Technology Adoption, Risk, and Intrahousehold Bargaining in Subsistence Agriculture

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Abstract

Leveraging unique data from four villages in Southern Ghana (Goldstein and Udry, 1999), we present and test a theoretical model where agents in a two-person agricultural household make individual portfolio allocations while looking forward to an intrahousehold bargaining process. The specific context is that of subsistence agriculture where individuals within households farm separate plots but also share resources. Still, our model allows connections to other contexts approaching the question of portfolio choice in general and can be extended as such.

Motivated by empirical findings that unequal access to household resources by individual members impedes investment, we show how an institution of gender bias determines allocations between spouses and feeds back onto investment strategies, ultimately affecting policy efficacy and welfare outcomes over time. In doing so, we portray the household as a simultaneous site of cooperation and conflict and offer a theoretical framework that reflects various aspects of gender inequality in this setting. Specifically, as individuals have separate spheres of influence over the household asset base they adopt heterogeneous portfolio strategies and have relatedly different means of coping with negative economic shocks. In this way, individual risk management strategies diverge from that of the a representative agent and affect prospects for growth in a risky environment.

As agent expectations over the returns from bargaining alter their investment strategies, and asset choices affect one's position at the bargaining table, household members are consequently linked over time, placing the institution of gender at the center of the household's technology adoption problem. Individuals exercise agency in maximizing their own objectives yet this agency is necessarily bounded by the social institution determining resource shares. In the end, egalitarian households are more able to adopt risky technologies and realize gains from related policies. While gender equality is obviously an end in itself, we ultimately show that it is also a relevant means for the complementary end of economic development.

1 Introduction

As a majority of the world's poor continue to farm for food, the adoption of productivity enhancing innovations offers a relevant means of development. Growth in this way is especially important for Sub-Saharan Africa (SSA), where farmers have been slow to uptake new technologies and seen relatedly low levels of productivity growth. For example, cereal yields in SSA grew at an average annual rate of 0.7 percent between 1980 and 2000 compared to other developing regions which saw between 1.2 and 2.3 percent average annual growth. Over the same period fertilizer intensity in SSA grew on average by just .93 percent annually compared to 2.32 percent in other developing countries (just under 5 percent in South Asia) (Kelly et al., 2007). A primary explanation for this relative stagnation that has gained traction in development literature is that new technologies are simply too risky to adopt (Dercon and Christiaensen, 2011; Barrett et al., 2008; Anderson, 2003). Demand for fertilizer, for example, is limited due to high variability in crop output and incomplete information regarding the availability and cost of fertilizer as well as a general lack of knowledge on how to use it efficiently (Kelly et al., 2007). As binding subsistence constraints are both non-trivial and possible, the downside of uncertainty deters innovation and results in safer (but lower return) asset portfolios (Zimmerman and Carter, 2003).

Growth and development literatures have offered various applied and theoretical explanations that feature the relationship between risk aversion and agricultural stagnation. At the same time, better access to intrahousehold panels has allowed researchers to isolate behavioral strategies resulting from living in a risky environment (Dercon, 2008). In doing so, they have been able to uncouple the related but separate strategies of managing risk ex ante and dealing with it ex post. By making this separation, Dercon argues that researchers have been able to supplement an understanding of how households cope with negative shocks with better insight as to how they manage risky environments through specific investment strategies, and ultimately how management and coping are interrelated. Conclusions from these models have suggested policies to support innovation uptake and improve the ability of households to both strategically manage risk in the face of potential shocks and cope with it after the fact if necessary.

By attempting to reduce risk exposure through improving credit and insurance mechanisms, providing asset and consumption stability with social protection schemes (Giesbert and Schindler, 2012), and reducing aid pressure on poor households (Barrett et al., 2008), resulting policy suggestions have targeted largely standard explanations as constraints to growth in a risky environment. These proposals have seen their corollary in applied micro and experimental literatures, where optimal subsidies, delivery mechanisms, and savings instruments attempt to plug inefficiencies in markets (e.g. Duflo et al. (2009), which simultaneously addresses inter temporal bias and fixed cost (time) burdens).[1] Although these conclusions have much to say about the growth implications of risk in this context, they provide little flexibility regarding institutional or political elements of the decision making process itself. If individuals *within* households pursue different strategies to manage risk and employ unique coping strategies as a result, then this criticism is relevant.

While the cited literatures have explored the inter temporal impacts of risk and uncertainty in subsistence agriculture, insights from feminist and bargaining theories have improved our understanding of intrahousehold dynamics and related effects on household consumption, labor choice, and economic development (Chiappori and Donni (2009) and Haddad et al. (1997) provide theoretical and empirical surveys). In doing so, both fields have challenged the assertion that households behave as efficiency maximizing firms (or at best benevolent planners). Instead, social institutions of power, culture, and distributive conflict arise to explain the resulting choices of household members. Regarding household production and agriculture, these political process have been shown to reduce household efficiency and imply diverging welfare outcomes (Udry et al., 1995; Udry, 1996). While these observations convincingly portray the household as a site of both cooperation and conflict, their conclusions have not put forward much in terms of long-run outcomes. In explaining the allocation of income and time, they have served to isolate the effects of intrahousehold processes and their interactions with common policy levers, but in a static setting. Here, we need a dynamic one.

In the context of subsistence agriculture, one institution that has routinely come forward as a source of inefficiency is that of intrahousehold inequality (Doss and Morris, 2000; Doss, 2006). While a gendered division of labor and separate spheres of influence might be optimal under heterogeneous productivities, this optimistic result has been invalidated (Udry, 1996). Regarding the ability of poor households to manage risk, egalitarian households have proven more adept (Agarwal, 1994). In maintaining household welfare, those with more equal bargaining power have been more resilient (Lancaster et al., 2006). Generally speaking, in separate spheres agriculture unequal access to productive inputs has been concluded Pareto-inferior (Udry et al., 1995; Udry, 1996; Slootmaker, 2013).

