction Schedule. This schedule reports household-level data on the value of items purchased, home produced, and acquired in other ways (such as gifts) is collected. Following Kinnan (2017), I sum the value of all items across categories to construct a measure of total household expenditure. Since different households have different sizes and age-sex structure, I convert total household expenditure to adult-equivalent terms by dividing it by the age-sex weight.

Monthly household income is calculated Mazzocco and Saini (2012)'s methodology. Making use of the household budget constraint, total income is computed as total expenditure minus resources borrowed, plus resources lent and saved, minus government benefits. Information on these variables is contained in the Transaction Schedule. The data is aggregated following the same procedure I use to calculate monthly household consumption. Again, I convert total household income to adult-equivalent terms using the age-sex weight.

The Cultivation Schedule contains information on the quantity and total value of each type of agricultural intermediate and labor used in all the operations performed (e.g., harvesting, irrigating, sowing) on every plot cultivated by the household. A distinction is made between family, hired, and exchanged labor. To build a proxy for monthly effort supply, I first compute the total amount of hours of work supplied by family members to the operations performed on all the plots cultivated by the family in each month. Then, I convert this measure to adult-equivalent terms using the age-sex weight.[15]

The Cultivation Schedule provides information on several agricultural intermediates; however, constructing an aggregate agricultural intermediate use variable is not straighforward. The reason is that the data reports the name of the agricultural intermediate (e.g., DAP, Pursuit, Acephate) but not its type (e.g., fertilizer, herbicide, pesticide). Hence, one would have to look manually for the type of each agricultural intermediate name reported, and there are almost 1000 different agricultural intermediate names. Given the importance played by fertilizers in agricultural production, I focus solely on constructing an aggregate fertilizer use

[15]Proxing effort by hours of work is not entirely uncommon: see e.g. Clark et al. (2003).

variable.[16] To aggregate use of different fertilizers into a per capita measure of fertilizer use at the household-month level, I sum the total *value* (instead of the physical quantity) of each type of fertilizer used in each operation performed on every plot (see Chen et al. (2017)). Then, I convert this measure to adult-equivalent terms using the age-sex weight. According to the Manual of Instructions for Economic Investigators in ICRISAT's Village Level Studies (see Singh et al. (1985)), the value of fertilizer is calculated on the basis of the prevailing market price. For my purposes, the key is that per capita fertilizer use at the household-month level reflects physical variation in physical quantity of different types of fertilizers. Valuing output at common market prices should therefore allow me to compare per capita fertilizer use across households and months, reflecting variation in quantity of fertilizers used.

Fertilizer prices are calculated using the Monthly Price Schedule. Interviews on fertilizer prices are not conducted at the household level. Instead, in each village, five respondents—labeled A, B, C, D, and E—are asked to report the average price of each type of fertilizer. These respondents correspond to a large farmer, a medium farmer, a landless laborer, a village trader, and a trader from the nearest market. Hence, for each village-month pair, five different prices are reported for each type of fertilizer. Since my fertilizer use variable is defined at the household-month level, I also need to aggregate these fertilizer prices at the household-month level. For each respondent, I average fertilizer prices across types of fertilizers. Then, I assign the average price reported by the large farmer (respondent A) to large landholding households and the average price reported by the medium farmer (respondent B) to medium landholding households. Then, I average the average fertilizer prices across all respondents and assign this average price to the rest of the households.

Summary statistics for the sample are reported in Table 1.

3.2 Reduced-Form Evidence Linking Agricultural Production and Risk Sharing

I document the following facts in the data: (i) risk sharing is imperfect; (ii) effort is lower when there is more risk sharing; (iii) effort supply and fertilizer use are positively correlated; and

[16] In the future, I plan to construct other aggregate agricultural intermediate use variables.

(iv) effort is lower when there is more risk sharing.

Risk sharing is imperfect. I estimate the following regression for household i in village v and month t:

$$\log(c_{it}) = \beta_1 \log(y_{it}) + \varphi_i + \phi_{vt} + \epsilon_{it}, \tag{8}$$

where φ_i and ϕ_{vt} are household and village-month fixed effects. Equation (8) is taken from Morten (2017). It estimates the elasticity of consumption with respect to income after controlling for aggregate income through village-month fixed effects. Standard errors are robust.

Table 2 reports the results of the test. Full sharing is strongly rejected. The elasticity of consumption with respect to income is approximately 0.26. Although the magnitude of this coefficient varies across studies, a value of 0.26 falls well within the expected range. For instance, Munshi and Rosenzweig (2009) estimate values between 0.17 and 0.26 for rural India, using data from the Rural Economic and Demographic Survey (REDS); Cochrane (1991) finds values between 0.1 and 0.2 for the United States using data from the Panel Study of Income Dynamic (PSID); Milán (2016) finds a value of 0.35 for indigenous villages in the Bolivian Amazon. Overall, the results square fairly well with the literature and unequivocally reject full insurance.

As robustness checks, I estimate Equation (8) aggregating the data at a quarterly and annual frequency, and run the alternative specifications outlined in Jalan and Ravallion (1999) and Mazzocco and Saini (2012). Reassuringly, the results do not change.

Effort is lower when risk sharing is higher. Theorem 1 says that effort decreases when risk sharing increases. To analyze the correlation between risk sharing and effort, I follow Morten (2017) and estimate the following regression:

$$\log(c_{it}) = \beta_1 \log(y_{it}) + \beta_2 \log(y_{it}) \overline{\log(e_i)} + \varphi_i + \phi_{vt} + \epsilon_{it}, \tag{9}$$

where e_{it} is the adult-equivalent total work hours supplied to own fields by household i in month t, and $\overline{\log(e_i)}$ is the average effort supplied by household i.[17] Coefficient β_2 is the correlation between average effort supplied at the household level and the elasticity of consumption with respect to the idiosyncratic component of income. If insurance is negatively correlated to effort, β_2 should be positive. In this case, the slope of consumption on income is higher as average effort increases. That is, comparing two households which are identical across any dimension captured by the household and village-month fixed effects, a positive β_2 indicates that the consumption of the household that supplied more effort is expected to be more responsive to idiosyncratic shocks to own income. Table 3 reports the results of the OLS estimation of Equation (9). The interaction term is positive and significant. To get a sense of the magnitudes, assume that effort supply is constant in time. Then, on average, doubling effort provision is associated to 14% increase in the elasticity of consumption with respect to income. This confirms that households that are less well insured put more effort.

Notice that, in Equation (9), I interact $\log(y_{it})$ with $\overline{\log(e_i)}$ instead of $\bar{e}_i$, hence effectively giving less weight to higher values of $\bar{e}_i$. Indeed, the relationship between insurance and and effort is non-linear. This can be seen by running the following regression:

$$\log(c_{it}) = \beta_1 \log(y_{it}) + \beta_2 \log(y_{it}) \bar{e}_i + \beta_3 \log(y_{it}) \bar{e}_i^2 + \varphi_i + \phi_{vt} + \epsilon_{it}. \quad (10)$$

Table 4 gives the results of the OLS estimation of the Equation (10). The interaction between the log of income and average effort is positive and significant, confirming the results obtained in Table 3. However, the interaction between the log of income and average effort squared is negative and significant. This suggests that as average effort supply increases, the negative relationship between effort and insurance becomes weaker. When omitting $\log(y_{it}) \bar{e}_i^2$(10) from Equation (10), β_2 narrowly becomes insignificant, suggesting that the non-linearity between effort and insurance is important.

Even though these tests do not speak to causality, they are consistent with the model and

[17] The main effect of $\overline{\log(e_i)}$ is omitted because it is captured by the household fixed effects. If I were to interact $\log(y_{it})$ with $\log(e_i)$, I would need to control for the main effect of $\log(e_i)$. Unfortunately, this strategy does not produce good results, as $\log(y_{it}) \log(e_i)$ and $\log(e_i)$ are almost collinear. This makes the standard errors explode, while barely affecting the point estimate of the interaction term.

provide suggestive evidence about the disincentive effect of insurance.

Effort and fertilizer. Next, I provide evidence about the complementary between effort and fertilizer. I run the following regression equation:

$$\log(f_{it}) = \gamma \log(e_{it}) + \varphi_i + \ell_{it} + \tau_t + \epsilon_{it}, \tag{11}$$

where f_{ivt} is the adult-equivalent value of fertilizer used by household i, ℓ_{it} is land area, and τ_t are month fixed effects. My measure of fertilizer includes organic compounds (such as urea), micro-nutrients, and manure. The results are reported in Table 5. Effort is significantly positively correlated with fertilizer, which suggests the existence of a complementarity.[18] Indeed, an argument to see why it makes sense to think of fertilizer as a complement to effort is the following. Fertilizer is generally considered to be a land-augmenting technologies: in efficiency units, a quantity of fertilized land can be conceived as a multiple of a smaller quantity of unfertilized land. Hence, whenever land and effort are complementary, so are effort and fertilizer.

I run a version of Equation (11) in levels as robustness check, and find that all the results go through.[19]

Fertilizer is lower when risk sharing is higher. Theorem 1 implies that (i) if a technology is complementary to effort, households use less of it as long as they are better insured; (ii) if a technology substitutes effort, households use more of it as long as they are better insured. Before, I provided suggestive evidence about the complementarity between effort and fertilizer. Hence, I expect to observe a negative correlation between insurance and fertilizer use. To test this hypothesis, I begin by running the following regression:

$$\log(c_{it}) = \beta_1 \log(y_{it}) + \beta_3 \log(y_{it}) \overline{\log(f_{it})} + \varphi_i + \phi_{vt} + \epsilon_{it}. \tag{12}$$

[18] A formal test for the complementarity between effort and fertilizer requires one to estimate the elasticity of substitution between effort and fertilizer. This test is carried out in Subsection 3.3.

[19] As a cautionary note, regression (11) surely cannot be interpreted in a casual fashion. In particular, there is an obvious problem of reverse causality. This is why the structural estimation of the elasticity of substitution between effort and fertilizer in Subsection 3.3 is needed to confirm the suggestive evidence herein reported.

The correlation between average fertilizer use and the elasticity of consumption with respect to income is given by β_3. If insurance is negatively correlated to the use of fertilizer, β_3 should be positive, and negative otherwise. Table 6 reports the results of running regression (12). Indeed, the results show that β_3 is positive and significant.

For completeness, I test the non-linearity between risk sharing and fertilizer use by running the following regression:

$$\log\left(c_{it}\right) = \beta_1 \log\left(y_{it}\right) + \beta_2 \log\left(y_{it}\right) \overline{f}_i + \beta_3 \log\left(y_{it}\right) \overline{f}_i^2 + \varphi_i + \phi_{vt} + \epsilon_{it}. \tag{13}$$

Table 7 gives the results of the OLS estimation of the Equation (10). While coefficients β_2 and β_3 narrowly lose significance, the signs of the coefficients clearly confirm the same intuition provided by Table 4.

3.3 Structural Estimation of a Simple Model of Risk Sharing

I now estimate the model outlined in Section 2. The estimates obtained in this subsection can be used to quantify the effect of risk sharing on effort supply and agricultural input use, as well as performing policy simulations. My strategy is to estimate the relative demand of fertilizer to effort, making use of Claim 2. Once I estimate this relative demand, I proceed to (i) quantify the impact of risk sharing on effort supply and fertilizer use, (ii) back out the optimal sharing rule, making use of Claim 4, and (iii) simulate the effect of a fertilizer subsidy on risk sharing and consumption-equivalent welfare.

This subsection begins by describing the identification and estimation of the model. The key advantage of this model is that strategic interactions between households are greatly simplified by the assumptions that (i) households have mean-variance expected utility and (ii) the sharing contract is linear (see Subsection A.1). Relaxing these assumptions would typically give rise to more complex strategic interactions, hence making identification and estimation substantially more complex. On the negative side, these assumptions are detrimental to the richness of the model and its ability to capture relevant sources of variation in the data.

First, I impose a specific functional form to the production function. In particular, assume that the value of agricultural output is given by

$$y(\boldsymbol{a}_i) = \ell_i^{1-\chi}\left[e_i^{\frac{\sigma-1}{\sigma}} + f_i^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\chi\sigma}{\sigma-1}},$$

where $\chi \in (0,1]$, $\sigma \in (0,\infty)$ is the elasticity of substitution between effort and fertilizer, and ℓ_i is land, which I assume to be fixed.[20] With this production function, the first-order conditions for effort and fertilizer given in Claim 2 read as follows:

$$\ell_i^{1-\chi}\chi\left[e_i^{*\frac{\sigma-1}{\sigma}} + f_i^{*\frac{\sigma-1}{\sigma}}\right]^{\frac{\chi\sigma}{\sigma-1}-1} e_i^{*-\frac{1}{\sigma}} = \frac{\kappa}{\left(1-\frac{n-1}{n}\alpha\right)}$$

and

$$\ell_i^{1-\chi}\chi\left[e_i^{*\frac{\sigma-1}{\sigma}} + f_i^{*\frac{\sigma-1}{\sigma}}\right]^{\frac{\chi\sigma}{\sigma-1}-1} f_i^{*-\frac{1}{\sigma}} = p,$$

where p denotes the price of fertilizer. Dividing the second equation by the first one, rearranging, and taking logs, I obtain

$$\log\left(\frac{f_i^*}{e_i^*}\right) = \sigma\log(\kappa) - \sigma\log\left(1-\frac{n-1}{n}\alpha\right) - \sigma\log(p).$$

In the data, I observe consumption (c), income (π), effort (e), and fertilizer use (f). The parameters of interest are the elasticity of substitution between effort and fertilizer (σ), the marginal disutility of effort (κ), and the wedge between the private and social marginal benefit of effort ($1-\frac{n-1}{n}\alpha$). Assuming that the model is correctly specified, if there is an error in the measurement of fertilizer or effort, I can estimate

$$\log\left(\frac{f_{it}}{e_{it}}\right) = \sigma\log(\kappa_i) - \sigma\log\left(1-\frac{n_{vt}-1}{n_{vt}}\alpha_{vt}\right) - \sigma\log(p_{it}) + \epsilon_{it}, \tag{14}$$

[20] Hence, the production function exhibits non-increasing returns to scale in $\boldsymbol{a}_i$. When performing the estimation and the counterfactual exercise, one can safely assume that $\chi = 1$ (i.e., constant returns in $\boldsymbol{a}_i$). However, when computing the optimal sharing rule and performing the policy analysis, I need to assume that $\chi < 1$ (i.e., decreasing returns in $\boldsymbol{a}_i$). This is because carrying out these two tasks requires me to calculate the responsiveness of effort supply and fertilizer use to α and the price of fertilizer. To see why I need decreasing returns to calculate this responsiveness, recall that the household's problem is equivalent to that of a competitive firm facing a real price of input q equal to p^q and a real price of effort equal to $\kappa\left(1+\frac{n-1}{n}\alpha\right)^{-1}$. (See the proof of Theorem 1.) Under constant returns, the profit-maximizing choices of inputs by a competitive firm are indeterminate. So, either one imposes an additional constraint to pin down some *ad hoc* production level to back out $\boldsymbol{a}_i^*$, or constant returns to scale should be abandoned.

where I am assuming that the marginal disutility of effort, κ, is constant in time but possibly heterogeneous across households. Notice that village size and risk sharing are allowed to be time varying and village specific. In principle, α_{vt} could also be defined at the household level. For example, when using the time series estimation proposed by Townsend (1994), the risk sharing coefficient is assumed to be household specific and time invariant. On the other hand, if one estimates α by following a pooling strategy, as I do in Subsection 3.2, then this coefficient is assumed to be constant across households, villages, and time. I do not take a stance on whether α_{vt} varies across time or villages, but I do require α_{vt} *not* to be household specific. This is a necessary condition to identify the parameters of interest, as explained below.