These observations necessarily have their corollary in risk coping, where men and women drawn down assets differently in dealing with negative shocks (Quisumbing, 2010), experience different portfolio sensitivities to price instability (Dillon and Quiñones, 2011), and have different off-farm opportunities in general (Goldstein, 1999). Gender specific strategies (and outcomes) on either side of the shock are necessarily linked as the ability to draw down assets and smooth consumption is a direct function of the portfolio chosen prior. At

[1] Although fertilizer per se is a relatively divisible asset, it is not perceived as such given the time constraints necessary to acquire it and become familiar with its use. This type of uncertainty was also evident anecdotally in the Ghana survey (Goldstein and Udry, 1999), where farmers perceived a significant fixed investment in pineapple production where the data didn't suggest one

the same time, portfolio choice represents an expectation of individual asset control and coping requirments. This relationship is only magnified by any heterogeneous preferences women and men may have towards certain household expenditures (e.g. child welfare, dependent care), and/or acceptable levels of risk.

While intrahousehold processes clearly effect both choices and outcomes, they have not been treated in a dynamic framework of technology adoption in subsistence agriculture. Although intrahousehold dynamics have been accepted as constraints to development, they have not been given their deserved treatment in problems of growth under uncertainty where decisions have inter temporal implications that interact with institutions of power and conflict through time.

The contribution of this paper is therefore to underline the role played by gender inequality in the technology adoption process. The specific context is one where households farm both subsistence and cash-crops and spouses farm separate plots.[2] The primary empirical observations our model considers are: (i) males and females often farm separate crops; (ii) female spouses have less access to productive inputs; (iii) females have less say over financial assets and returns from cash crop production and therefore invest less in the latter (Quisumbing (2010)), and that (iv) fewer household resources are applied to female plots.

Motivated by our empirical analysis of four villages in southern Ghana and building on both intrahousehold bargaining and stochastic growth literatures, we develop a deterministic and a stochastic model to explore the interaction between an institution of gender bias and household portfolio choice and the effects of both on development outcomes and policy performance. The decision framework we present focuses on levels of investment by individuals in a two-person household as a function of wealth, technology parameters and related uncertainty, and a (potential) gender bias in control over the household asset base and returns. In doing so, we show that more equal households are better able to invest in risky technologies while maintaining food security. Specifically, as egalitarian households avoid the negative effect of intrahousehold transfers, they are able to invest more while maintaining consumption and other forms of savings.

Furthermore, policies aimed at supporting technology uptake and asset accumulation

[2]While this context and related conclusions of productive inefficiency have been drawn in Udry et al. (1995) and Udry (1996) regarding Burkina Faso, our model presented here builds directly on empirical work in Slootmaker (2013) exploring intrahousehold inequity and resulting inefficiencies in Ghana, which utilizes data from the Agricultural Innovation and Resource Management Study from Ghana (Goldstein and Udry, 1999). Similar patterns of atomized household agriculture are common in other developing regions including much of sub-saharan Africa and south Asia (Goldstein and Udry, 2008). Although this setting provides a natural experiment for empirical analysis to both motivate our model and test its primary hypotheses, it does produce some bounds in terms of representativeness. Still, the general question of unequal control over household resources described above and in other investment applications (e.g. the effect of intrahousehold bargaining power on retirement investment strategies in the U.S. in Neelakantan et al. (2008) and Yilmazer and Lich (2013)) has its parallel here.

have their strongest impacts on both household investment and consumption growth in the egalitarian case. In contexts where individuals within households enjoy different levels of access to productive resources and relatedly different control over their returns, policies will necessarily be bounded by the extent of inequality. While of course gender equality is an end in itself, we also show how it is a means to the complementary end of economic development.

The rest of the paper is organized as follows. First, we discuss unequal access to productive inputs as an institutional bias a la North (1990) and related intrahousehold bargaining models that have treated gender in such a way. Then we develop an analytical framework centering this institution in the technology adoption process. In doing so, we set aside for the moment the realities of diminishing returns, uncertainty, and multiple crop portfolios to highlight the role of gender inequality in the investment decision. While this section uncovers the core interaction between the institution of gender bias and uptake policy, we then extend the framework to a stochastic environment to consider the previously disregarded elements as well as heterogeneous risk preferences and household welfare over time. Finally, we return to the data collected in Goldstein and Udry (1999) to test the core hypotheses of the model and discuss existing conclusions and exciting next steps.

2 Gender as an Institution

The analytical portion of our model necessarily relies on an operationalization of gender norms. Beyond the modeling components though, it is important to define the qualitative aspects of gender as it represents a social characteristic underlying the problem itself. For this we adopt North's (1990) general conceptualization of institutions as "the rules of the game". Since gender is not a biological determinant of individual productivity, and enters the individual's investment problem directly by defining one's control over the household asset base, gender in our model also matches North's more formal definition of an institution: a humanly devised constraint that shapes human interaction.[3,4] Whether the unequal sharing of resources and division of wealth is a rule of thumb surviving as an artifact from earlier forms of production that *did* merit specialization, or a cultural convention unrelated to productivity differences, gender inequality in access to productive resources exists and affects household investment by altering individual strategies.

A definition of power also contributes to our analysis of the effect gender has on individual choices and household outcomes. Even as a socially determined convention, the

[3]Gender of the plot manager was not found to be a statistically significant determinant of output variation in the dataset from Ghana. This conclusion was also drawn in a related context but slightly different manner in Udry et al. (1995).

[4]The suggested endogeneity of institutions as humanly devised, which might evolve with such interaction is not treated here but is certainly a relevant (and intended) extension.

institution of gender-bias has real effects on the distribution of wealth and the resulting strategies agents adopt. Our treatment thus entails a parallel notion of power. We make this connection as the bargaining portion of our model includes gender-bias in a way that simulates power. While we distinguish the two approaches (gender-specific bargaining power versus institutional bias), our specification resembles the definition of power in Palermo (2000): the ability of one person to deliberately generate economic results even (but not necessarily) against the will of others.

While we don't model gender as power explicitly - as in principal-agent or cooperative games with unequal bargaining skill - the effect is similar. Still, our related notion of power is essentially operationalized through the institution of gender bias by influencing the subjective elements of the individuals' system of constraints.

The household is then characterized not as a calculating machine (as we might think of a firm) but as a social/political institution where some members routinely give commands while others are constrained by the threat of sanctions (Bowles and Gintis (2008)). Individuals have agency in the sense that they maximize their own objectives, however this agency is necessarily bounded by the social institution determining the distribution of the household asset base and related spheres of influence. While as we will show, the outcomes of this agency represent individually optimal best-responses, one spouse may effectively have power in that their adherence to an institutional convention provides them with additional gains at the expense of their partner. What appears to be a passive coherence to the existing convention may be the same result had the agent also chosen their preferred institutional rule.

2.1 Bargaining or Benevolence?

As unequal access to household resources creates productive inefficiency, and given the related observations cited above, we follow Chiappori and Donni (2009) by starting with the assumption that an analytical approach that does not consider the multiplicity of decision makers in the household cannot be entirely satisfactory . The referenced contradiction between self-interested firms and supposedly altruistic families is one that leads Folbre (1986) towards intrahousehold bargaining as a way to accommodate conflict within the household. A wide body of research has been devoted to moving beyond the benevolent dictator model of the unitary framework to consider such conflict. Such extensions that include individual-specific preferences can be classified as either cooperative or non-cooperative games. The theoretical difference between these two sets of models is the requirement of Pareto-efficient choices. While cooperative models assume only that the household decision process leads to outcomes on the Pareto frontier, non-cooperative models do not. The choice of bargaining model therefore depends greatly on the relevance of the Pareto-efficiency assumption.

Common tests of the unitary model have included empirical testing of the symmetry of the Slutsky matrix on consumption or labor supply, and the income pooling hypothesis. All of these tests have been routinely rejected and challenge the Pareto-efficiency assumption implied by both the unitary and cooperative bargaining models (Chiappori and Donni (2009)). In the context of household agricultural production, resource allocations resulting in production within the household frontier implies that a reallocation could make one person better off without decreasing the utility of the other. The presence of allocative efficiency across individuals within a household is therefore a necessary (but not sufficient) condition for Pareto efficient production decisions. We find significant inefficiency of this form in the Ghana sample as do Udry et al. (1995) in a similar study in Burkina Faso.[5] Therefore, like the models of Carter and Katz (1997) and Chen and Woolley (2001), we include a non-cooperative element to allow for Pareto-inferior outcomes.

2.2 Bargaining under Inefficient Institutions

The main contribution of our model is to combine potentially inferior institutional conventions and intrahousehold bargaining in a dynamic production setting. Here, individuals are firstly linked through the distribution of the household asset base, affecting individual investments and household outcomes. While agent goals are essentially at odds in that they maximize individual objectives and compete over household resources, it is also reasonable to expect that within marriage, cooperation develops over time, (Manser and Brown (1980)). In Ghana, as in similar contexts, this involves both the application of one's labor time and other inputs to each other's plots as well as regular intrahousehold transfers or "chop-money". In addition to the division of household wealth, this provides the second link between individual strategies and their spouse's outcomes. In Carter and Katz (1997) individuals are linked through joint production of a household good, while in Chen and Woolley (2001) they are linked through both a household good and "caring," via somewhat altruistic preferences.[6] Here, agents are linked over time through the bargaining over returns from the new technology.[7] While this has contextual relevance as intrahousehold risk sharing and transfers made for maintenance of the household, this link also provides for not only strategic response in spousal behavior but important interdependencies that policies must consider. Haddad et al. (1997) summarize four general arguments in favor of

[5]Interestingly, in an often-cited study modeling the dynamic implications of risk aversion in subsistence agriculture, Zimmerman and Carter (2003) use the same data from Burkina Faso to parameterize a unitary household (where Udry et al. estimate that a redistribution of assets within the same households could increase output by 15 - 20%). While the purpose of Zimmerman and Carter (2003) was to highlight the reaction of risk aversion to subsistence constraints under endogenous prices, this still gives a relevant example of the argument in McElroy and Horney (1981) that economic behavior modeled with individual constrained maximization is often the result of group processes.

[6]Both of these are static models of resource and consumption allocation.

[7]We have developed a similar model including both a risky technology with returns subject to bargaining and a household public good, however as the core relationship between gender and investment is the same, we don't consider the public good problem here. While this may be relevant in the case of food contributions, we continue to focus on the institution of gender inequality.

these considerations:

1. The effectiveness of public transfer payments depends on which individual within the household receives it,

2. The response of the non-recipient matters,

3. The unitary model assumes that it doesn't matter which individual policies target since, for example information and resources will be shared optimally, and

4. Many policy levers are disabled since the resulting focus on relative prices misses opportunities to leverage intrahousehold allocation mechanisms.

As agents are linked by both the division of household wealth and bargaining over revenues, these arguments will have clear implications for inter temporal strategies and outcomes for both individuals and the household unit. As per the data, since the division of household wealth follows a largely systematic rule, the analytical mechanism of the (potential) gender-bias will be an exogenously determined level of relative say over total assets. Generally speaking, it is a measure of female say over household wealth relative to male say, given by the parameter $\pi \in [0, 1]$. Although similar, this measure of gender-specific decision making power is different from the usual mechanism of bargaining power since here the gender difference will enter the agent's allocation decision directly. While bargaining power can be a function of institutional conventions, our specifications take a more direct approach given the operation of gender bias in our context. For example, McElroy and Horney (1981) use institutional variables as parameters that shift extra-marital opportunities (and therefore threat points) in the bargaining process.[8]

To simultaneously accommodate individual objectives based on competition over resources and intrahousehold cooperation, our decision framework proceeds in two stages:

1. Investment: Agents choose individual investments at time t to maximize their own objectives taking the behavior of their spouse (and therefore bargained transfers of returns) as given.

2. Bargaining: After returns are realized in period $t + 1$, the household chooses wealth transfers between spouses to maximize the gains from cooperation in a Nash-bargain where individual farm revenues (assumed to be controllable gains in the event of non-cooperation) act as "outside options".

[8]Since their goal is a general description of bargained household demands, their vagueness in regards to institutional effects on the outside option is not a relevant criticism. However, in our more applied problem we choose a specific source of threat point.

This process is based on the separate spheres literature of Lundberg and Pollak (1993) and Carter and Katz (1997), and gives the first primary characteristics of our model. First, since (even complete) information regarding spousal behavior gives best-response functions by each agent in the investment stage, optimal choices are a result of strictly competitive non-cooperative play. The allocation of resources amongst uses thus represents a decentralized equilibrium as opposed to an explicit bargaining mechanism.[9] Second, the bargaining stage considers the simultaneous role of cooperation within marriage, which involves a degree of cooperation that may be absent in other bargains (Manser and Brown (1980)).

The existence of an intrahousehold bargaining process is clearly a fundamental departure from the unitary decision framework utilized by the existing growth models described above. As will be shown below, the non-cooperative element defining the investment stage can generate Pareto-inferior outcomes, placing our model beyond the realm of explicitly cooperative ones as well. Additionally, non-cooperative play allows strategic behavior to result in this inferiority endogenously.