Estimation. Under the premise that the model is correctly specified, the underlying assumptions for the consistent estimation of σ, κ_i, and $\left(1 - \frac{n_{vt}-1}{n_{vt}}\alpha_{vt}\right)$ is that (i) the measurement error in fertilizer or effort is uncorrelated with any of the independent variables, and (ii) there is no measurement error in the price of fertilizer. In this case, one can use OLS to estimate the following regression equation:

$$\log\left(\frac{f_{it}}{e_{it}}\right) = \varphi_i + \phi_{vt} - \sigma \log\left(p_{it}\right) + \epsilon_{it},$$

where φ_i are household fixed effects and ϕ_{vt} are village-month fixed effects, which estimate κ_i and $\left(1 - \frac{n_{vt}-1}{n_{vt}}\alpha_{vt}\right)$, respectively. The identification of κ_i relies on the assumption that risk sharing is not household-specific; otherwise, φ_i would be also capturing variation in risk sharing at the household level. Also notice that I need both cross-sectional and time variation in fertilizer prices, because otherwise all their variation would be captured by the fixed effects.

The estimated elasticity of substitution between effort and fertilizer, $\widehat{\sigma}$, is approximately equal to 0.35, confirming the complementarity between effort and fertilizer suggested by the evidence presented in Section 3.2.

In order to back out the marginal disutilities of effort, I compute $\widehat{k}_i = \exp\left\{\widehat{\log\left(\kappa_i\right)}\right\}$, where $\widehat{\log\left(\kappa_i\right)}$ is obtained by diving the household fixed effects by $\widehat{\sigma}$. Figure 1 shows the histogram of $\widehat{k}_i$.[21] The median marginal disutility of effort is approximately 3.7. To get a sense of this

[21] I only show the estimates up the 85th percentile to make the graph more readable.

number, assume that households have quadratic utility. Then, on average, the increase in consumption that would exactly compensate household i for an increase in one hour of work (i.e., the marginal rate of substitution of effort for consumption) is pinned down by the following equation:

$$\frac{\mathrm{d}c_i(\alpha)}{\mathrm{d}e_i} = \frac{3.7}{\rho c_i(\alpha)}.$$

As average household consumption is approximately 118 rupees, the increase in consumption compensating the average household for an additional hour of work is $0.031\rho^{-1}$ rupees. According to the estimates provided by the Indian government (Indian Labour Bureau (2010)), in 2009, the daily wage rate for an adult male agricultural worker fell in the range of 50 to 120 2009 rupees, which roughly correspond to a hourly wage rate (assuming eight hours of work per day) of 0.5 to 1.2 1975 rupees. If the labor market were competitive, then the marginal rate of substitution of effort for consumption would be equal to the hourly wage rate. This would imply a coefficient of absolute risk aversion between 0.062 and 0.026. These numbers are comparable with the coefficients of absolute risk aversion for medium stakes estimated by Binswanger (1981).

I can back out the wedges between the private and social marginal benefit of effort using the same procedure employed to obtain the marginal disutilities of effort. Clearly, n_{vt} and α_{vt} cannot be separately identified. Nevertheless, following the standard practice in the literature (Ligon et al. (2002), Laczó (2015), Bold and Broer (2016)), I can set village size equal to the number of households sampled by ICRISAT and back out a structural estimate of risk sharing at the village-month level, $\widehat{\alpha}_{vt}$, by computing

$$\widehat{\alpha}_{vt} = \left(1 - \widehat{\zeta}_{vt}\right) \frac{\widetilde{n}_{vt}}{\widetilde{n}_{vt} - 1},$$

where $\widetilde{n}_{vt}$ is the imputed number of households sampled by ICRISAT. The number of households observed for each village and month is rather small: on average, less than 40 observations are used to compute a village-month fixed effect. This implies that $\widehat{\zeta}_{vt}$ is likely to be imprecisely estimated. By construction, $\zeta_{vt} \in [0, 1)$; however, half of the estimates of ζ_{vt} fall out of this range, being bigger than one. These observations cannot be used to estimate α_{vt}, because they would imply a negative sharing coefficient. The histogram of $\widehat{\alpha}_{vt}$ I obtain after dropping the estimates of ζ_{vt} that are bigger than one is given in Figure 2. On average, $\widehat{\alpha}_{vt}$ is equal to 0.7, but the estimates are more concentrated on the right of the distribution, with the median being equal to 0.8. Overall, these numbers square fairly well with existing empirical evidence on risk sharing in village economies, as well with the estimates obtained using the contrast estimator on my data (see Appendix C).

Comparative Statics. I consider the following comparative statics exercise: how do choices of fertilizer and effort change when insurance changes? From Equation (14), one can see that, once parameters σ, κ_i, and n_{vt} are pinned down, I can freely move the sharing coefficient, α, hence quantifying its effect on the expected relative choices of fertilizer over effort, $\mathbb{E}\left(\frac{f_{it}}{e_{it}}\right)$. I pin down parameters σ and κ_i by using the estimates obtained in the previous paragraph. As for n_{vt}, I set village size equal to the number of households sampled by ICRISAT. Formally, I compute

$$\widetilde{x} := \widetilde{\log\left(\frac{f_{it}}{e_{it}}\right)} = \widehat{\sigma}\widehat{\log\left(\kappa_i\right)} - \widehat{\sigma}\log\left(1 - \frac{\widetilde{n}_{vt} - 1}{\widetilde{n}_{vt}}\widetilde{\alpha}_{vt}\right) - \widehat{\sigma}\log\left(p_{it}\right),$$

where $\widetilde{n}_{vt}$ is the number of households sampled by ICRISAT, $\widetilde{\alpha}_{vt}$ is imputed by me, and $\widetilde{x}$ is the resulting choice of fertilizer over effort (i.e., fertilizer used per hours worked). Figure 3 shows the kernel density estimate of fertilizer used per hours worked when setting $\widetilde{\alpha}_{vt} = 0$ (black) and $\widetilde{\alpha}_{vt} = 1$ (grey). (The upper bound of the support of the two distributions is set equal to 10 to make the graphs readable.) The summary statistics of $\widetilde{x}$ for $\widetilde{\alpha}_{vt} = 0$ (black) and $\widetilde{\alpha}_{vt} = 1$ are reported in Table 9. On average, when going from no insurance ($\alpha = 0$) to full insurance ($\alpha = 1$), the growth rate of fertilizer over effort is $1.6952 + .6033 = 2.2985$; i.e., fertilizer over effort is more than four times higher under full sharing than under autarky. The intuition behind this result is that both effort supply and fertilizer use decrease when moving from autarky to full sharing; however, effort supply is more responsive to changes in risk sharing than fertilizer use, and hence goes down more than what fertilizer use does. This simple calculation highlights that risk sharing is a quantitatively important factor in shaping households' effort supply and fertilizer use.

The comparative statics exercise presented up to this point show the quantitative effect of risk sharing on fertilizer use per hours worked. Next, let me disentangle the effect of risk sharing on effort supply and fertilizer use. The analytical steps required to do perform the disentanglement are outlined in Appendix E. Tables report the summary statistics of the growth rates of effort and fertilizer use when going from $\alpha = 0$ to $\alpha = 1$ are reported in Table 10. When going from no insurance to full insurance, the average growth rate of fertilizer use is -100%; hence, on average, fertilizer use is halved. On the other hand, on average, effort supply decreases by more than 6 times.

It is interesting to understand which households are more affected by insurance. I find that, on average, effort supply and fertilizer use is more responsive to changes in insurance for bigger households, and that effort supply is less responsive to changes in insurance for households with higher monthly income. Also, bigger households have lower monthly income on average. Overall, these pieces of evidence suggest that the choices of poor households are more affected by changes in insurance relative to the choices of rich households. A possible explanation to this evidence is that relatively poor households rely more on village-level risk-sharing arrangements than richer households.

Validating the Model. The reduced-form test for perfect risk sharing conducted in Subsection 3.2 indicates that the elasticity of consumption with respect to idiosyncratic income shocks is approximately equal to 0.74 (see Table 2). If I take this elasticity as a proxy measure for α, I can consider the following validation exercise: compare the distribution of simulated fertilizer per hours worked for $\alpha = 0.74$ with the actual distribution of fertilizer over effort. If this elasticity is indeed a good proxy measure for α, and if the model is 'well specified,' then one should expect the simulated distribution for $\alpha = 0.74$ to be able to match reasonably well the moments of the actual distribution. Figure 4 compares the two distributions. The grey line is the density of simulated fertilizer per hours worked, while the grey line is the density of the data. As one can see, this validation exercise provides visual confirmation of the ability of the model to capture relevant sources of variation in fertilizer per hours worked.

A second validation exercise is the following. Calibrate the sharing rule to match a particular moment of the distribution of fertilizer per hours worked, and compare the resulting calibrated rule with estimates of α. If the model performs well, then the calibrated rule should be comparable to these estimates. First, I calibrate the sharing rule to match the mean of fertilizer per hours worked. To do so, I pick an α that minimizes the mean squared difference between $\log(f_{it}/e_{it})$ and $\log\widetilde{(f_{it}/e_{it})}$. The calibrated α is approximately 0.82, a number that squares very well with existing estimates of risk sharing. I also calibrate the sharing rule to match the median of fertilizer per hours worked. To do so, I choose an α that minimizes the mean absolute difference between $\log(f_{it}/e_{it})$ and $\log\widetilde{(f_{it}/e_{it})}$. In this other case, the calibrated α is approximately 0.75, which is extremely close to elasticity of consumption with respect to idiosyncratic income shocks estimated in Subsection 3.2.

A third validation exercise is as follows. Given the estimates of α obtained above, predict consumption using Equation (3). (Refer to this predicted consumption as simulated consumption.) Then, estimate Equation (8) using simulated consumption instead of actual consumption. If the model performs well, the estimated elasticity of simulated consumption with respect to idiosyncratic income shocks should be comparable to the estimates obtained in Subsection 3.2. Fist, I simulate consumption using the calibrated sharing rules calculated in the previous graph; then, I do so by using the estimated sharing rules backed out using $\widehat{\zeta}_{vt} := \left(1 - \widehat{\frac{n_{vt}-1}{n_{vt}}\alpha_{vt}}\right)$ and setting village size equal to the number of households interviewed by ICRISAT (I disregard the estimated sharing rules that do not lie in the $[0, 1]$ interval). Table 8 reports the OLS estimation of simulated consumption on actual income controlling for household and village-time fixed effects. Then, I simulate consumption using the estimated sharing rules computed in the previous paragraph. The elasticity of simulated consumption to idiosyncratic income shocks is positive and significant. When I use the α calibrated to match the mean of fertilizer use per hours worked the elasticity is 0.16, while when I use the α calibrated to match the median the elasticity is 0.21. These estimates are close to 0.26, the elasticity estimated using actual consumption in Subsection 3.2. However, my model seems to slightly underestimate the empirical loading on own income. Underestimation of income elasticity of consumption might be expected, as there probably are other relevant impediments to risk sharing other than private information frictions. When I use the the estimated sharing rules, elasticity is 0.29, which is slightly bigger than the actual elasticity. This slight overestimation might be due to the fact that the number of observations is significantly smaller.

Optimal risk sharing. Next, I compute the optimal sharing rule, solving Equation (6). Appendix F reports the algebraic steps to solve this equation, and shows that I need values for χ, ρ, and η^2. Notice that my empirical strategy does not allow to retrieve these parameters. Hence, I proceed as follows. I build a grid of possible values for χ and ρ. In principle, $\chi \in [0, 1]$; however, for computational reasons, I take $\chi \in (0.1, 0.9)$.[22] and, following the evidence presented in Binswanger (1981), $\rho \in [0.001, 0.500]$. I set $\eta = 0.75$, following Morten (2017)'s estimate. Figure 5 shows the optimal sharing rule as a function of χ and ρ. The rows represent different values of ρ, and the columns represent different values of χ. The colors in the box represent different values of the optimal sharing rule: the darker a point, the closer to autarky. A first intuition is that when households are more risk averse it is optimal to give them more insurance: for a given χ, optimal sharing increases when moving to the right. The relationship between optimal sharing and land share is more complex and can exhibit a non-monotonicity. To see this, notice that, when ρ is sufficiently close to 0.001, the optimal sharing rule first decreases and then increases in χ. This non-monotonicity happens because the responsiveness of effort to the effective price of effort depends non-monotonically on χ.[23]

Optimal risk sharing: The Effect of a Fertilizer Subsidy. The Indian government subsidizes fertilizer by assigning a so-called retention price to fertilizer. This price is fixed; i.e., it is independent of the quantity of fertilizer bought and sold in the market. The government pays the difference between retention price and sale price as subsidy to fertilizer manufactures for each unit sold. Hence, from the standpoint of the households, the government is exogenously changing the price of fertilizer. My model implies that fertilizer subsidies will affect risk sharing. Intuitively, when fertilizer price decreases, fertilizer use increases. Since effort and fertilizer are complements, households exert more effort. Thus, effort shifts to a flatter region of the marginal product curve. This shift increases the marginal cost of risk sharing, because now a marginal increase in α gives rise to a bigger decrease in effort supply. Hence, I expect the optimal sharing rule to be decreasing in fertilizer subsidy. Figure 6 plots the optimal risk sharing rule (on the

[22]To solve Equation (6), I make use of the bisection method, which is quicker but simpler than Newton's method. When χ gets close to 0 or 1, the bisection method does not perform well, as it is not able to compute any root.

[23]In particular, $\partial e_i^* / \partial p_e \, (\alpha)$ it is first increasing and then decreasing in χ. Hence, when χ is sufficiently small, the cost of risk sharing (in terms of underprovision of effort) is increasing in χ, then becoming decreasing in χ.

y-axis) against $s \in (0,1]$ (on the x-axis), where I define s to be such that the price of fertilizer faced by household i in month t is sp_{it}.[24] Hence, one can see that higher fertilizer price leads to more risk sharing. For example, if the fertilizer subsidy is set cut fertilizer price in half, my model predicts that risk sharing goes from 0.83 to 0.77, an almost 8% drop.

Another implication of my model is that if the countervailing effect of insurance on fertilizer use is not taken into account, a researcher would overestimate the elasticity of fertilizer to subsidy. The standard practice to estimate input demands in agricultural economics begins by specifying a translog production function, which can be conceived as a linear approximation to a CES production function. Then, Sheppard lemma is invoked to state that

$$\frac{\partial \pi_{it}}{\partial p_{it}^{f}} = f_{it}^{*} = \beta_f + \beta_{fy} \log(y_{it}) + \beta_{fe} \log(p_{it}^{e}) + \beta_{ff} \left(p_{it}^{f}\right).$$

Suppose that one does not take into account the effect of risk sharing on fertilizer use. Then, one would estimate

$$\frac{\partial f_{it}^{*}}{\partial p_{it}^{f}} = \beta_{ff} \frac{1}{p_{it}^{f}}.$$

On the other hand, my model suggests that

$$\frac{\partial f_{it}^{*}}{\partial p_{it}^{f}} = \beta_{fe} \frac{1}{p_{it}^{e}} \frac{\partial p_{it}^{e}}{\partial \alpha^{*}} \frac{\partial \alpha^{*}}{\partial p_{it}^{f}} + \beta_{ff} \frac{1}{p_{it}^{f}}.$$

Since effort and fertilizer are complements, $\beta_{fe} < 0$; moreover, I have argued above that $\partial \alpha^{*}/\partial p_{it}^{f} > 0$. Hence, noticing that $\beta_{ff} < 0$ and $\partial f_{it}^{*}/\partial p_{it}^{f} < 0$, one can see that

$$\frac{\partial f_{it}^{*}}{\partial p_{it}^{f}} < \beta_{ff} \frac{1}{p_{it}^{f}}.$$

Optimal fertilizer subsidy. Next, let me consider the problem of designing an optimal fertilizer subsidy. This problem is interesting as it involves a trade-off between aggregate output and risk sharing. A simple way to formalize this problem is outlined in Appendix G. I have argued above that $\partial \alpha^{*}/\partial p > 0$ (see Figure 6). Hence, to be sure, a fertilizer subsidy has a cost in terms of social welfare, as it reduces risk sharing. On the other hand, a fertilizer subsidy

[24] To draw this graph, I take $\rho = 0.01$ and $\chi = 0.6$.

increases effort supply. To see why this is the case, notice that, first of all, effort supply increase when fertilizer price decreases, because effort and fertilizer are complements. Moreover, since $\partial\alpha^*/\partial p > 0$, a decrease in fertilizer price also decreases the effective price of effort. Increasing effort supply has an undoubted positive impact on social welfare. This is because, at the outset, there is underprovision of effort due to the negative externality generated by risk sharing, so that increasing effort supply gets the economy closer to the efficient action profile. So, in general, the effect of a fertilizer subsidy on social welfare is ambiguous: on the one hand, there is an increase in the size of the pie, as households exert more effort; on the other hand, the split of the pie gets worse, as risk sharing deteriorates.

In the previous paragraph, I show that cutting fertilizer price in half leads to an almost 8% drop in risk sharing. However, we are ultimately interested in social welfare. I find that the consumption-equivalent gain in welfare from cutting the price of fertilizer in half is 47%. Hence, while being detrimental to risk sharing, the social benefit of the increase in aggregate output markedly overcomes the social cost of getting worse insurance.

4 Conclusions

While rural households in low-income countries face sizable random fluctuations in income, they often lack access to formal insurance. Despite this shortfall, these households manage to smooth their consumption, albeit imperfectly, by relying on informal insurance arrangements. Given the pervasiveness of these type of arrangements in village economies, it is paramount to uncover their impact on technology adoption and agricultural input use, an extremely relevant topic in today's academic and policy circles. Studies on risk sharing abound, but few of them try to relate informal insurance to agricultural production decisions. In this paper, I analyze the impact of informal insurance arrangements on agricultural input use when there are private information frictions in production decisions. Once the presence of these frictions is taken into account, risk sharing is shown to play a significant and quantitatively important role in explaining farmers' effort supply and fertilizer use in rural India.

The paper makes use of the following two insights. First, informal insurance may well have a discouraging effect on households' incentives to exert effort, as economists have long been arguing. Second, effort exhibits different degrees of complementarity and substitutability with distinct agricultural intermediates, such as fertilizer. The paper outlines a static model of linear risk sharing with private effort and private agricultural inputs which combines these two insights, and demonstrates theoretically that better insured households decrease effort provision, increase the rate of adoption of inputs substituting effort, and decrease the use of inputs complementing effort. The model is useful in generating testable implications for the sign of the correlation between insurance and input use based on the complemenarity or substitutability between that input and effort. Moreover, it can be easily tested with a number of different data sets, as it only requires data on consumption, income, and agricultural activities to be present.

I test the model using the last ICRISAT panel from rural India. First, I propose a reduced-form strategy to test the main theoretical predictions. I confirm these predictions by showing that (i) insurance and effort supply are negatively correlated, (ii) effort supply and fertilizer use are positively correlated (which I interpret to be suggestive evidence of the existence of a complementarity), and (iii) more insurance is associated to lower fertilizer use, as the theory suggests. Then, I structurally estimate the model. I obtain estimates for the elasticity of substitution between effort and fertilizer, the household-specific marginal disutility of effort, and the village-month-specific constrained-efficient sharing rule. I use these estimates to quantify the importance of risk sharing on fertilizer use and effort supply. I find that insurance plays a big role in shaping households' production decisions: when moving from no insurance to full insurance, average fertilizer use is cut in half and average effort supply decreases by more than 6 times. I also analyze the effect of a fertilizer subsidy on risk sharing and social welfare. My model predicts that a 50% reduction in fertilizer price would make risk sharing go from 0.83 to 0.77; i.e., an almost 8% drop. More importantly, the consumption-equivalent gain in welfare from cutting fertilizer price in half is 47%,[25] implying that the social benefit of getting the economy closer to the efficient action profile is much bigger than the social cost of deteriorating risk sharing.

[25] This gain is defined as the percentage increase in aggregate consumption that would make the planner indifferent to switching back from the subsidized fertilizer price to the actual price.

Clearly many factors have been suggested that surely play a relevant role in explaining farmers' decisions of effort supply and agricultural input use. Moreover, insurance itself may affect input use through channels different from the one I propose here. For example, Miller and Paulson (2007) argues that better insured households shift their portfolios toward riskier investments, and hence should be more willing to increase their use of riskier technologies. On the other hand, Jakiela and Ozier (2015) introduces the idea of a kinship tax discouraging productive activities. They demonstrate that individuals are willing to reduce their income in order to keep it hidden to their kin and neighbors. This evidence suggests that informal insurance might give rise to a public good problem, preventing the adoption of a profitable technology for the fear of being forced to share the proceeds of that technology. These views and the one I propose here complement each other and together deepen our knowledge of how informal insurance affects agricultural input use. Indeed, the fact the use of different agricultural inputs might also affect output volatility would open a new channel through which insurance might affect input use. While my model strips away from this channel, if the marginal impact of inputs on output volatility is not too big, then the insights here presented would remain valid.

While this paper has been focusing on agricultural input use, many other production decisions may also be jointly determined with informal insurance. For example, in a very promising project, Mazur (2018) studies the joint determination of risk sharing and commonly owned agricultural equipment in the presence of limited commitment frictions. This project and my paper are part of a very recent endeavor to analyze the interaction between informal insurance and different decisions made by households in village economies (Advani (2017) and Morten (2017)). I strongly believe that this recent surge of interest in the impact of risk-sharing arrangements on different facets of the village economy is motivated by the recognition that the design of these institutions can interact with households' decisions through different frictions at place. A fruitful avenue for future research may be to not only take into account the interaction of risk sharing and agricultural input use, but to simultaneously consider the presence of other frictions and production choices. For example, what if, as Mazur (2018) suggests, under limited commitment villages that share more also choose to cultivate crops that rely more heavily on commonly owned agricultural equipment, such as rice? And what if fertilizer is relatively more productive when applied to rice? Then, interestingly, the presence of the limited commitment friction may reduce the severity of private information in production decisions.

A A Full-Fledged Model of Risk Sharing

In this appendix, I extend the model outlined in Section 2 by dropping the assumption that sharing contracts are linear.

As before, consider n household-farms, each of which chooses an action, $\boldsymbol{a}_i = (e_i, \boldsymbol{z}_i)$, which is combined with an idiosyncratic productivity shock, ε_i, to generate a random output, $y_i = y(\boldsymbol{a}_i) + \varepsilon_i$. Let

$$\begin{aligned} \pi_i := \pi(\boldsymbol{a}_i, \varepsilon_i) &:= y_i - \boldsymbol{p}\boldsymbol{z}_i \\ &= y(\boldsymbol{a}_i) + \varepsilon_i - \boldsymbol{p}\boldsymbol{z}_i \end{aligned} \tag{15}$$

be i's profit. Denote by Φ^{ε_i} and ϕ^{ε_i} the cumulative distribution function (CDF) and the probability density function (PDF) of ε_i. Letting $\widehat{\pi}_i$ be a realization of π_i, the CDF of π_i conditional on $\boldsymbol{a}_i$ is given by $\Phi^{\pi_i}(\widehat{\pi}_i \mid \boldsymbol{a}_i) := \Pr(\pi_i \leq \widehat{\pi}_i)$. This CDF can be calculated as follows:

$$\begin{aligned} \Phi^{\pi_i}(\widehat{\pi}_i \mid \boldsymbol{a}_i) &= \Pr(\pi(\boldsymbol{a}_i; \varepsilon_i) \leq \widehat{\pi}_i) \\ &= \Pr(\varepsilon_i \leq \widehat{\pi}_i - y(\boldsymbol{a}_i) + \boldsymbol{p}\boldsymbol{z}_i) \\ &= \Phi^{\varepsilon_i}(\widehat{\pi}_i - y(\boldsymbol{a}_i) + \boldsymbol{p}\boldsymbol{z}_i) \\ &= \int_{-\infty}^{\widehat{\pi}_i - y(\boldsymbol{a}_i) + \boldsymbol{p}\boldsymbol{z}_i} \phi^{\varepsilon_i}(\varepsilon_i)\, \mathrm{d}\varepsilon_i. \end{aligned} \tag{16}$$

This is a 'parametrized distribution representation' of profit. This representation highlights that different actions give rise to different distributions of profit. It turns out to be analytically convenient to work with both the parametrized distribution representation of profit and its primitive 'state-space representation,' given in Equation (15).[26] Given Equation (16), one can

[26] See, e.g., Conlon (2009) for a discussion of the differences between state-space and parametrized distribution representations.

write

$$\begin{aligned}
\phi^{\pi_i}\left(\widehat{\pi}_i \mid \boldsymbol{a}_i\right) &= \frac{\partial \Phi^{\pi_i}\left(\widehat{\pi}_i \mid \boldsymbol{a}_i\right)}{\partial \widehat{\pi}_i} \\
&= \frac{\mathrm{d}}{\mathrm{d}\widehat{\pi}_i} \int_{-\infty}^{\widehat{\pi}_i - y(\boldsymbol{a}_i) + \boldsymbol{p}\boldsymbol{z}_i} \phi^{\varepsilon_i}\left(\varepsilon_i\right) \mathrm{d}\varepsilon_i \\
&= \phi^{\varepsilon_i}\left(\widehat{\pi}_i - y\left(\boldsymbol{a}_i\right) + \boldsymbol{p}\boldsymbol{z}_i\right).
\end{aligned}$$

Throughout the paper, I assume that ϕ^{ε_i} is differentiable.

Let $\boldsymbol{\pi} := \left(\pi_i\right)_i$ be a profile of profits. The consumption received by i when $\boldsymbol{\pi}$ realizes is denoted $c_i\left(\boldsymbol{\pi}\right)$. The feasibility constraint dictates that

$$\sum_{i \in N} c_i\left(\boldsymbol{\pi}\right) \leq \sum_{i \in N} \pi_i,$$

for each $\boldsymbol{\pi}$. Household i's utility is

$$u\left(c_i\left(\boldsymbol{\pi}\right)\right) - \kappa e_i,$$

where u is twice-continuously differentiable, strictly increasing, and strictly concave.

Let $\boldsymbol{a} := \left(\boldsymbol{a}_i\right)_i$ and $\Phi^{\boldsymbol{\pi}}\left(\boldsymbol{\pi} \mid \boldsymbol{a}\right) := \prod_i \Phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i\right)$. This is the cumulative distribution function of $\boldsymbol{\pi}$, because profits are independent between households once conditioning on actions taken. Finally, let $\boldsymbol{c}\left(\boldsymbol{\pi}\right) := \left(c_i\left(\boldsymbol{\pi}\right)\right)_i$ be the sharing contract. An allocation is a pair $\left(\boldsymbol{c}\left(\boldsymbol{\pi}\right), \boldsymbol{a}\right)$.

Full Information. Assume that $\boldsymbol{a}$ is observed by the planner. In this case, there are no information frictions, so the planner can implement any action profile at no cost. Formally, the planner's problem is

$$\begin{aligned}
&\max_{\boldsymbol{c}(\boldsymbol{\pi}), \boldsymbol{a}} \sum_{i \in N} \left\{\mathbb{E}_{\boldsymbol{\pi}}\left[u\left(c_i\left(\boldsymbol{\pi}\right)\right) \mid \boldsymbol{a}\right] - k e_i\right\}, \\
&\text{subject to} \sum_{i \in N} c_i\left(\boldsymbol{\pi}\right) = \sum_{i \in N} \pi_i, \ \forall \boldsymbol{\pi}.
\end{aligned} \tag{17}$$

Notice that the feasibility constraint holds with equality. This is without loss of generality, as the constraint must bind at a solution to the problem. The following proposition characterizes the optimal sharing contract under full information. The proposition shows that the first-order conditions for households' consumptions imply that the ratio of marginal utilities across any two households is constant across profit realizations. This is Borch's rule; i.e., the condition for perfect risk sharing (when the solution is interior).

Proposition 1. *Under full information there is perfect risk sharing.*

The following claim characterizes the an optimal action profile.

Claim 5. *Let $(\boldsymbol{c}^*(\boldsymbol{\pi}), \boldsymbol{a}^*)$ be a solution to Problem (17). At $\boldsymbol{a}^*$, (i) the social expected marginal benefit of effort is equal to its private marginal cost, and (ii) the marginal product of any intermediate q is equal to its price.*

The intuition behind this corollary is provided by Samuelson's rule for the optimal provision of public goods. The rule states that, at an optimum, the social marginal benefit of a public good equals the marginal cost of providing it. The key is to notice that, when households share profits, effort is a public good: an increase in effort on the part of j directly affects i's consumption. On the other hand, the condition for the optimal use of intermediate q is the standard optimality condition for a market-provided private good. This is because under profit sharing agricultural inputs remain private goods.

Private Information. Next, assume that the action taken by i and the shock it receives are private to i. In this case, profits are publicly observable, noisy signals of actions taken. After observing the signals, the planner collects the profits realized and redistributes them to the households according to the sharing contract he designs. The planner takes into account that the households non-cooperatively choose an action profile given the sharing contract. Formally, the planner's problem is

$$\begin{aligned} &\max_{\boldsymbol{c}(\boldsymbol{\pi}),\boldsymbol{a}} \sum_{i\in N} \left\{\mathbb{E}_{\boldsymbol{\pi}}\left[u\left(c_i\left(\boldsymbol{\pi}\right)\right) \mid \boldsymbol{a}\right] - ke_i\right\} \\ &\text{subject to } \sum_i c_i\left(\boldsymbol{\pi}\right) = \sum_i \pi_i, \ \forall \boldsymbol{\pi}, \\ &\text{and } \boldsymbol{a}_i \in \arg\max_{\widetilde{\boldsymbol{a}}_i} \mathbb{E}_{\boldsymbol{\pi}}\left[u\left(c_i\left(\boldsymbol{\pi}\right)\right) \mid \widetilde{\boldsymbol{a}}_i, \boldsymbol{a}_{-i}\right] - k\widetilde{e}_i, \ \forall i. \end{aligned} \tag{18}$$

The IC constraints essentially define a pure-strategy Nash equilibrium: at $\boldsymbol{a}$, no household wants to deviate when it correctly anticipates the other households' actions. The set of IC constraints is a complicated object, as it comprises of a set of intertwined optimization problems. Moreover, there might exist more than one Nash equilibrium (or even none).[27]

Many papers in the principal-agent literature dealing with similar contracting problems have relied on the first-order approach (FOA), by which the agent's IC constraint is replaced by its first-order conditions. The optimal contract is then easily derived. The literature (Rogerson (1985) and Jewitt (1988)) has then focused on providing sufficient conditions under which the FOA is valid. My problem is different from the canonical principal-agent problem as there are n agents and each of them is choosing a multidimensional action. To gain intuition, it is worthwhile to set the stage by characterizing the optimal sharing contract under the assumption that the FOA is valid. More formally, I begin by considering a relaxed version of Problem (18), in which the IC constraints are replaced with the requirement that the action chosen by each household be a stationary point, given the actions chosen by the other households and the sharing contract. The key assumption is that a solution to the relaxed version of the problem is also a solution to Problem (18).[28]

Assumption 1. *Let* $(\boldsymbol{c}^*(\boldsymbol{\pi}), \boldsymbol{a}^*)$ *be a solution to the following relaxed version of Problem (18):*

$$
\begin{aligned}
&\max_{\boldsymbol{c}(\boldsymbol{\pi}),\boldsymbol{a}} \sum_{i\in N} \left\{ \mathbb{E}_{\boldsymbol{\pi}} \left[u\left(c_i\left(\boldsymbol{\pi}\right)\right) \mid \boldsymbol{a} \right] - k e_i \right\} \\
&\textit{subject to } \sum_i c_i\left(\boldsymbol{\pi}\right) = \sum_i \pi_i, \ \forall \boldsymbol{\pi}, \\
&\int u\left(c_i\left(\boldsymbol{\pi}\right)\right) \phi^{\pi_i}_{e_i}\left(\pi_i \mid \boldsymbol{a}_i\right) \prod_{j\neq i} \phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j\right) \mathrm{d}\boldsymbol{\pi} = k, \forall i, \\
&\int u\left(c_i\left(\boldsymbol{\pi}\right)\right) \phi^{\pi_i}_{z_i^q}\left(\pi_i \mid \boldsymbol{a}_i\right) \prod_{j\neq i} \phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j\right) \mathrm{d}\boldsymbol{\pi} = 0, \ \forall i, \forall q.
\end{aligned}
\tag{19}
$$

$(\boldsymbol{c}^*(\boldsymbol{\pi}), \boldsymbol{a}^*)$ *is a solution to Problem (18).*

The following proposition characterizes the optimal sharing rule under private information

[27] If expected utility is continuous and concave in own action, continuous in others' actions, and action sets are compact and convex, then there exists a Nash equilibrium. Notice that the action sets in this model are not compact, as they are unbounded by above. Moreover, households' actions expected utility is not necessarily concave in own action. Hence, the existence of a Nash equilibrium cannot be guaranteed.