3 A One Technolgy, Deterministic Model

Before simultaneously addressing the effects of gender and risk, we start with an analytical treatment to highlight the mechanism of intrahousehold inequality and its role in the investment process. Here, we show that household investment is maximized and uptake policies are most effective in the case of equality.

3.1 Intrahousehold Cooperation

While individuals in Ghanaian farming households make portfolio decisions largely independent from one another (Doss and Morris, 2000), we have also made a case for intrahousehold cooperation. We accommodate such cooperation in the bargaining stage, where agents bargain over wealth/resource transfers once harvests are realized. Since we let wealth, W_t represent a composite asset base, these transfers are a similar amalgamation. They could contain both in-kind or cash transfers/chop-money, or represent the sharing of individual assets such as labor time or other inputs.[10] Effectively transfers are side payments made between individuals to maximize the gains from cooperation and maintain the partnership over time. In this way, transfers may amount to Sen (1987)'s idea that inequalities often survive by making allies out of the deprived. Here, post-harvest transfers

[9] The bargaining over transfers in the second stage implies an enforceable contract but the investment stage does not. The importance and purpose of this assumption will be developed shortly.

[10] Traditionally men control financial assets so that chop-money is regularly transferred to women for maintenance of the household. A more specific relationship will be developed below and confirmed in the data.

can effectually maintain the marriage without fully giving up one's position of power over household wealth.

The household problem in period $t+1$ is to choose a net male-to-female transfer, Θ, from the range of individually controlled assets, $(-W_{ft+1}, W_{mt+1})$ to maximize the Nash Product:

$$\max_{\Theta \in (-W_{ft+1}, W_{mt+1})} N = [V_f(W_{ft+1} + \Theta) - V_f^e][V_m(W_{mt+1} - \Theta) - V_m^e], \quad (1)$$

where $V_f(W_{ft+1} + \Theta)$ and $V_m(W_{mt+1} - \Theta)$ represent female and male indirect utilities from next period wealth (net of transfers), and V_f^e and V_m^e are the amounts of indirect utility obtained from outside options.[11,12]

The choice of outside option or threat point is clearly an important element in the bargaining mechanism as it not only represents the source of power an agent has but also says something specific about an individual's exit opportunities. For example, Manser and Brown (1980) and McElroy and Horney (1981) both consider the indirect utility from divorce to be an individual's threat point. This implicitly assumes that individuals could sell their labor at a similar wage upon divorce (their models are static ones of income and consumption). An analogous assumption in our model would be problematic for two reasons. First, the assumption of well-functioning asset markets may be even more unrealistic in the development context of subsistence agriculture. Second, as Katz (1997) argues, female perceptions of exit opportunities may be misjudged due to female seclusion (perhaps by male intention) or biased reference groups, and carry additional social stigmas if chosen.

Katz and others have argued that utility received in the event of non-cooperation within marriage is a more justifiable threat point. We follow this strategy in order to avoid the use of potentially misestimated divorce utility as a bargaining chip in regular interactions between spouses. We therefore assume individual threat points $V_f(f_f(x_f))$ and $V_m(f_m(x_m))$, or the utilities from female and male production on their farms, which are functions of their respective investment choices x_f and x_m. In this way the outside option cementing one's bargaining position is the wealth actually generated on one's farm in a given period and what one could expect to receive without cooperation, as opposed to what they might earn upon divorce or outside of the household. Cooperative outcomes $V_f(W_{ft+1}(\pi) + \Theta)$ and $V_m(W_{mt+1}(\pi) - \Theta)$ are next period indirect utilities if the bargain succeeds, or that

[11] This is effectively a social planner's problem where the solution to the bargain will be Pareto-Optimal. We make this assumption for two important reasons. Firstly, it considers the joint objective of household members to cooperate over time. Second, it forces any inefficiency in production choices to come from the investment stage, which allows us to focus on the role of unequal access to inputs in the technology *adoption* problem.

[12] This accommodates transfers in either direction, depending on the form of household inequality. A positive transfer $\Theta > 0$ is then a payment from the male to the female, while a negative transfer, $\Theta < 0$ is a payment from the female to the male.

from their individually controlled share of household wealth net of transfers. The Nash product to be maximized is then:

$$\max_{\Theta \in (-W_{ft+1}, W_{mt+1})} N = [V_f(W_{ft+1}(\pi) + \Theta) - V_f(f_f(x_f))][V_m(W_{mt+1}(\pi) - \Theta) - V_m(f_m(x_m))]. \tag{2}$$

In this specification of the household problem, we formalize our treatment of gender bias as an institutional parameter influencing an agent's relative gain from the bargain (as opposed to the more common, generalized Nash product, $N = [\text{gain}_f]^{\pi}[\text{gain}_m]^{1-\pi}$ which weights relative gains from bargaining as bargaining skill or power). As described in section 3, this allows us to focus on the influence of relative say as it changes the elements defining individual gains as opposed to their relative skill at the bargaining table.

Since as we will show, the level of investment in the production technology also depends on the institutional sharing rule, the points of non-cooperation in equation (2) are also functions of π. Although the Nash bargain as we have specified does not incorporate voice as a parameter determining the relative weights of cooperative gains as Katz (1997) describes, both terms (the gain from success and outside option) are effected by the institutional rule π which is voice in the more vague sense of decision making power over household wealth. As individual investments, and therefore outside options are also functions of the gender institution, our specification is similarly based on the dual notion of "exit".

The optimal transfer to be chosen by the household is a function of both individual threat points and controllable returns. Since Θ represents net (male-to-female) transfers, it captures both the effects of outside options but also transfers that support survival of the partnership. In the former, the institutional sharing rule acts similarly to bargaining power, as it will effect individual investments and therefore threat points. We believe this is an important result as the institutional sharing rule which enters the individual investment decision directly (and therefore investment revenues), alters one's position in the cooperative bargain without making any additional assumptions about relative bargaining skill. As a direct constraint in the investment decision though, relative say takes on the more pragmatic meaning of a gendered constraint as in Folbre (1994), where it represents both a shared identity and a cultural norm that shapes the power of different groups. Gladwin (2002) also discusses this dual nature of gendered constraints in agriculture, as women in Africa are constrained by crop type (women are often limited to farming subsistence crops) but also consider farming for food to be part of their group identity. In the framework of our model it follows that the resulting (lower) revenue females realize from subsistence crops gives them less say over liquid assets and cash-crop decisions, which simultaneously deters their investments in cash-crops if they can't be leveraged as a coping mechanism.