[28] Most likely, it is not so useful to give general conditions for the validity of the FOA, as these would probably not be conditions that generalize the specific assumptions of the model in Section 2. I would be better off showing that with quadratic utility (which implies mean-variance expected utility) and Lagrange shocks, the first-order approach is valid, as suggested in Wang (2013).

when Assumption 1 holds.

Proposition 2. *Suppose that Assumption 1 holds. Then, the optimal sharing rule is pinned down by*

$$\frac{u'\left(c_i^*\left(\boldsymbol{\pi}\right)\right)}{u'\left(c_j^*\left(\boldsymbol{\pi}\right)\right)} = \frac{1+\psi_j\Lambda_j\left(\pi_j \mid \boldsymbol{a}_j^*\right)}{1+\psi_i\Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right)}, \tag{20}$$

for each $i, j \in N$, where ψ_i is the Lagrange multiplier associated to household i's first-order condition for effort and

$$\Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right) := \frac{\phi_{e_i}^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right)}{\phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right)}.$$

Equation (20) is a modified Borch rule. In particular, if $\psi_i \neq 0$ or $\psi_j \neq 0$, then the households' marginal utilities are not equalized across profit realizations. The wedge between Equation (20) and the Borch rule is designed by the planner to take into account the effect of the sharing contract on the incentives to exert effort. On the other hand, the planner does *not* take into account the effect of the sharing contract on the use of agricultural inputs. This follows because the households are sharing profits—the revenues of production minus the monetary costs of agricultural inputs. Profit sharing implies that the effect of the sharing contract on the marginal benefit of an agricultural input is compensated by the effect of the contract on the marginal cost of that input; i.e., the sharing contract does not distort the incentives to use inputs purchased in the market. Finally, the wedge between Equation (20) and the Borch rule implies that risk sharing is generally imperfect under private information, as shown in the following corollary.

Corollary 1. *Under private information risk sharing is imperfect.*

In the following, I consider the interaction between insurance, effort choices, and use of agricultural inputs. To do so, I focus on the implementation of a given action profile, and analyze how actions change when the sharing contract is perturbed. A more satisfying approach would be to jointly deriving an optimal action profile and the optimal sharing contract implementing it as a function of the parameters of the model—the utility cost of effort, the price of fertilizer, the variance of the production shock, and so on. Then, one could analyze how exogenous changes in these parameters jointly affect the sharing contract and the action profile, and thus keep track of the relationship between risk sharing and actions. I choose to follow the first approach because jointly deriving an optimal action in addition to the optimal contract that implements it is typically a very complex problem. Analyzing how actions change when the sharing contract is perturbed allows for significant tractability and is useful for practical applications.[29] To gain tractability, consider the case in which the optimal sharing contract is differentiable,[30] and define the slope of the contract at $\boldsymbol{\pi}$ for household i as

$$\frac{\partial c_i^* (\boldsymbol{\pi})}{\partial \pi_i}.$$

Intuitively, the slope of the contract measures the responsiveness of consumption to income. The smaller is the slope of the contract at $\boldsymbol{\pi}$, the higher is the insurance it provides at that profit realization. If the sharing contract is linear, than its slope is constant. Moreover, as shown in Subsection C, in a closed economy with no savings, the slope of a linear sharing contract coincides with the within estimator, δ^W. The following claim generalizes the intuition provided by the model of exogenous risk sharing in Section 2 by showing that, when the optimal sharing contract is differentiable, making the contract steeper (i.e., decreasing insurance) for household i induces the household to exert more effort.

Claim 6. *Assume that the optimal sharing contract is differentiable. The higher is the slope of the contract at any $\boldsymbol{\pi}$, the higher is the effort provided.*

This result is based on the fact that the 'effective' price of effort is decreasing in the slope of the contract. Next, I prove the main theorem, which extends the results of Theorem 1 to the case in which risk sharing is endogenous.

Theorem 2. *Let $(\boldsymbol{c}^* (\boldsymbol{\pi}), \boldsymbol{a}^*)$ be a solution to the planner's problem under private information. Suppose that e_i and z_i^q are substitutes at $(p(c_i^* (\boldsymbol{\pi})), \boldsymbol{p})$; i.e.,*

$$\frac{\partial z_i^{q*} (p(c_i^* (\boldsymbol{\pi})), \boldsymbol{p})}{\partial p(c_i^* (\boldsymbol{\pi}))} > 0.$$

[29] In fact, most of the papers in both the theoretical and applied literatures on the principal-agent problem focus exclusively or predominantly on implementing a given action (Edmans and Gabaix (2011)).

[30] This approach is not entirely satisfactory, as $\boldsymbol{c}^* (\boldsymbol{\pi})$ is an endogenous object which was computed by means of point-wise maximization; hence, there is no a priori reason to expect $\boldsymbol{c}^* (\boldsymbol{\pi})$ to be differentiable. While not being rigorous, this approach is common practice (see e.g. Appendix B in Attanasio and Pavoni (2011)).

Then,

$$\frac{\partial z_i^{q*}\left(p\left(c_i^*\left(\boldsymbol{\pi}\right)\right),\boldsymbol{p}\right)}{\partial\frac{\partial c_i^*(\boldsymbol{\pi})}{\partial\pi_i}}<0.$$

The signs of the latter two inequalities are reversed if e_i and z_i^q are complements at $\left(p\left(c_i^*\left(\boldsymbol{\pi}\right)\right),\boldsymbol{p}\right)$.

This theorem generalizes Theorem 1. In particular, it makes it clear that all of the results obtained in Section 2 can be obtained in a model of endogenous risk sharing, in which the first-order approach is valid and the optimal sharing contract is differentiable. In the latter case, decreasing α would amount to making the sharing contract steeper.

A.1 Mean-Variance Expected Utility

Problem (18) is a complicated one, as the n incentive-compatibility constraints define a pure-strategy Nash equilibrium. In this subsection, I show that if households have mean-variance expected utility and the optimal sharing rule is linear, Problem (18) can be greatly simplified as each household's optimal action is independent of what the other households do.[31] Mean-variance expected utility can be justified in two cases. First, one can assume that the utility from consumption is quadratic; i.e.,

$$u\left(c_i\left(\boldsymbol{\pi}\right)\right)=c_i\left(\boldsymbol{\pi}\right)-\frac{\rho}{2}c_i\left(\boldsymbol{\pi}\right)^2.$$

In this case, the expected utility of consumption takes a mean-variance specification, independently of the distribution of $c_i\left(\boldsymbol{\pi}\right)$. Alternatively, if the sharing contract is indeed linear and the production shocks are normally distributed,[32] then $c_i\left(\boldsymbol{\pi}\right)$ is also normally distributed, and the households have mean-variance expected utility when their utility from consumption is CARA; i.e.,

$$u\left(c_i\left(\boldsymbol{\pi}\right)\right)=-\exp\left\{-\rho c_i\left(\boldsymbol{\pi}\right)\right\}.$$

[31] I.e., in this case, the n incentive-compatibility constraints define a dominant strategy equilibrium.

[32] The second argument *assumes* that the sharing contract is linear. In fact, if I were to posit that the sharing contract is chosen by the planner, then this argument would break, as Mirrlees famously shows that in a CARA-normal principal-agent model an optimal sharing contract does not exist (see Bolton and Dewatripont (2005)).

I begin by showing that, in the two cases justifying mean-variance expected utility, the optimal sharing contract under full information is equal sharing. Let $\boldsymbol{c}^{\mathrm{FI}}$ be the optimal sharing rule under full information (superscript FI stands for 'full information'). The following claim holds:

Claim 7. *If the households have quadratic utility from consumption, or if they have CARA utility from consumption and the planner can only use linear contracts, then $c_i^{\mathrm{FI}}(\boldsymbol{\pi}) = \overline{\pi}$, for each $i, j \in N$.*

Mean-variance expected utility is particularly tractable because household i's choices are independent of the other households' choices when the sharing contract is linear. I proceed by demonstrating this result under the assumption that the sharing contract is linear. Let $\boldsymbol{c}^{\mathrm{PI}}$ be the optimal sharing rule under private information (superscript PI stands for 'private information'). Assume that $\boldsymbol{c}^{\mathrm{PI}}$ is linear; i.e.,

$$c_i^{\mathrm{PI}}(\boldsymbol{\pi}) = \sum_{j \in N} \alpha_{ij}^{\mathrm{PI}} \pi_j,$$

for some $\left(\alpha_{ij}^{\mathrm{PI}}\right)_{ij} \in [0,1]^{2n}$ such that $\sum_i \alpha_{ij}^{\mathrm{PI}} = 1$, for each $j \in N$. The following claim proves that when the households have mean-variance expected utility, household i's choices are independent the other households' choices.

Claim 8. *If $\boldsymbol{c}^{\mathrm{PI}}$ is linear and the households have mean-variance expected utility, household i's choices are independent of what the other households do.*

B Effort and Inputs Affect the Variance of Output

Suppose that $y_i = y(\boldsymbol{a}_i, \varepsilon_i)$, so that, in general,

$$\frac{\partial \mathbb{V}\mathrm{ar}(y_i)}{\partial \boldsymbol{a}_i} \neq \boldsymbol{0}.$$

In this case, given some α, household i's utility maximization problem is equivalent to

$$\max_{\boldsymbol{a}_i} \left(1 - \frac{n-1}{n}\alpha\right) \mathbb{E}\left(y(\boldsymbol{a}_i; \varepsilon_i) - \boldsymbol{p}\boldsymbol{z}_i\right) - \frac{\rho}{2} \mathbb{V}\mathrm{ar}\left(y(\boldsymbol{a}_i; \varepsilon_i)\right) - \kappa e_i.$$

Letting $\overline{y}(\boldsymbol{a}_i) := \mathbb{E}(y(\boldsymbol{a}_i;\varepsilon_i))$, the first-order conditions for e_i and $\boldsymbol{z}_i$ read

$$\overline{y}_e(\boldsymbol{a}_i^*) = \frac{\kappa}{\left(1-\frac{n-1}{n}\alpha\right)} + \frac{\rho}{2}\left(1-\frac{n-1}{n}\alpha\right)\frac{\partial \mathbb{V}\mathrm{ar}\left(y\left(\boldsymbol{a}_i^*;\varepsilon_i\right)\right)}{\partial e_i}$$

and

$$\overline{y}_{\boldsymbol{z}}(\boldsymbol{a}_i^*) = \boldsymbol{p} + \frac{\rho}{2}\left(1-\frac{n-1}{n}\alpha\right)\frac{\partial \mathbb{V}\mathrm{ar}\left(y\left(\boldsymbol{a}_i^*;\varepsilon_i\right)\right)}{\partial \boldsymbol{z}_i}.$$

First of all, notice that if $\partial \mathbb{V}\mathrm{ar}\left(y\left(\boldsymbol{a}_i^*;\varepsilon_i\right)\right)/\partial e_i < 0$ (i.e., supplying more effort reduces output volatility), then $\partial e_i^*/\partial \alpha < 0$, following the same steps used to prove Theorem 1. However, notice that now, contrary to what happens in the model outlined in Section 2, also the 'effective prices' of the agricultural inputs are affected by risk sharing. More specifically, notice that if $\partial \mathbb{V}\mathrm{ar}\left(y\left(\boldsymbol{a}_i^*;\varepsilon_i\right)\right)/\partial z_i^q < 0$ then risk sharing has direct negative effect on the use of input q, while if $\partial \mathbb{V}\mathrm{ar}\left(y\left(\boldsymbol{a}_i^*;\varepsilon_i\right)\right)/\partial z_i^q > 0$ then this direct effect is positive. This is intuitive: a direct effect of bettering insurance is that households optimally increase the use of inputs that make production riskier, while reducing the use of inputs that reduce output volatility. To this direct effect one has to sum the indirect effect coming from the complementarity and substitutability with the other inputs and effort. In general, one cannot say whether the direct effect will dominate the indirect one or vice-versa; however, to be sure, if the marginal impact of inputs on output volatility is sufficiently small, then Theorem 1 still holds. Formally, there exists $\vartheta > 0$ such that if $\partial \mathbb{V}\mathrm{ar}\left(y\left(\boldsymbol{a}_i^*;\varepsilon_i\right)\right)/\partial z_i^q > 0$ for each q and $\boldsymbol{a}_i^*$ then Theorem 1 remains valid.

C Contrast Estimator

In this appendix, I describe the relationship between the risk sharing contract specified in Equation (3) and the contrast estimator proposed by Suri (2011). Consider the following regression equation:

$$c_{it} - \overline{c}_{vt} = \delta^W\left(\pi_{it} - \overline{\pi}_{vt}\right) + \epsilon_{it}, \tag{21}$$

where c_{it} and π_{it} are household i's consumption and income in village and period t, and $\overline{c}_{vt}$ and $\overline{\pi}_{vt}$ are average consumption and income in village v and period t. Suri (2011) refers to δ^W as the within-estimator. Assume that the village is a closed economy with no saving technology.

Then, the accounting identity $\overline{c}_{vt} = \overline{\pi}_{vt}$ trivially holds, and Equation (21) can be rewritten as follows:

$$c_{it} = \delta^W y_{it} + \left(1 - \delta^W\right) \overline{y}_{vt} + \epsilon_{it}. \tag{22}$$

Equation (22) makes it clear that sharing rule α, as defined in Equation (3), theoretically coincides with δ^W when the village is a closed economy with no saving technology.

Next, consider the following regression equation:

$$\overline{c}_{vt} = \delta^B \overline{\pi}_{vt} + \epsilon_{vt}. \tag{23}$$

Suri (2011) refers to δ^B as the between-estimator, and defines the contrast estimator as follows:

$$\delta := 1 - \frac{\delta^W}{\delta^B}.$$

Note that if the village is a closed economy with no saving technology then $\delta^B = 1$. Thus, in this case, $\delta = 1 - \delta^W = 1 - \alpha$, and Equation (3) can be rewritten as follows:

$$c_{it} = \delta^W \pi_{it} + \delta \overline{\pi}_{vt}.$$

Table 11 reports the results of estimating Equation (21). The estimated coefficient is positive and significant. Table 12 reports the results of estimating Equation (23). A simple t-test reveals that $\widehat{\delta}^B$ is significantly lower than 1, suggesting the existence of inter-village risk sharing or saving technologies. Using point estimates $\widehat{\delta}^W$ and $\widehat{\delta}^B$ obtained in Tables 11 and 12, one can see that $\widehat{\delta} \approx 0.81$.

D Complements and Substitutes

Theorems 1 and 2 make use of the concepts of complementarity and substitutability. The theorems rely on the usual price-theoretic notion of complementarity and substitutability, as found for example in Mas-Colell et al. (1995). Here, I explore a different notion of complementarity and substitutability based on the concept of supermodularity, as in Acemoglu (2010), and show when the results of Theorems 1 and 2 still apply under this other definition. For simplicity, I will restrict attention to the case in which the sharing contract is linear. The argument extends to the other case; just substitute α with the slope of the contract, as in Theorem 2.