We now turn to the investment stage where agents choose their agricultural portfolios given their expectations of the future bargain. As they look forward to the cooperative process just described, we will return to our specification of the Nash bargain in terms of the model specifics. Then, we can fully account for the dynamic links between individuals and develop the inseparability between risk management and coping and how gender affects throughout.

3.2 Decentralized Investments

The general allocation decision for the household is to distribute wealth between consumption and investment. The former provides utility in the current period while returns from the latter provide (discounted) utility next period. We approach our problem this way to account for the inseparability between consumption and production decisions facing agricultural households as in Bardhan and Udry (1999). For the separate spheres household which may not allocate wealth evenly amongst members, we now specify two agents, $i \in \{f, m\}$, who share total wealth according to the socially determined allocation rule $\pi \in [0, 1]$. This rule determines control over household wealth in each period, W_t between agents f and m linearly so that each control a portion of total wealth, W_{ft} and W_{mt}:

$$\begin{aligned} W_{ft} &= \pi W_t \\ W_{mt} &= (1 - \pi) W_t \\ W_t &= W_{ft} + W_{mt} \end{aligned} \tag{3}$$

Female and male agents allocate their individually controlled portions of household wealth between consumption and investment on their own farms. Individual agents thus face potentially different budget constraints and while maximizing their own objectives may adopt heterogeneous savings decisions. As we will show, the gendered division of influence over household assets and the resulting divergence in individual strategies will have important implications for household welfare and wealth accumulation. With the social convention π dividing the household asset base W_t, the female and male problems are:

$$\begin{aligned} f : \max_{c_{ft} \in (0, W_{ft})} & u(c_{ft}) + \beta u(W_{ft+1}) & \qquad m : \max_{c_{mt} \in (0, W_{mt})} & u(c_{mt}) + \beta u(W_{mt+1}), \\ & \text{s.t.} & & \text{s.t.} \\ & W_{ft} = \pi W_t \geq c_{ft} + p x_{ft} & & W_{mt} = (1 - \pi) W_t \geq c_{mt} + p x_{mt} \\ & W_{ft+1} = f(x_{ft}) + \Theta_{t+1} & & W_{mt+1} = f(x_{mt}) - \Theta_{t+1} \end{aligned} \tag{4}$$

where individual budgets are allocated between a consumption good c_{it} with price normalized to 1, and an investment product x_{it} with price p, and next period utility is discounted by a factor $\beta \in (0,1]$.[13] From the perspective of the investment stage in time t, the evolution of individually controlled wealth consists of returns from one's own farm, $f(x_{it})$, plus or minus any net transfer Θ made in the bargaining stage described in section 3.1. While agents are independent in farming their own plots, they are simultaneously linked through both the sharing of household wealth in period t and intrahousehold transfers in period $t+1$. These links describe not only the elements of competition and cooperation, as individuals both compete over household wealth and maximize gains from cooperation with post harvest transfers, they also describe the inter-temporal connections between agents and the dynamic components of the bargaining framework. Before describing these links in more detail, we assume that agents can calculate the effect of their (and their spouse's) investment on the bargaining stage and therefore determine the optimal transfer chosen and its effect on each agent's allocation decision.

3.3 Individual Best Responses

From equation (2) in section 3.1, the post-harvest transfer chosen in cooperation is clearly a function of individual investments, as they determine an agent's threat point but also the amount of household wealth to be divided upon cooperation. At the same time, the transfer determines a portion of one's utility received next period, so it also affects the level of wealth each agent is willing to allocate away from consumption towards investment on their farm in period t. We assume that agents are able to take this into account and therefore calculate the effect of their (and their spouse's) investment on the bargain, the resulting transfer that will maximize the gains from cooperation, and finally the transfer they can expect to give or receive. This is the link between *future* cooperation and *current* investment.

With logarithmic preferences $u(c) = ln(c)$, a simple linear production technology $f(x) = Rx$ with productivity parameter R, the Nash bargain that will be maximized at time $t+1$ is:

$$\max_{\Theta \in (-W_{ft+1}, W_{mt+1})} N = \Big[ln\big(\pi R[x_f + x_m] + \Theta\big) - ln\big(Rx_f\big)\Big]\Big[ln\big((1-\pi)R[x_f + x_m] - \Theta\big) - ln\big(Rx_m\big)\Big], \tag{5}$$

where the range of net male-to-female transfer is bounded by individually controlled wealth

[13]By characterzing household resources in this way, we are effectively forming a composite of potentially multiple asset types. In this light, we can consider household wealth as an amalgam of capital resources, labour power of household members, or cash used to purchase labor or other inputs. Individually controlled portions of household wealth thus represent the portion of total resources that each may leverage. In the Ghanaian villages we consider, males and females apply labor and inputs to each other's plots, the key is that there are gender specific levels of command over these resources overall.

levels next period, $W_{ft+1} = \pi R[x_f + x_m]$ and $W_{mt+1} = (1 - \pi)R[x_f + x_m]$.[14,15]

The post harvest transfer that maximizes the gains from cooperation is a function of the technology parameter, the institutional sharing rule, and individual investments:[16]

$$\Theta^* = R\big[(1 - \pi)x_f - \pi x_m\big] \tag{6}$$

Proposition 1. *Holding constant individual investments (which also depend on the institutional sharing rule), post-harvest transfers are inversely related to one's control over the household asset base.*[17]

An increase in one's control of household wealth causes the transfer to shift towards the other agent. From equation (B.3) the more (less) wealth the female controls, the less (more) she can expect as transfers from the male. This parallels our treatment of transfers as both chop-money and a side payment to maintain the partnership by maximizing the gains from cooperation. In many cases (as in Ghana), males control most of the resource pool ($\approx 80-90\%$), and make regular transfers to the female for consumption purposes. This relationship is both statistically and economically significant for the Ghanaian villages.

If we first consider the individual objectives of agents taking transfers as given, we can see the dynamic link between the bargaining stage and investment strategies.[18]

By solving the individual budget constraints for consumption, and using preferences, technologies, and time preferences from above, the two period problems for the male and

[14] We make this assumption in part for analytical tractability and for satisfying the Inada conditions, but primarily because they exhibit decreasing absolute risk aversion. The latter quality allows us to focus on the interaction between gender inequality and investment separate from that of wealth (level) effects. While the latter effect might also be relevant as individuals might be more amenable to risk as wealth increases, it is not our concern here.