Acemoglu (2010) bases its definition of complementarity and substitutability on supermodularity. In particular, consider a two-input production function $y\left(e_i, z_i^q\right)$. Input q is strongly effort-complement if y is supermodular in (e_i, z_i^q), while it is strongly effort-saving if y is submodular in (e_i, z_i^q). These definitions are different but related to the price-theoretic definitions of complementarity and substitutability. Consider the following lemma:

Claim 9. *If $y\left(\boldsymbol{a}_i\right)$ is supermodular, then z_i^{q*} is decreasing in α. If $y\left(\boldsymbol{a}_i\right)$ is submodular, then z_i^{q*} is increasing in α.*

If the production function can be written as

$$y\left(\boldsymbol{a}_i\right) = \sum_{q \in Q} y\left(e_i, z_i^q\right),$$

then Claim 9 readily extents to the case in which there is more than one agricultural inputs.

E Disentangling the Impact of Risk Sharing on Effort Supply and Fertilizer Use

Household i's problem can be written as

$$\max_{e_i, f_i} \ell_i^{1-\chi} \left[e_i^{\frac{\sigma-1}{\sigma}} + f_i^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\chi\sigma}{\sigma-1}} - p f_i - \frac{\kappa}{1 - \frac{n-1}{n}\alpha} e_i.$$

This is equivalent to the profit maximization problem of a competitive firm choosing effort and fertilizer while facing a real price of effort equal to $p_e\left(\alpha\right) = \kappa \left(1 - \frac{n-1}{n}\alpha\right)^{-1}$ and a real price of fertilizer equal to p. Since cost minimization is a necessary condition for profit maximization, consider the following cost minimization problem:

$$\min_{e_i,f_i} pf_i + p_e(\alpha)\, e_i$$
$$\text{subject to } \ell_i^{1-\chi}\left[e_i^{\frac{\sigma-1}{\sigma}} + f_i^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\chi\sigma}{\sigma-1}} \geq \widehat{y}_i$$

Since land is fixed, the previous problem is equivalent to

$$\min_{e_i,f_i} pf_i + p_e(\alpha)\, e_i$$
$$\text{subject to } \left[e_i^{\frac{\sigma-1}{\sigma}} + f_i^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \geq y_i^{\dagger},$$

where $y_i^{\dagger} := \left(\frac{\widehat{y}_i}{\ell_i^{1-\chi}}\right)^{\frac{1}{\chi}}$. By the standard cost minimization problem with a CES technology, one obtains

$$e_i^* = \frac{y_i^{\dagger} p_e(\alpha)^{-\sigma}}{p^{1-\sigma} + p_e(\alpha)^{1-\sigma}}$$

and

$$f_i^* = \frac{y_i^{\dagger} p^{-\sigma}}{p^{1-\sigma} + p_e(\alpha)^{1-\sigma}}.$$

Taking logs, one gets

$$\log(e_i^*) = \log\left(y_i^{\dagger}\right) - \sigma\log(\kappa) + \sigma\log\left(1 - \frac{n-1}{n}\alpha\right) - \log\left(p^{1-\sigma} + \left(\frac{\kappa}{1-\frac{n-1}{n}\alpha}\right)^{1-\sigma}\right)$$

and

$$\log(f_i^*) = \log\left(y_i^{\dagger}\right) - \sigma\log(p) - \log\left(p^{1-\sigma} + \left(\frac{\kappa}{1-\frac{n-1}{n}\alpha}\right)^{1-\sigma}\right).$$

Using the structural estimates of σ and κ_i, and setting village size equal to the number of households sampled by ICRISAT, one can simulate the choices of fertilizer and effort for different levels of α. The only issue is that $y_i^{\dagger}$ is unobserved. To avoid this problem, I focus attention on the growth rates of effort and fertilizer when moving from α_0 to α_1. These growth rates can be calculated as follows:

$$\begin{aligned}\frac{e_{it}(\alpha_1)-e_{it}(\alpha_0)}{e_{it}(\alpha_0)} =& \log\left(e_{it}(\alpha_1)\right)-\log\left(e_{it}(\alpha_0)\right)\\ =&\widehat{\sigma}\log\left(\frac{\widetilde{n}_{vt}-1}{\widetilde{n}_{vt}}\alpha_1\right)-\log\left(\frac{\widetilde{n}_{vt}-1}{\widetilde{n}_{vt}}\alpha_1\right)+\\ &\log\left(p_{it}^{1-\widehat{\sigma}}+\left(\frac{\widehat{\kappa}_i}{1-\frac{\widetilde{n}_{vt}-1}{\widetilde{n}_{vt}}\alpha_0}\right)^{1-\widehat{\sigma}}\right)-\log\left(p_{it}^{1-\widehat{\sigma}}+\left(\frac{\widehat{\kappa}_i}{1-\frac{\widetilde{n}_{vt}-1}{\widetilde{n}_{vt}}\alpha_1}\right)^{1-\widehat{\sigma}}\right),\end{aligned}$$

and

$$\begin{aligned}\frac{f_{it}(\alpha_1)-f_{it}(\alpha_0)}{f_{it}(\alpha_0)} &= \log\left(f_{it}(\alpha_1)\right)-\log\left(f_{it}(\alpha_0)\right)\\ &=\log\left(p_{it}^{1-\widehat{\sigma}}+\left(\frac{\widehat{\kappa}_i}{1-\frac{\widetilde{n}_{vt}-1}{\widetilde{n}_{vt}}\alpha_0}\right)^{1-\widehat{\sigma}}\right)-\log\left(p_{it}^{1-\widehat{\sigma}}+\left(\frac{\widehat{\kappa}_i}{1-\frac{\widetilde{n}_{vt}-1}{\widetilde{n}_{vt}}\alpha_1}\right)^{1-\widehat{\sigma}}\right).\end{aligned}$$

Notice that these growth rates are independent of $y_i^{\dagger}$.

F Computing the Optimal Sharing Rule

The aim is to solve Equation (6). To do so, I need an expression for $\partial e_i^*/\partial\alpha$. Let $P := \left(p_e(\alpha)^{1-\sigma}+p^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$. The optimal use of fertilizer and effort are pinned down by

$$f_i^* = \left(\frac{p}{P}\right)^{-\sigma}\left(\frac{\chi}{P}\right)^{\frac{1}{1-\chi}}\ell_i$$

and

$$e_i^* = \left(\frac{p_e(\alpha)}{P}\right)^{-\sigma}\left(\frac{\chi}{P}\right)^{\frac{1}{1-\chi}}\ell_i$$

From this equation, I can compute $\frac{\partial e_i^*}{\partial\alpha}$. First, I make use of the chain rule to write

$$\frac{\partial e_i^*}{\partial\alpha} = \frac{\partial e_i^*}{\partial p_e(\alpha)}\frac{\partial p_e(\alpha)}{\partial\alpha}.$$

Then, notice that

$$\frac{\partial p_e(\alpha)}{\partial\alpha} = \frac{\kappa}{\left(1-\frac{n-1}{n}\alpha\right)^2}\left(\frac{n-1}{n}\right)$$

and

$$\frac{\partial e_i^*}{\partial p_e(\alpha)} = \chi^{\frac{1}{1-\chi}}\ell_i\left[-\sigma p_e(\alpha)^{-\sigma-1}P^{\sigma-\frac{1}{1-\chi}} + p_e(\alpha)^{-2\sigma}\left(\sigma - \frac{1}{1-\chi}\right)P^{\sigma-\frac{1}{1-\chi}-1}\left(p_e(\alpha)^{1-\sigma}+p^{1-\sigma}\right)^{\frac{1}{1-\sigma}-1}\right].$$

Finally,

$$\frac{\partial \mathbb{V}\text{ar}(c_i(\alpha))}{\partial\alpha} = \left(-2(1-\alpha) - \frac{2\alpha}{n} + \frac{2}{n}\right)\eta^2.$$

G Computing the Optimal Fertilizer Subsidy

Assume that the government (i) aims to maximize utilitarian social welfare, (ii) can freely choose the price of fertilizer, and (iii) has no budget constraint. Then, the government's problem is equivalent to

$$\max_p \sum_{i\in N}\left[y(e_i^*, f_i^*) - pf_i^* - ke_i^* - \frac{\rho}{2}\mathbb{V}\text{ar}(c_i(\alpha^*))\right].$$

The first-order condition with respect to p reads

$$\sum_{i\in N}\left[y_e(e_i^*, f_i^*)\frac{\mathrm{d}e_i^*}{\mathrm{d}p} + y_f(e_i^*, f_i^*)\frac{\mathrm{d}f_i^*}{\mathrm{d}p} - f_i^* - p^r\frac{\mathrm{d}f_i^*}{\mathrm{d}p} - k\frac{\mathrm{d}e_i^*}{\mathrm{d}p} - \frac{\rho}{2}\frac{\partial\mathbb{V}\text{ar}(c_i(\alpha^*))}{\partial\alpha^*}\frac{\partial\alpha^*}{\partial p}\right] = 0.$$

Notice that I apply the total derivative operator (with respect to p) to e_i^* and f_i^*. This is because e_i^* and f_i^* are functions of α^*, and α^* is itself a function of p. Collecting terms, one gets

$$\sum_{i\in N}\left[(y_e(e_i^*, f_i^*) - \kappa)\frac{\mathrm{d}e_i^*}{\mathrm{d}p} + (y_f(e_i^*, f_i^*) - p_r)\frac{\mathrm{d}f_i^*}{\mathrm{d}p} - \frac{\rho}{2}\frac{\partial\mathbb{V}\text{ar}(c_i(\alpha^*))}{\partial\alpha^*}\frac{\partial\alpha^*}{\partial p}\right] = 0.$$

Using Claim 2, one obtains

$$\sum_{i\in N}\left[\kappa\left(\frac{1}{1-\frac{n-1}{n}\alpha} - 1\right)\frac{\mathrm{d}e_i^*}{\mathrm{d}p} - \frac{\rho}{2}\frac{\partial\mathbb{V}\text{ar}(c_i(\alpha^*))}{\partial\alpha^*}\frac{\partial\alpha^*}{\partial p}\right] = 0.$$

Notice that

$$\frac{1}{1-\frac{n-1}{n}\alpha} - 1 > 0$$

and $\mathrm{d}e_i^*/\mathrm{d}p < 0$.

H Proofs

Proof of Claim 1. Problem (4) is equivalent to

$$\max_{\boldsymbol{a}} \sum_{i\in N} \left((1-\alpha)\left(y\left(\boldsymbol{a}_i\right) - \boldsymbol{p}\cdot\boldsymbol{z}_i\right) + \alpha \frac{\sum_{j\in N} y\left(\boldsymbol{a}_j\right) - \boldsymbol{p}\cdot\boldsymbol{z}_j}{n} - \kappa e_i \right);$$

i.e.,

$$\max_{\boldsymbol{a}} \sum_{i\in N} \left((1-\alpha)\left(y\left(\boldsymbol{a}_i\right) - \boldsymbol{p}\cdot\boldsymbol{z}_i\right)\right) + \alpha \sum_{j\in N} \left(y\left(\boldsymbol{a}_j\right) - \boldsymbol{p}\cdot\boldsymbol{z}_j\right) - \sum_{i\in N} \kappa e_i.$$

If $\boldsymbol{a}^{\diamond}(\alpha)$ is an interior solution, then

$$(1-\alpha)\, y_e\left(\boldsymbol{a}_k^{\diamond}(\alpha)\right) + \alpha y_e\left(\boldsymbol{a}_k^{\diamond}(\alpha)\right) - \kappa = 0,$$

for each $k \in N$; i.e., the marginal product of effort equals its marginal utility cost. The same argument holds for the agricultural inputs. □

Proof of Claim 2. Problem (5) is equivalent to

$$\max_{\boldsymbol{a}_i} \left(1 - \frac{n-1}{n}\alpha\right) y\left(\left(\boldsymbol{a}_i\right) - \boldsymbol{p}\cdot\boldsymbol{z}_i\right) - ke_i,\ \forall i \in N.$$

If $\boldsymbol{a}^*(\alpha)$ is an interior solution, then

$$\left(1 - \frac{n-1}{n}\alpha\right) y_e\left(\boldsymbol{a}_i^*(\alpha)\right) - k = 0$$

and

$$\left(1 - \frac{n-1}{n}\alpha\right) \left(y_{\boldsymbol{z}}\left(\boldsymbol{a}_i^*(\alpha)\right) - \boldsymbol{p}\right) = 0,$$

for each $i \in N$. □

Proof of Theorem 1. Notice that the household i's IC constraint is equivalent to the problem of a competitive firm facing a real price of intermediate q equal to p^q and a real price of effort equal to $p_e(\alpha)$. This is easily checked by considering the problem of such a firm and noticing that the profit-maximizing choices of effort and intermediates coincide with the first-order conditions given in Claim 2. Notice that p_e is decreasing in α. By the law of supply, the demand for an input is decreasing in its price. Hence, e_i^* is decreasing in α.

Moreover, α only affects p_e. Hence,

$$\begin{aligned}\frac{\partial z_i^{q*}(\alpha)}{\partial \alpha} &= \frac{\partial z_i^{q*}(\alpha)}{\partial p_e}\frac{\partial p_e}{\partial \alpha} \\ &= \frac{\partial z_i^{q*}(\alpha)}{\partial p_e}\left(-\left(1-\frac{n-1}{n}\alpha\right)^{-1}\left(-\frac{n-1}{n}\right)\right).\end{aligned}$$

□

Proof of Claim 3. The problem of finding a welfare-maximizing sharing contract under full information is equivalent to

$$\begin{aligned}\max_{\alpha}\sum_{i\in N}\Bigg(&(1-\alpha)\left(y\left(\boldsymbol{a}_i^{\diamond}(\alpha)\right)-\boldsymbol{p}\cdot\boldsymbol{z}_i^{\diamond}(\alpha)\right)+\alpha\frac{\sum_{j\in N}y\left(\boldsymbol{a}_j^{\diamond}(\alpha)\right)-\boldsymbol{p}\cdot\boldsymbol{z}_j^{\diamond}(\alpha)}{n} \\ &-\frac{\rho}{2}\mathbb{V}\text{ar}\left(c_i(\alpha)\right)-\kappa e_i^{\diamond}(\alpha)\Bigg),\end{aligned}$$

where

$$\mathbb{V}\text{ar}\left(c_i(\alpha)\right)=\left((1-\alpha)^2+\frac{\alpha^2}{n}+\frac{2\alpha(1-\alpha)}{n}\right)\eta^2.$$

Claim 1 implies that, under full information, $\boldsymbol{a}^{\diamond}(\alpha)$ is independent of α. Hence, the problem is equivalent to minimizing $\mathbb{V}\text{ar}(c_i(\alpha))$. It is easy to check that $\mathbb{V}\text{ar}(c_i(\alpha))$ is minimized when $\alpha=1$. □

Proof of Claim 4. The problem of finding a welfare-maximizing sharing contract under private information is equivalent to

$$\max_{\alpha}\sum_{i\in N}\left(\mathbb{E}\left(c_i(\alpha)\right)-\frac{\rho}{2}\mathbb{V}\text{ar}\left(c_i(\alpha)\right)-\kappa e_i^*(\alpha)\right)$$

subject to

$$\left(1-\frac{n-1}{n}\alpha\right)y_e\left(\boldsymbol{a}_i^*\left(\alpha\right)\right)=\kappa,$$
$$y_{\boldsymbol{z}}\left(\boldsymbol{a}_i^*\left(\alpha\right)\right)=\boldsymbol{p},$$

for each $i \in N$. This problem can be written as

$$\max_{\alpha}\sum_{i\in N}\left(y\left(\boldsymbol{a}_i^*\left(\alpha\right)\right)-\boldsymbol{p}\cdot\boldsymbol{z}_i^*\left(\alpha\right)+\mu-\kappa e_i^*\left(\alpha\right)\right)-\frac{n\rho}{2}\mathbb{V}\mathrm{ar}\left(c_i\left(\alpha\right)\right).$$

Derivate the planner's objective function with with respect to α to obtain

$$\sum_{i\in N}\left(y_e\left(\boldsymbol{a}_i^*\left(\alpha\right)\right)\frac{\partial e_i^*\left(\alpha\right)}{\partial\alpha}+\sum_{q\in Q}y_{z^q}\left(\boldsymbol{a}_i^*\left(\alpha\right)\right)\frac{\partial z_i^{q*}\left(\alpha\right)}{\partial\alpha}-\boldsymbol{p}\cdot\frac{\partial\boldsymbol{z}_i^*\left(\alpha\right)}{\partial\alpha}-\kappa\frac{\partial e_i^*\left(\alpha\right)}{\partial\alpha}\right)$$
$$-\frac{n\rho}{2}\frac{\partial\mathbb{V}\mathrm{ar}\left(c_i\left(\alpha\right)\right)}{\partial\alpha}.$$

Rearranging, I get

$$\sum_{i\in N}\left(\left(y_e\left(\boldsymbol{a}_i^*\left(\alpha\right)\right)-\kappa\right)\frac{\partial e_i^*\left(\alpha\right)}{\partial\alpha}+\left(y_{z^q}\left(\boldsymbol{a}_i^*\left(\alpha\right)\right)-\boldsymbol{p}\right)\cdot\frac{\partial\boldsymbol{z}_i^*\left(\alpha\right)}{\partial\alpha}\right)-\frac{n\rho}{2}\frac{\partial\mathbb{V}\mathrm{ar}\left(c_i\left(\alpha\right)\right)}{\partial\alpha}.$$

From the IC constraints given in Claim 2, the previous expression boils down to

$$\sum_{i\in N}\left(\kappa\left(\frac{1}{1-\frac{n-1}{n}\alpha}-1\right)\frac{\partial e_i^*\left(\alpha\right)}{\partial\alpha}\right)-\frac{n\rho}{2}\frac{\partial\mathbb{V}\mathrm{ar}\left(c_i\left(\alpha\right)\right)}{\partial\alpha}.$$

Notice that $\left(\frac{1}{1-\frac{n-1}{n}\alpha}-1\right)>0$, $\frac{\partial e_i^*(\alpha)}{\partial\alpha}<0$ by the law of supply (see the proof of Theorem 1), and $\frac{\partial\mathbb{V}\mathrm{ar}(c_i(\alpha))}{\partial\alpha}<0$ (see the proof of Claim 3). □

Proof of Proposition 1. Let $\left(\boldsymbol{c}^*\left(\boldsymbol{\pi}\right),\boldsymbol{a}^*\right)$ be a solution to the planner's problem, and $\varpi\left(\boldsymbol{\pi}\right)$ be the Lagrange multiplier of the feasibility constraint when profit profile $\boldsymbol{\pi}$ realizes. The first-order conditions for $c_i\left(\boldsymbol{\pi}\right)$ are

$$u'\left(c_i^*\left(\boldsymbol{\pi}\right)\right)\phi^{\boldsymbol{\pi}}\left(\boldsymbol{\pi}\mid\boldsymbol{a}^*\right)=\varpi\left(\boldsymbol{\pi}\right).$$

Combining this with the first-order conditions for $c_j(\boldsymbol{\pi})$ yields

$$\frac{u'\left(c_i^*\left(\boldsymbol{\pi}\right)\right)}{u'\left(c_j^*\left(\boldsymbol{\pi}\right)\right)} = 1,$$

for each i, j and each $\boldsymbol{\pi}$. That is, for each profit realization, consumption is adjusted so that the households' marginal utilities are equalized. □

Proof of Claim 5. The first-order condition for e_i reads[33]

$$\sum_{j \in N} \int u\left(c_j^*\left(\boldsymbol{\pi}\right)\right) \phi_{e_i}^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right) \prod_{k \neq i} \phi^{\pi_k}\left(\pi_k \mid \boldsymbol{a}_k^*\right) \mathrm{d}\boldsymbol{\pi} = k,$$

Notice that the right-hand side of this equation is i's private marginal cost of effort, while the right-hand size is the marginal increase in social welfare associated to a unitary increase in i's effort. On the other hand, the first-order condition for z_i^q is given by

$$\sum_{j \in N} \int u\left(c_i^*\left(\boldsymbol{\pi}\right)\right) \phi_{z_i^q}^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right) \prod_{k \neq i} \phi^{\pi_k}\left(\pi_k \mid \boldsymbol{a}_k^*\right) \mathrm{d}\boldsymbol{\pi} = 0, \tag{24}$$

Recall that $\phi^{\pi^i}\left(\pi_i \mid \boldsymbol{a}_i\right) = \phi^{\varepsilon^i}\left(\pi_i - y\left(\boldsymbol{a}_i\right) + \boldsymbol{p}\boldsymbol{z}_i\right)$. Hence,

$$\phi_{z_i^q}^{\pi_i^i}\left(\pi_i \mid \boldsymbol{a}_i\right) = \phi_{\varepsilon_i}^{\varepsilon^i}\left(\pi_i - y\left(\boldsymbol{a}_i\right) + \boldsymbol{p}\boldsymbol{z}_i\right)\left[-y_{z^q}\left(\boldsymbol{a}_i\right) + p^q\right].$$

Thus, Equation (24) can be rewritten as

$$\left[-y_{z^q}\left(\boldsymbol{a}_i^*\right) + p^q\right] \sum_{j \in N} \int u\left(c_j^*\left(\boldsymbol{\pi}\right)\right) \phi_{\varepsilon_i}^{\varepsilon^i}\left(\pi_i - y\left(\boldsymbol{a}_i^*\right) + \boldsymbol{p}\boldsymbol{z}_i^*\right) \prod_{k \neq i} \phi^{\pi_k}\left(\pi_k \mid \boldsymbol{a}_k^*\right) \mathrm{d}\boldsymbol{\pi} = 0,$$

which is true if and only if $y_{z^q}\left(\boldsymbol{a}_i^*\right) - p^q$. That is, the marginal product of intermediate q is equal to its price. □

Proof of Proposition 2. Recall that $\phi^{\pi^i}\left(\pi_i \mid \boldsymbol{a}_i\right) = \phi^{\varepsilon^i}\left(\pi_i - y\left(\boldsymbol{a}_i\right) + \boldsymbol{p}\boldsymbol{z}_i\right)$. Hence,

$$\phi_{z_i^q}^{\pi_i^i}\left(\pi_i \mid \boldsymbol{a}_i\right) = \phi_{\varepsilon_i}^{\varepsilon^i}\left(\pi_i - y\left(\boldsymbol{a}_i\right) + \boldsymbol{p}\boldsymbol{z}_i\right)\left[-y_{z^q}\left(\boldsymbol{a}_i\right) + p^q\right].$$

[33]In the following, $\frac{\partial \phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i\right)}{\partial x} := \phi_x^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i\right)$.

As a consequence, the first-order condition for z_i^q can be rewritten as

$$[-y_{z^q}(\boldsymbol{a}_i)+p^q]\int u(c_i(\boldsymbol{\pi}))\,\phi_{\varepsilon_i}^{\varepsilon^i}(\pi_i-y(\boldsymbol{a}_i)+\boldsymbol{p}\boldsymbol{z}_i)\prod_{j\neq i}\phi^{\pi_j}(\pi_j\mid\boldsymbol{a}_j)\,\mathrm{d}\boldsymbol{\pi}=0,$$

which is true as long as

$$y_{z^q}(\boldsymbol{a}_i)=p^q.$$

Hence, Problem (19) can be rewritten as

$$\begin{aligned}
&\max_{\boldsymbol{c}(\boldsymbol{\pi}),\boldsymbol{a}}\sum_{i\in N}\left\{\mathbb{E}_{\boldsymbol{\pi}}\left[u(c_i(\boldsymbol{\pi}))\mid\boldsymbol{a}\right]-ke_i\right\}\\
&\text{subject to }\sum_i c_i(\boldsymbol{\pi})=\sum_i\pi_i,\ \forall\boldsymbol{\pi},\\
&\int u(c_i(\boldsymbol{\pi}))\,\phi_{e_i}^{\pi_i}(\pi_i\mid\boldsymbol{a}_i)\prod_{j\neq i}\phi^{\pi_j}(\pi_j\mid\boldsymbol{a}_j)\,\mathrm{d}\boldsymbol{\pi}=k,\forall i,\\
&y_{z^q}(\boldsymbol{a}_i)=p^q,\ \forall i,\forall q.
\end{aligned}\tag{25}$$

The Lagrangian associated to Problem (25) is

$$\begin{aligned}
\mathcal{L}(\boldsymbol{c}(\boldsymbol{\pi}),\boldsymbol{a}):=\int\Bigg\{&\sum_i\left[u(c_i(\boldsymbol{\pi}))-ke_i\right]\\
&-\varpi(\boldsymbol{\pi})\left[\sum_i c_i(\boldsymbol{\pi})-\sum_i\pi_i\right]\frac{1}{\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a})}\\
&-\sum_i\psi_i\left[u(c_i(\boldsymbol{\pi}))\frac{\phi_{e_i}^{\pi_i}(\pi_i\mid\boldsymbol{a}_i)\prod_{j\neq i}\phi^{\pi_j}(\pi_j\mid\boldsymbol{a}_j)}{\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a})}-v'(e_i)\right]\\
&-\sum_i\sum_q\xi_{iq}\left[y_{z^q}(\boldsymbol{a}_i)-p^q\right]\frac{1}{\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a})}\Bigg\}\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a})\,\mathrm{d}\boldsymbol{\pi}
\end{aligned}$$

Then, the first-order condition for $c_i(\boldsymbol{\pi})$ reads

$$u'(c_i^*(\boldsymbol{\pi}))-\frac{\varpi(\boldsymbol{\pi})}{\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a}^*)}-\psi_i u'(c_i^*(\boldsymbol{\pi}))\frac{\phi_{e_i}^{\pi_i}(\pi_i\mid\boldsymbol{a}_i^*)\prod_{j\neq i}\phi^{\pi_j}\left(\pi_j\mid\boldsymbol{a}_j^*\right)}{\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a}^*)}=0.\tag{26}$$

By independence, $\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a})=\phi^{\pi_i}(\pi_i\mid\boldsymbol{a}_i)\prod_{j\neq i}\phi^{\pi_j}(\pi_j\mid\boldsymbol{a}_j)$. Hence, Equation (26) boils down to

$$u'(c_i^*(\boldsymbol{\pi}))-\frac{\varpi(\boldsymbol{\pi})}{\phi^{\boldsymbol{\pi}}(\boldsymbol{\pi}\mid\boldsymbol{a}^*)}-\psi_i u'(c_i^*(\boldsymbol{\pi}))\,\Lambda_i(\pi_i\mid\boldsymbol{a}_i^*)=0,$$

Combining this with the first-order condition for $c_j(\boldsymbol{\pi})$ delivers Equation (20). □

Proof of Claim 1. Perfect sharing requires Equation (20) to be constant across profit realizations. Suppose this is true; i.e.,

$$\frac{1+\psi_j\Lambda_j\left(\pi_j \mid \boldsymbol{a}_j^*\right)}{1+\psi_i\Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right)} = r_{ij}, \tag{27}$$

where r_{ij} is a constant. Rearrange Equation (27) to

$$r_{ij}\psi_i\Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right) - \psi_j\Lambda_j\left(\pi_j \mid \boldsymbol{a}_j^*\right) = 1 - r_{ij} := \widehat{r}_{ij},$$

where $\widehat{r}_{ij}$ is yet another constant. Multiply both sides of the previous equation by $\phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right)$ to obtain

$$r_{ij}\psi_i\phi_{e_i}^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right) - \psi_j\frac{\phi_{e_j}^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right)}{\phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right)}\phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right) = \widehat{r}_{ij}\phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right).$$

Integrate over π_i using the fact that $\int \phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right) = 1$ to get

$$r_{ij}\psi_i\int \phi_{e_i}^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right)\,\mathrm{d}\pi_i - \psi_j\frac{\phi_{e_j}^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right)}{\phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right)} = \widehat{r}_{ij}.$$

Next, multiply both sides of the previous equations by $\phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right)$, integrate over π_i, and use the fact that $\int \phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right) = 1$ to obtain

$$r_{ij}\psi_i\int \phi_{e_i}^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right)\,\mathrm{d}\pi_i - \psi_j\int \phi_{e_j}^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right)\,\mathrm{d}\pi_j = \widehat{r}_{ij}.$$

Notice that $\int \phi_{e_i}^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right)\,\mathrm{d}\pi_i = \int \phi_{e_j}^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right)\,\mathrm{d}\pi_j = 0$, since $\int \phi^{\pi_i}\left(\pi_i \mid \boldsymbol{a}_i^*\right) = \int \phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right) = 1$. Hence, it must be the case that

$$\widehat{r}_{ij} = 1 - r_{ij} = 0.$$

This is true if and only if $r_{ij} = 1$. Combining this last observation with Equation (27), one gets

$$\frac{1+\psi_j\Lambda_j\left(\pi_j \mid \boldsymbol{a}_j^*\right)}{1+\psi_i\Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right)} = 1;$$

i.e.,

$$\psi_j \Lambda_j\left(\pi_j \mid \boldsymbol{a}_j^*\right) = \psi_i \Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right). \tag{28}$$

Suppose $\psi_i, \psi_j \neq 0$ (otherwise perfect risk sharing would trivially obtain). Next, I show that Equation (28) cannot hold for each $\boldsymbol{\pi}$. To see this, pick $(\pi_j, \boldsymbol{\pi}_{-j}) = (\widehat{\pi}_j, \boldsymbol{\pi}_{-j})$. Equation (28) implies that

$$\Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right) = \frac{\psi_j}{\psi_i}\Lambda_j\left(\widehat{\pi}_j \mid \boldsymbol{a}_j^*\right).$$

Next, pick $(\pi_j, \boldsymbol{\pi}_{-j}) = \left(\widehat{\pi}'_j, \boldsymbol{\pi}_{-j}\right)$, with $\widehat{\pi}_j \neq \widehat{\pi}'_j$. Since Equation (28) holds for each $\boldsymbol{\pi}$, it must be the case that

$$\frac{\psi_j}{\psi_i}\Lambda_j\left(\widehat{\pi}_j \mid \boldsymbol{a}_j^*\right) = \Lambda_i\left(\pi_i \mid \boldsymbol{a}_i^*\right) = \frac{\psi_j}{\psi_i}\Lambda_j\left(\widehat{\pi}'_j \mid \boldsymbol{a}_j^*\right).$$

Given that the choices of $\widehat{\pi}_j$ and $\widehat{\pi}'_j$ were totally arbitrary, I conclude that $\Lambda_j\left(\pi_j \mid \boldsymbol{a}_j^*\right)$ must be a constant function of π_j. Hence, it must be the case that

$$\phi_{e_j}^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right) = w_j \phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right),$$

for some constant w_j. This is a first-order linear differential equation in e_i. The solution to this equation is given by

$$\phi^{\pi_j}\left(\pi_j \mid \boldsymbol{a}_j^*\right) = \frac{1}{\exp\left\{\int_0^E w_j \,\mathrm{d}e_i\right\}}\int_0^E \exp\left\{\int_0^E w_j \,\mathrm{d}e_i\right\} 0 \,\mathrm{d}e_i = 0.$$

This contradicts Equation (16). □

Proof of Claim 6. Applying a change of variables from $\boldsymbol{\pi}$ to $\boldsymbol{\varepsilon}$ and assuming that the optimal sharing contract is differentiable, one can write the first-order condition for effort as

$$\int u'\left(c_i^*\left(\boldsymbol{\pi}\right)\right)\frac{\partial c_i^*\left(\boldsymbol{\pi}\right)}{\partial \pi_i} y_e\left(\boldsymbol{a}_i^*\right) \mathrm{d}\Phi^{\boldsymbol{\varepsilon}}\left(\boldsymbol{\varepsilon}\right) = k.$$

This can be rewritten as

$$y_e\left(\boldsymbol{a}_i^*\right) = \frac{k}{\int u'\left(c_i^*\left(\boldsymbol{\pi}\right)\right)\frac{\partial c_i^*\left(\boldsymbol{\pi}\right)}{\partial \pi_i}\mathrm{d}\Phi^{\boldsymbol{\varepsilon}}\left(\boldsymbol{\varepsilon}\right)} := p\left(c_i^*\left(\boldsymbol{\pi}\right)\right).$$