[15] While a decreasing returns to scale technology would exacerbate the effects of an unequal sharing rule, and be more relevant for the crops considered in Ghana, we continue to focus on the impact of gender inequality in say over household assets.

[16] Derivations and proofs can be found in Appendix B

[17] This relationship also holds generally when considering the additional effect of π on investments as $\Theta^*\big(x_f^*(\pi), x_m^*(\pi)\big) > 0 \;\forall\; \pi \in [0, .5]$ and $< 0 \;\forall\; \pi \in [.5, 1]$.

[18] Data collected from Ghanaian households shows significant discrepancies in the values men report giving relative to what females report receiving, which is at least interesting, but potentially a source of information inefficiency in the bargaining process as well. We return to this issue when testing the hypothesis of Proposition 1 below.

female are:

$$\max_{x_f} V_f = ln(\pi W - px_f) + \beta ln(Rx_f + \hat{\Theta})$$
$$\max_{x_m} V_m = ln\Big((1-\pi)W - px_m\Big) + \beta ln(Rx_m - \hat{\Theta}) \tag{7}$$

Individual maximization of these objectives show that agents will invest less as they expect more transfers in their direction:[19]

$$x_f^*(\hat{\Theta}) = \frac{\pi\beta W}{p(1+\beta)} - \frac{\hat{\Theta}}{(1+\beta)R}$$
$$x_m^*(\hat{\Theta}) = \frac{(1-\pi)\beta W}{p(1+\beta)} + \frac{\hat{\Theta}}{(1+\beta)R}. \tag{8}$$

$$\frac{\partial x_f^*(\hat{\Theta})}{\partial\hat{\Theta}} = -\frac{1}{(1+\beta)R} < 0$$
$$\frac{\partial x_m^*(\hat{\Theta})}{\partial\hat{\Theta}} = \frac{1}{(1+\beta)R} > 0. \tag{9}$$

This outcome is necessarily a result of the atomistic strategies we have portrayed, which beyond their contextual relevance also provides the dynamic link between agents and is crucial in determining the main result of the model, described in Proposition 2.

As individual investments also alter one's position and gains from the cooperative bargain, we must consider that investments also change the value of the expected transfer. Assuming that agents can calculate the optimal transfer as a function of individual investments, male and female objectives in the investment stage become functions of each other's strategy. In this way, backward induction from the household bargain to the individual game allows us to combine individual objectives from equations (7) with the optimal transfer in equation (6), giving the pair of Bellman equations:

[19] Recall a negative transfer represents a payment from the female to the male.

$$
\begin{aligned}
V_f(x_f, x_m) &= \max_{x_f} \Big\{ ln(\pi W - p x_f) + \beta ln\Big(R x_f + R\big[(1-\pi)x_f - \pi x_m\big]\Big)\Big\} \\
V_m(x_m, x_f) &= \max_{x_m} \Big\{ ln\Big((1-\pi)W - p x_m\Big) + \beta ln\Big(R x_m - R\big[(1-\pi)x_f - \pi x_m\big]\Big)\Big\}
\end{aligned} \tag{10}
$$

Next period utility is now a function of returns from one's own investment as well as from their spouse's. Taking each other's behavior as given, individuals choose the level of investment on their own farm to maximize two period indirect utility. Optimal strategies are now best responses to their partner's investment:

$$
\begin{aligned}
x_f^*(\hat{x}_m) &= \frac{\pi \beta W}{p(1+\beta)} + \frac{\pi \hat{x}_m}{(1+\beta)(2-\pi)} \\
x_m^*(\hat{x}_f) &= \frac{(1-\pi)\beta W}{p(1+\beta)} + \frac{(1-\pi)\hat{x}_f}{(1+\pi)(1+\beta)}.
\end{aligned} \tag{11}
$$

Definition 1. *The pair of individual best response strategies, $x_f^*(x_m^*)$ and $x_m^*(x_f^*)$ are a subgame-perfect Nash equilibrium $\big(x_f^*(x_m(x_f)\big)$.*

As agents take into account the behavior of their spouse and assume their partner will do the same, best responses to one other's strategies give a decentralized Cournot-Nash equilibrium that is subgame-perfect.

Solving the conditions in equations (11) simultaneously gives equilibrium strategies, x_f^* and x_m^* as functions of household wealth, the investment's price, the discount factor, and the institutional sharing rule:

$$
\begin{aligned}
x_f^* &= \frac{\pi \beta W (1+\pi)\big(2\pi + \beta(\pi - 2) - 3\big)}{p\big[\beta(1+\pi)(\pi-2)(2+\beta) - 2\big]} \\
x_m^* &= \frac{\beta W (2-\pi)(\pi-1)\big(1+\beta+\pi(2+\beta)\big)}{p\big[\beta(1+\pi)(\pi-2)(2+\beta) - 2\big]}
\end{aligned} \tag{12}
$$

Individual investments are increasing in one's control over the household asset base but at a diminishing rate. This follows from Proposition 1, where as an individual controls more of total wealth, they transfer more to their partner post-harvest.

Proposition 2. *Total household investment is maximized in the case of equal control over household wealth.*

In the case where agents have equal preferences and similar productivities, (household) investment is largest when $\pi = .5$. In this case, each agent controls half of the household asset base and makes no transfer post-harvest as they invest the same amount in equilibrium. With some inequality on the other hand ($\pi \neq .5$) the expectations of transfers lower total household investment. Assuming household wealth accumulates strictly from production returns, household growth is defined as the periodic rate of wealth accumulation:

$$g = \frac{Rx_{hh}^{NE} - W}{W}, \tag{13}$$

Proposition 2 implies that the household's growth rate is also highest in the case of equality. While the simplifications made in preferences and technology limit the scope of comparative statics for the model so far, we can still examine the interaction between gender bias and two common policies in this context: input subsidies and extension programs.

Proposition 3. *Input subsidies and productivity improvements have their largest impact on the household growth rate in the case of equality.*

Household investment and per period growth rate are both highest in the case of equal sharing. As equations (B.13)-(B.16) show, inputs subsidies and extension programs aimed at supporting investment also have their largest impact in the case of $\pi = .5$. This parallels the empirical observation in Lancaster et al. (2006) that household welfare is better protected in households where bargaining power is spread evenly between spouses, and in Agarwal (1994), which shows that in South Asia improvements in women's land rights can reduce the household's risk of poverty. While we have abstracted from some realities of our specific context, we can already see the important interaction between intrahousehold resource distribution and investment uptake policies. In ranking policy options, relative benefit comparisons must consider the effect of inequality on the expected gains from increased investment and obviously the ends which such investments hope to achieve. If the cooperative bargain as we have assumed is in reality less benign (e.g. due to unequal bargaining power, imperfect information regarding investments and transfers, less cooperation in the case of negative shocks, or even bargaining breakdowns), then the recipient of policy benefits will be especially important.

To include the possibilities for multiple crop types (exhibiting diminishing returns to scale), heterogeneous risk preferences and choice under uncertainty, we now extend our bargaining framework to include two production technologies, one of which yields uncertain returns.

4 Stochastic Portfolio Choice

To include the realities of uncertainty and portfolios of multiple crops, we now develop a stochastic model with two investment technologies, x_i and z_i. Where the investment product x_i is still the technology of interest, we add a random (covariant) productivity shock, $\tilde{R} \sim N(\overline{R}, \sigma_R^2)$, so that the risky technology produces according to $f(x_i) = \tilde{R}x_i^d$ with diminishing returns parameter $d < 1$.[20] While this form of uncertainty might represent productivity shocks, price instability, or imperfect information on effective input use, the key mechanism is an uncertain mapping between input cost and output revenue. The risk-free alternative, z_i may also exhibit diminishing returns to scale, and generates revenue according to $f(z_i) = Gz_i^h$.

As before individuals make allocation choices, now between consumption and a two technology portfolio, in relative isolation from one another. Agents still compete over household resources encompassed by the asset base W_t, and cooperate by bargaining over wealth transfers to maximize the gains from cooperation. Since in the context of subsistence agriculture we might consider the risky technology a cash crop, we assume that the bargain entails revenue from the cash crop x_i as opposed to z_i which we now consider a subsistence food crop that can be either consumed or held as personal savings (e.g. seeds for future production).[21] This specification might also represent other pairs of technologies where one is subject to an institution of unequal control. The key here is that social conventions result in separate spheres of influence between household members.

Although we also extend the choice model to include a more general form of CRRA preferences, $u_i(c_i) = \frac{1}{1-\alpha_i}(c_i)^{1-\alpha_i}$, we maintain logarithmic preferences in the cooperative Nash bargain so that heterogeneous risk preferences do not alter the relative valuation of an individual's utility gain from intrahousehold transfers. We allow risk preferences to diverge only in regards to investment portfolios. With a production technology that now allows for the more realistic assumption of diminishing returns, $f(x_i) = Rx_i^d$, the household problem in the cooperative bargaining stage is to maximize the Nash bargain:[22]

$$\max_{\Theta \in (-W_{ft+1}, W_{mt+1})} N = \Big[ln\big(\pi R[x_f^d + x_m^d] + \Theta\big) - ln\big(Rx_f^d\big)\Big]\Big[ln\big((1-\pi)R[x_f^d + x_m^d] - \Theta\big) - ln\big(Rx_m^d\big)\Big], \tag{14}$$

[20] We consider only the case where each individual is equally effected as opposed to others (e.g. Zimmerman and Carter (2003)), who consider both covariant and idiosyncratic shocks. This might be additionally relevant in our case where individual specific shocks put additional pressure on the cooperation of agents to smooth consumption after negative outcomes.

[21] Similar models employ a known return equal to $\frac{1}{\beta}$ so that the safe asset represents a risk-free savings instrument. We are only concerned with it providing a known return which is not subject to bargained transfers.

[22] Since this bargain takes place after harvests are realized, the revenues from cash-crop production are presented here as a known quantity.

The optimal transfer chosen is again a function of individual investments, technology parameters, and the institutional sharing rule:

$$\Theta^* = R\big[(1-\pi)x_f^d - \pi x_m^d\big] \tag{15}$$

As agents continue to calculate the effect of their and their partner's investments on the bargaining stage, we can substitute the value of the optimal transfer into each agent's maximization problem. Where the price of the safe asset and consumption good are normalized to one and individuals have isoelastic preferences over consumption with constant rates of relative risk aversion, α_f and α_m, the pair of Bellman equations is now:

$$V_f(x_f, x_m, z_f) = \max_{x_f, z_f} \left\{ \frac{\Big(\pi W - p x_f - z_f\Big)^{1-\alpha_f}}{1-\alpha_f} + \beta E_{\tilde{R}} \left[\frac{\Big(\tilde{R}x_f^d + G z_f^h + \tilde{R}\big[(1-\pi)x_f^d - \pi x_m^d\big]\Big)^{1-\alpha_f}}{1-\alpha_f} \right] \right\}$$

$$V_m(x_f, x_m, z_m) = \max_{x_m, z_m} \left\{ \frac{\Big((1-\pi)W - p x_m - z_m\Big)^{1-\alpha_m}}{1-\alpha_m} + \beta E_{\tilde{R}} \left[\frac{\Big(\tilde{R}x_m^d + G z_m^h - \tilde{R}\big[(1-\pi)x_f^d - \pi x_m^d\big]\Big)^{1-\alpha_m}}{1-\alpha_m} \right] \right\} \tag{16}$$

Agents maximize two-period utility by allocating their individual assets between consumption and a combination of the two production technologies according to the four first order conditions in equations (B.17). The solutions to these still represent best response functions to each other's portfolios and again give a pair of decentralized equilibrium strategies.

Definition 2. *The pair of value functions $V_f(x_f, x_m, z_f)$ and $V_m(x_f, x_m, z_f)$, and policies $x_f^*(x_m; s_t)$ and $x_m^*(x_f; s_t)$, is a Markov perfect equilibrium such that given x_m and x_f, x_f^* and x_m^* satisfy equations (16), where the state of the world at time t, s_t, encompasses the household endowment W_t, institutional rule π, time and risk preferences, technology parameters, and the form of uncertainty over $\tilde{R}$.*

We turn to numerical methods to solve the four first order conditions simultaneously, maximizing the Bellman equations (16). This is done by iterating on each agent's pair of strategies until both are playing a best response to each other's portfolio given their (institutionally bounded) state of the world and expectations over the return of the risky technology.[23] This includes the following parameter values based on the Ghana data described above:[24]

Parameters		
W_0	100	Initial household wealth
p	2	Price of risky technology
α_f, α_m	1.4	Relative risk aversion
$\overline{R}$	10.0	Mean return on risky technology
σ_R	8	Std. dev. of return on risky technology
d	.756	Decreasing returns parameter on risky technology
G	7.0	Productivity parameter on safe technology
d	.607	Decreasing returns parameter on safe technology
β	.95	Discount factor

When both agents share the same preferences for risk, total household investment in the risky asset is again maximized in the case of equality. Household portfolio risk, defined as the portion of total investment expenditure invested in the risky technology, is plotted against the value of the institutional sharing rule in figure 1 below.