Notice that, when Assumption 1 holds, household i's problem is equivalent to that of a competitive firm facing a real price of input q equal to p^q and a real price of effort equal to $p\left(c_i^*\left(\boldsymbol{\pi}\right)\right)$. By the law of supply, e_i^* is strictly decreasing in $p\left(c_i^*\left(\boldsymbol{\pi}\right)\right)$. Finally, notice that $p\left(c_i^*\left(\boldsymbol{\pi}\right)\right)$ is increasing in $\frac{\partial c_i^*(\boldsymbol{\pi})}{\partial \pi_i}$. □

Proof of Theorem 2. By Claim 6, e_i^* is increasing in $\frac{\partial c_i^*(\boldsymbol{\pi})}{\partial \pi_i}$. Notice that $\frac{\partial c_i^*(\boldsymbol{\pi})}{\partial \pi_i}$ affects $p\left(c_i^*\left(\boldsymbol{\pi}\right)\right)$, but not the prices of the other inputs. Hence,

$$\frac{\partial z_i^{q*}\left(p\left(c_i^*\left(\boldsymbol{\pi}\right)\right),\boldsymbol{p}\right)}{\partial \frac{\partial c_i^*(\boldsymbol{\pi})}{\partial \pi_i}} = \frac{\partial z_i^{q*}\left(p\left(c_i^*\left(\boldsymbol{\pi}\right)\right),\boldsymbol{p}\right)}{\partial p\left(c_i^*\left(\boldsymbol{\pi}\right)\right)} \frac{\partial p\left(c_i^*\left(\boldsymbol{\pi}\right)\right)}{\partial \frac{\partial c_i^*(\boldsymbol{\pi})}{\partial \pi_i}}.$$

□

Proof of Claim 7. Proposition 1 shows that, under full information, the optimal sharing rule is pinned down by the Borch rule:

$$\frac{u'\left(c_i^{\mathrm{FI}}\left(\boldsymbol{\pi}\right)\right)}{u'\left(c_j^{\mathrm{FI}}\left(\boldsymbol{\pi}\right)\right)} = 1,$$

If agents have quadratic utility from consumption, this boils down to

$$\frac{1-\rho c_i^{\mathrm{FI}}\left(\boldsymbol{\pi}\right)}{1-\rho c_j^{\mathrm{FI}}\left(\boldsymbol{\pi}\right)} = 1.$$

Hence, it must be the case that $c_i^{\mathrm{FI}}\left(\boldsymbol{\pi}\right) = c_j^{\mathrm{FI}}\left(\boldsymbol{\pi}\right)$, for each $j \neq i$. Using the feasibility constraint, this implies that $c_i^{\mathrm{FI}}\left(\boldsymbol{\pi}\right) = \frac{\sum_j \pi_j}{n}$.

See Ambrus et al. (2017) for a proof that $c_i^{\mathrm{FI}}\left(\boldsymbol{\pi}\right) = \overline{\pi}$ with CARA utility and linear contracts.

□

Proof of Claim 8. When $\boldsymbol{c}^{\mathrm{PI}}$ is linear and the agents have mean-variance expected utility, household i's problem can be written as

$$\max_{\boldsymbol{a}_i} \sum_{j\in N} \alpha_{ij}^{\mathrm{PI}}\left(y\left(\boldsymbol{a}_j\right) - \boldsymbol{p}\cdot\boldsymbol{z}_j + \mu\right) - \frac{\rho}{2}\sum_{j\in N} {\alpha_{ij}^{\mathrm{PI}}}^2\sigma^2 - \kappa e_i.$$

The objective function is continuously differentiable and jointly concave in e_i and z_i^q. Hence, the maximization problem is a concave program and the first-order conditions pin down an interior solution. The first-order conditions for e_i and z_i^q are given by

$$\alpha_{ii}^{\mathrm{SB}} y_e\left(\boldsymbol{a}_i^*\right) = \kappa$$

and

$$y_{z^q}\left(\boldsymbol{a}_i^*\right) = p^q,$$

respectively. Notice that these conditions are independent of $\boldsymbol{a}_j$, for $j \neq i$. □

Proof of Claim 9. Recall that the household's problem is to that of a competitive firm facing a real price of input q equal to p^q and a real price of effort equal to $p\left(c_i^*\left(\boldsymbol{\pi}\right)\right)$. Hence, household i's objective function can be written as

$$y\left(e_i, \boldsymbol{z}_i\right) - p^q z_i^q - \frac{k}{\left(1 - \frac{n-1}{n}\alpha\right)} e_i$$

Since $y\left(\boldsymbol{a}_i\right)$ is increasing and supermodular, the household's objective function is supermodular in $\left(e_i, z_i^q, -p_e\right)$. Since the choice set is a sublattice, by Topkis' Monotonicity Theorem, $\left(e_i^*\left(p_e, p^q\right), z_i^{q*}\left(p_e, p^q\right)\right)$ is decreasing in p_e. Finally, notice that p_e is strictly increasing in α. This argument extends symmetrically for the case in which $y\left(\boldsymbol{a}_i\right)$ is submodular. □

I Tables and Figures

Table 1: Summary Statistics

Variable	Average	Std. Dev.
Household size	4.97	2.13
Number of infants	0.05	0.23
Average adult age	40.76	8.97
Age-sex weight	4.31	1.69
Monthly consumption	117.87	73.60
Monthly income	115.29	147.51
Monthly effort	21.26	26.38
Monthly fertilizer	24.65	69.14
Number of households	876	
Observations	20044	

Notes: All money values in 1975 rupees. Consumption, income, effort, and fertilizer expressed in adult-equivalent terms. Effort is hours of supplied by family members. Household-month observations.

Table 2: A Test for Full Sharing

Dep. variable: $\log(c_{it})$	$\widehat{\beta}$ (s.e.)
$\log(y_{it})$	.2594*** (.0207)
Household fixed effects	Yes
Village-month fixed effects	Yes
R-squared	0.773
Observations	18,931

Notes: OLS regressions of log income on log consumption. Standard errors are robust.

Table 3: risk sharing and Effort

Dep. variable: $\log(c_{it})$	$\widehat{\beta}$ (s.e.)
$\log(y_{it})$	.1878*** (.0515)
$\log(y_{it}) \times \overline{\log(e_i)}$	.0278* (.0155)
Household fixed effects	Yes
Village-month fixed effects	Yes
R-squared	0.773
Observations	18,929

Notes: OLS regressions of log income and log income times average log effort on log consumption. Standard errors are robust.

Table 4: Non-Linearity between risk sharing and Effort

Dep. variable: $\log(c_{it})$	$\widehat{\beta}$ (s.e.)
$\log(y_{it})$	.1841*** (.0416)
$\log(y_{it}) \times \overline{e}_i$	.0048** (.0016)
$\log(y_{it}) \times \overline{e}_i^2$	-.0001** (.0001)
Household fixed effects	Yes
Village-month fixed effects	Yes
R-squared	0.774
Observations	18,931

Notes: OLS regressions of log income, log income times average effort, and log income times average effort squared on log consumption. Standard errors are robust.

Table 5: Effort and Fertilizer

Dep. variable: $\log(f_{it})$	$\widehat{\gamma}$ (s.e.)
$\log(e_{it})$	.4348*** (.0141)
Land area	.0032*** (.0003)
Household fixed effects	Yes
Village-month fixed effects	Yes
R-squared	0.326
Observations	8,794

Notes: OLS regressions of effort on fertilizer. All regressions with household and month fixed effects. Standard errors are robust.

Table 6: risk sharing and Fertilizer

Dep. variable: Consumption	$\widehat{\beta}$ (s.e.)
Income	.0575 (.1014)
Income × fertilizer	.0619** (.0269)
Household fixed effects	Yes
Village-month fixed effects	Yes
R-squared	0.774
Observations	18,890

Notes: OLS regressions of log income and log income times average log fertilizer on log consumption. Standard errors are robust.

Table 7: Non-Linearity between risk sharing and Fertilizer

Dep. variable: $\log(c_{it})$	$\widehat{\beta}$ (s.e.)
$\log(y_{it})$	.2143*** (.0416)
$\log(y_{it}) \times \overline{f}_i$	.0026 (.0022)
$\log(y_{it}) \times \overline{f}_i^2$	-.0001 (.0001)
Household fixed effects	Yes
Village-month fixed effects	Yes
R-squared	0.773
Observations	18,931

Notes: OLS regressions of log income, log income times average fertilizer, and log income times average fertilizer squared on log consumption. Standard errors clustered are robust.

Table 8: A Test for Full Sharing with Simulated Consumption

Dep. variable:	$\log(\widetilde{c}_{it})$ $(\widetilde{\alpha}_{vt} = 0.82)$	$\widehat{\beta}$ (s.e.)	$\log(\widetilde{c}_{it})$ $(\widetilde{\alpha}_{vt} = 0.75)$	$\widehat{\beta}$ (s.e.)	$\log(\widetilde{c}_{it})$ $(\widehat{\alpha}_{vt})$	$\widehat{\beta}$ (s.e.)
$\log(y_{it})$		.1600*** (.0142)		.2123*** (.0187)		.2968*** (.0662)
Household fixed effects		Yes		Yes		Yes
Village-month fixed effects		Yes		Yes		Yes
R-squared		0.967		0.962		0.817
Observations		15,069		15,095		5,465

Notes: OLS regressions of log income on log of simulated consumption. Standard errors are robust.

Table 9: Summary Statistics for $\widetilde{\log\left(\frac{f_{it}}{e_{it}}\right)}$.

	Average	S.d.	Min	Max
$\widetilde{\alpha}_{vt} = 0$	-.6033	1.3189	-6.5593	3.1884
$\widetilde{\alpha}_{vt} = 1$	1.6952	1.3150	-4.3519	5.3811

Table 10: Summary Statistics of the Growth Rates of Effort and Fertilizer Use (from $\widetilde{\alpha}_{vt} = 0$ to $\widetilde{\alpha}_{vt} = 1$).

	Average	S.d.	Min	Max
$\log(e_{it}(0)) - \log(e_{it}(1))$	-3.2224	.3450	-4.0675	-2.246
$\log(f_{it}(0)) - \log(f_{it}(1))$	-.9150	.2833	-1.534	-.0387

Table 11: Within-Estimator

Dep. variable: $c_{it} - \overline{c}_{vt}$	$\widehat{\beta}$ (s.e.)
$\pi_{it} - \overline{\pi}_{vt}$	.1731*** (.0029)
Household fixed effects	No
Village-month fixed effects	No
R-squared	0.1519
Observations	20044

Notes: OLS regressions of deviations of household income from village-month average income on deviations household consumption from village-month average consumption.

Table 12: Between-Estimator

Dep. variable: $c_{it} - \overline{c}_{vt}$	$\widehat{\beta}$ (s.e.)
$\pi_{it} - \overline{\pi}_{vt}$	.9228*** (.0021)
Household fixed effects	No
Village-month fixed effects	No
R-squared	0.8978
Observations	21080

Notes: OLS regressions of village-month average income on village-month average consumption.

Figure 1: Histogram of $\widehat{k}_i$

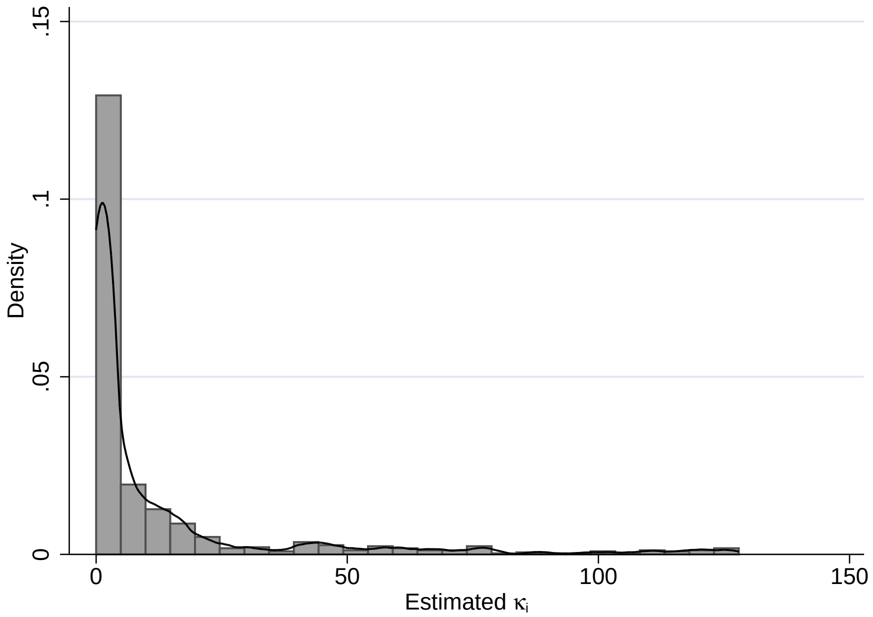


Figure 2: Histogram of $\widehat{\alpha}_{vt}$

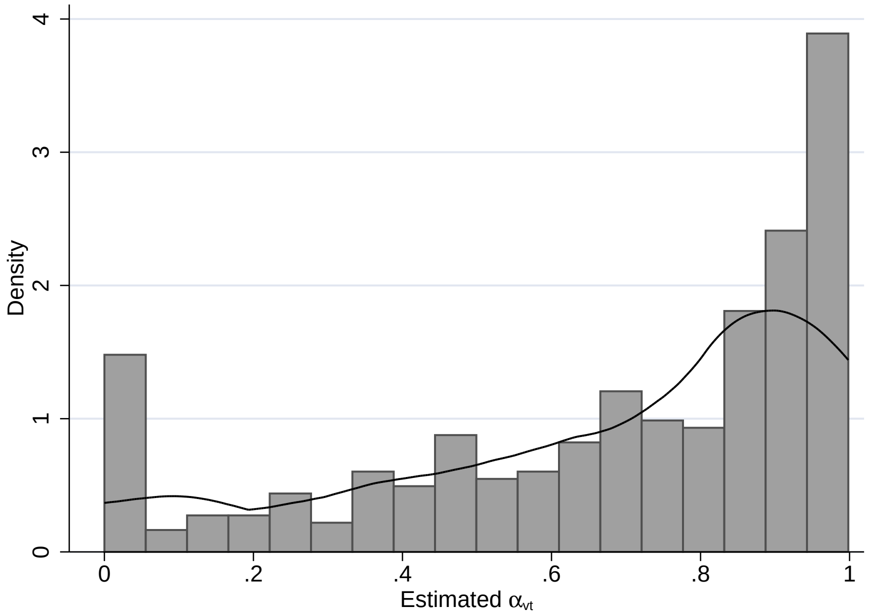


Figure 3: Comparative Statics

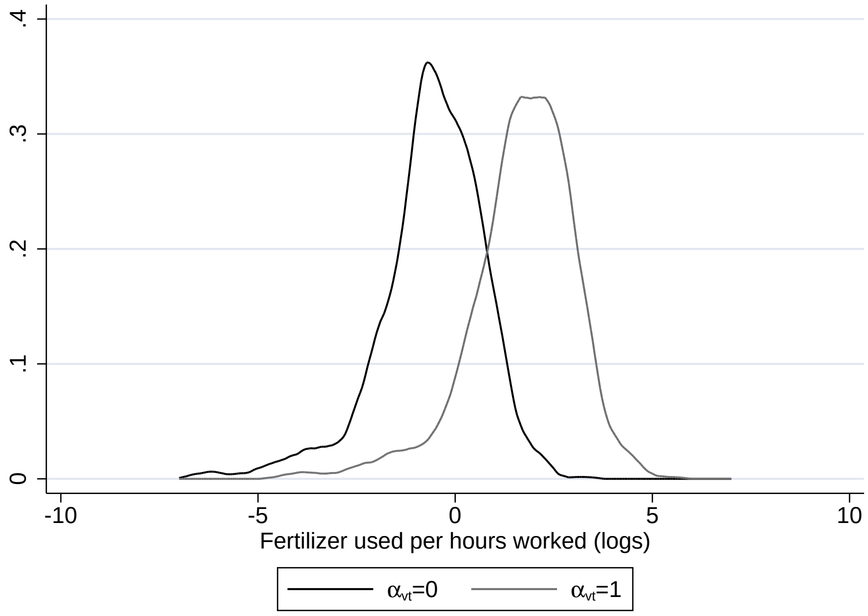


Figure 4: A Validation Exercise

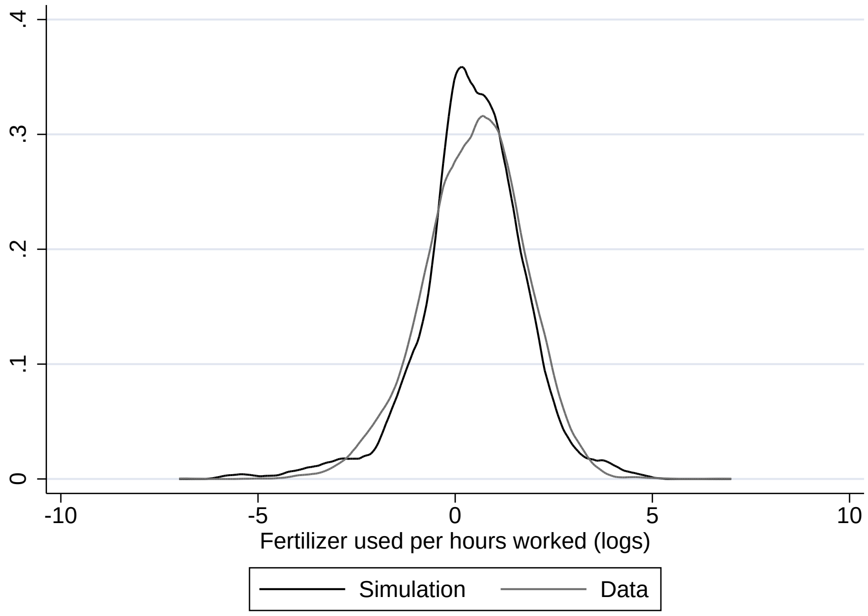


Figure 5: Optimal Sharing

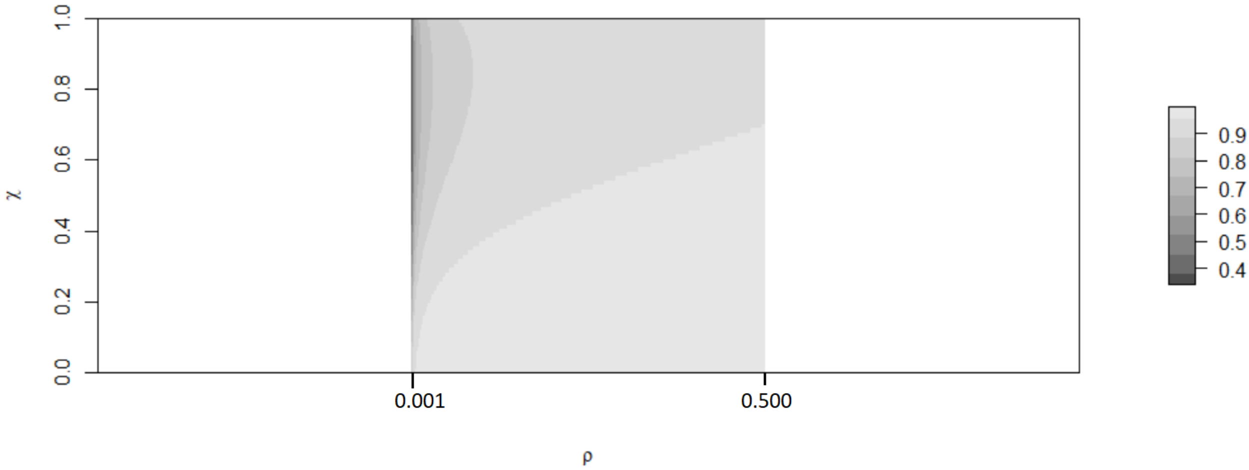
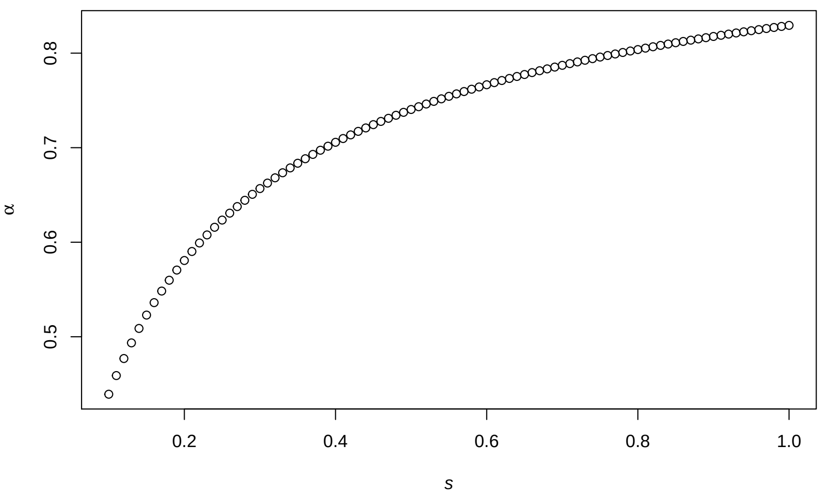


Figure 6: Optimal Sharing and Fertilizer Subsidy



References

Ábrahám, Á. and Pavoni, N. (2005). The Efficient Allocation of Consumption under Moral Hazard and Hidden Access to the Credit Market. *Journal of the European Economic Association*, 3(2-3):370–381.

Acemoglu, D. (2010). When Does Labor Scarcity Encourage Innovation? *Journal of Political Economy*, 118(6):1037–1078.

Advani, A. (2017). Insurance Networks and Poverty Traps. Working paper, University College London.

Ambrus, A., Gao, W. Y., and Milán, P. (2017). Informal Risk Sharing with Local Information. Working paper.

Arcand, J.-L., Ai, C., and Éthier, F. (2007). Moral Hazard and Marshallian Inefficiency: Evidence from Tunisia. *Journal of Development Economics*, 83(2):411–445.

Attanasio, O. P. and Pavoni, N. (2011). Risk Sharing in Private Information Models with Asset Accumulation: Explaining the Excess Smoothness of Consumption. *Econometrica*, 79(4):1027–1068.

Beaman, L., Karlan, D., Thuysbaert, B., and Udry, C. (2013). Profitability of Fertilizer: Experimental Evidence from Female Rice Farmers in Mali. *American Economic Review*, 103(3):381–86.

Binswanger, H. P. (1981). Attitudes Toward Risk: Theoretical Implications of an Experiment in Rural India. *The Economic Journal*, 91(364):867–890.

Bold, T. and Broer, T. (2016). Risk-Sharing in Village Economies Revisited. Working paper.

Bolton, P. and Dewatripont, M. (2005). *Contract Theory*. MIT press.

Carroll, G. (2015). Robustness and Linear Contracts. *American Economic Review*, 105(2):536–63.

Chen, C., Restuccia, D., and Santaeulàlia-Llopis, R. (2017). The Effects of Land Markets on Resource Allocation and Agricultural Productivity. Working paper, National Bureau of Economic Research.

Clark, D. E., Herrin, W. E., Knapp, T. A., and White, N. E. (2003). Migration and Implicit Amenity Markets: Does Incomplete Compensation Matter? *Journal of Economic Geography*, 3(3):289–307.

Cochrane, J. H. (1991). A Simple Test of Consumption Insurance. *Journal of Political Economy*, 99(5):957–976.

Conlon, J. R. (2009). Two New Conditions Supporting the First-Order Approach to Multisignal Principal–Agent Problems. *Econometrica*, 77(1):249–278.

Dercon, S. and Christiaensen, L. (2011). Consumption Risk, Technology Adoption and Poverty Traps: Evidence from Ethiopia. *Journal of Development Economics*, 96(2):159–173.

Dorfman, J. H. (1996). Modeling Multiple Adoption Decisions in a Joint Framework. *American Journal of Agricultural Economics*, 78(3):547–557.

Dutta, J. and Prasad, K. (2002). Stable Risk-Sharing. *Journal of Mathematical Economics*, 38(4):411–439.

Edmans, A. and Gabaix, X. (2011). Tractability in Incentive Contracting. *The Review of Financial Studies*, 24(9):2865–2894.

Fafchamps, M. (2011). Risk Sharing Between Households. In *Handbook of Social Economics*, pages 1255–1279. Elsevier.

Feder, G., Just, R. E., and Zilberman, D. (1985). Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change*, pages 255–298.

Foster, A. D. and Rosenzweig, M. R. (2001). Imperfect Commitment, Altruism, and the Family: Evidence from Transfer Behavior in Low-Income Rural Areas. *Review of Economics and Statistics*, 83(3):389–407.

Foster, A. D. and Rosenzweig, M. R. (2009). Should Poor Farmers Use More Inputs? Working paper.

Foster, A. D. and Rosenzweig, M. R. (2010). Microeconomics of Technology Adoption. *Annual Review of Economics*, 2(1):395–424.

Foster, A. D. and Rosenzweig, M. R. (2011). Are Indian Farms Too Small? Mechanization, Agency Costs, and Farm Efficiency. Working paper.

Giné, X. and Yang, D. (2009). Insurance, Credit, and Technology Adoption: Field Experimental Evidence from Malawi. *Journal of Development Economics*, 89(1):1–11.

Haider, H., Smale, M., and Theriault, V. (2018). Intensification and Intrahousehold Decisions: Fertilizer Adoption in Burkina Faso. *World Development*.

Holmström, B. and Milgrom, P. (1987). Aggregation and Linearity in the Provision of Intertemporal Incentives. *Econometrica*, pages 303–328.

Hornbeck, R. and Naidu, S. (2014). When the Levee Breaks: Black Migration and Economic Development in the American South. *The American Economic Review*, 104(3):963–990.

Indian Labour Bureau (2010). Wage Rates in Rural India. Technical report, Labor Bureau, Ministry of Labor & Employment, Government of India.

Jack, B. K. (2013). Market Inefficiencies and the Adoption of Agricultural Technologies in Developing Countries. Working paper, Agricultural Technology Adoption Initiative.

Jakiela, P. and Ozier, O. (2015). Does Africa Need a Rotten Kin Theorem? Experimental Evidence from Village Economies. *The Review of Economic Studies*, 83(1):231–268.

Jalan, J. and Ravallion, M. (1999). Are the Poor Less Well Insured? Evidence on Vulnerability to Income Risk in Rural China. *Journal of Development Dconomics*, 58(1):61–81.

Jewitt, I. (1988). Justifying the First-Order Approach to Principal-Agent Problems. *Econometrica*, 56(5):1177–1190.

Kaplan, G. (2006). The Cross-Sectional Implications of Incomplete Markets: Private Information or Limited Enforcement? Working paper, New York University.

Karaivanov, A. and Townsend, R. M. (2014). Dynamic Financial Constraints: Distinguishing Mechanism Design from Exogenously Incomplete Regimes. *Econometrica*, 82(3):887–959.

Kinnan, C. (2017). Distinguishing Barriers to Insurance in Thai Villages. Working paper, Northwestern University.

Kocherlakota, N. and Pistaferri, L. (2009). Asset Pricing Implications of Pareto Optimality with Private Information. *Journal of Political Economy*, 117(3):555–590.

Laczó, S. (2015). Risk Sharing with Limited Commitment and Preference Heterogeneity: Structural Estimation and Testing. *Journal of the European Economic Association*, 13(2):265–292.

Laffont, J.-J. and Matoussi, M. S. (1995). Moral Hazard, Financial Constraints and Sharecropping in El Oulja. *The Review of Economic Studies*, 62(3):381–399.

Ligon, E. (1998). Risk Sharing and Information in Village Economies. *The Review of Economic Studies*, 67(4):847–864.

Ligon, E., Thomas, J. P., and Worrall, T. (2002). Informal Insurance Arrangements with Limited Commitment: Theory and Evidence from Village Economies. *The Review of Economic Studies*, 69(1):209–244.

Mace, B. J. (1991). Full Insurance in the Presence of Aggregate Uncertainty. *Journal of Political Economy*, 99(5):928–956.

Mas-Colell, A., Whinston, M. D., and Green, J. R. (1995). *Microeconomic Theory*. Oxford University Press.

Mazur, K. (2018). Sharing Risk to Avoid Tragedy: Theory and Application to Farming. Working paper, European University Institute.

Mazzocco, M. and Saini, S. (2012). Testing Efficient Risk Sharing with Heterogeneous Risk Preferences. *American Economic Review*, 102(1):428–468.

Milán, P. (2016). Network-Constrained Risk Sharing in Village Economies. Working paper, Universitat Autónoma de Barcelona and Barcelona GSE.

Miller, D. and Paulson, A. (2007). Risk Taking and the Quality of Informal Insurance: Gambling and Remittances in Thailand. Working paper, Federal Reserve Bank of Chicago.

Morten, M. (2017). Temporary Migration and Endogenous Risk Sharing in Village India. *Journal of Political Economy*. Forthcoming.

Munshi, K. and Rosenzweig, M. (2006). Traditional Institutions Meet the Modern World: Caste, Gender, and Schooling Choice in a Globalizing Economy. *The American Economic Review*, 96(4):1225–1252.

Munshi, K. and Rosenzweig, M. (2009). Why is Mobility in India So Low? Social Insurance, Inequality, and Growth. Working paper, National Bureau of Economic Research.

Munshi, K. and Rosenzweig, M. (2016). Networks and Misallocation: Insurance, Migration, and the Rural-Urban Wage Gap. *The American Economic Review*, 106(1):46–98.

Paulson, A. L., Townsend, R. M., and Karaivanov, A. (2006). Distinguishing Limited Liability from Moral Hazard in a Model of Entrepreneurship. *Journal of Political Economy*, 114(1):100–144.

Prachi, J. (2016). Imperfect Monitoring and Informal Risk Sharing: The Role of Social Ties. Working paper, Princeton University.

Quibria, M. G. and Rashid, S. (1984). The Puzzle of Sharecropping: A Survey of Theories. *World Development*, 12(2):103–114.

Ricker-Gilbert, J. (2014). Wage and Employment Effects of Malawi's Fertilizer Subsidy Program. *Agricultural Economics*, 45(3):337–353.

Rogerson, W. P. (1985). The First-Order Approach to Principal-Agent Problems. *Econometrica*, 53(6):1357–1367.

Rosenzweig, M. R. and Binswanger, H. P. (1993). Wealth, Weather Risk, and the Composition and Profitability of Agricultural Investments. *The Economic Journal*, 103(416):56–78.

Sen, D. (2016). Sharecropping in Theory and Practice: A Selective Review. In *Understanding Development*, pages 53–72. Springer.

Singh, N. (1991). Theories of Sharecropping. In *The Economic Theory of Agrarian Institutions*, pages 19–71. Oxford University Press.

Singh, R. P., Binswanger, H. P., and Jodha, N. S. (1985). Manual of Instructions for Economic Investigators in ICRISAT's Village Level Studies. Technical report, International Crops Research Institute for the Semi-Arid Tropics.

Sunding, D. and Zilberman, D. (2001). The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector. In *Handbook of Agricultural Economics*, pages 207–261. Elsevier.

Suri, T. (2011). Estimating the Extent of Local Risk Sharing between Households. Working paper, MIT Sloan School of Management.

The Organisation for Economic Co-operation and Development (2003). Farm Household Income: Issues and Policy Responses. Technical report, OECD.

Townsend, R. M. (1994). Risk and Insurance in Village India. *Econometrica*, 62(3):539–591.

Udry, C. (2010). The Economics of Agriculture in Africa: Notes Toward a Research Program. *African Journal of Agricultural and Resource Economics*, 5(1).

Wang, X. Y. (2013). A Note on Moral Hazard and Linear Compensation Schemes. Working paper, Duke University.