[23]Defined as updating each of their investments by at most $\epsilon = 2.2204 \times 10^{-16}$.

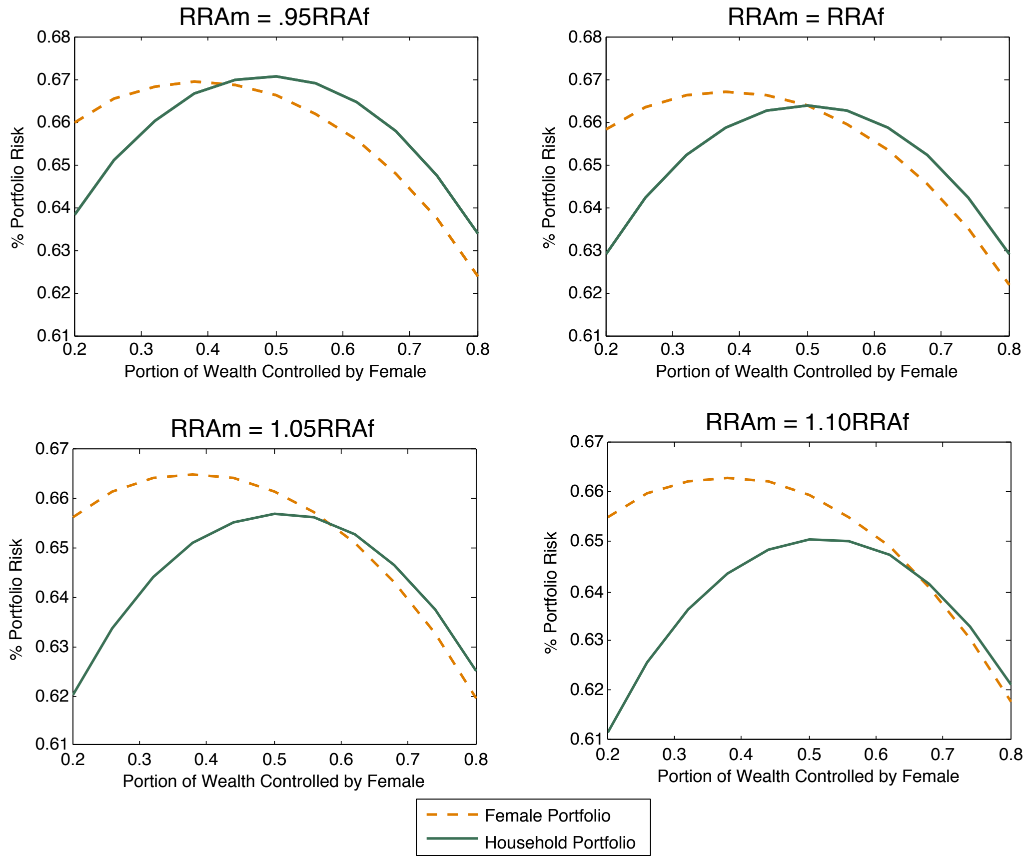
[24]The primary characteristics we consider are that the risky technology has higher marginal returns than the safe technology and that both exhibit decreasing returns to scale. As we have abstracted from the realities of multiple inputs per technology as well as assumed generic time and risk preferences, specific parameters are relatively unimportant beyond the primary characteristics.

Figure 1: Household Portfolio Risk with Homogeneous Preferences

While this result is expected given our analytical treatment in section 3, it is likely that males and females may have different preferences for risk. To explore this impact on the household portfolio, we repeat the previous simulation with heterogeneous levels of risk aversion, specifically, where the male becomes more risk averse relative to the female. The results of four simulations are below in figure 2. Here, we show the result predicted (and confirmed empirically with U.S. data on retirement portfolio choice) in Neelakantan et al. (2008) and Yilmazer and Lich (2013) that the risk level of the household portfolio approaches that of the individual with more bargaining power over household assets.[25]

[25]Their models use fully cooperative frameworks to develop this result.

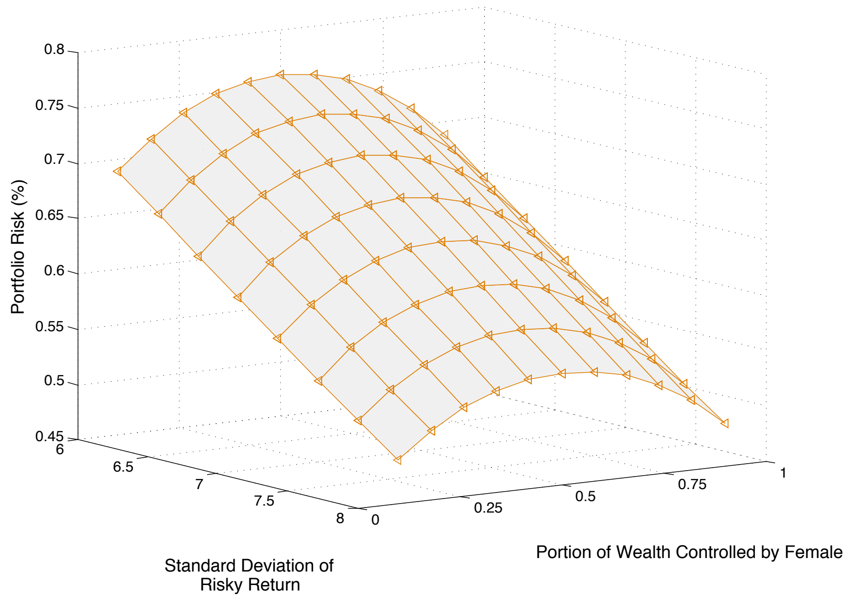
Figure 2: Female and Household Portfolio Risk with Heterogeneous Preferences



Moving from the top left to bottom right frame of figure 2, the female becomes more amenable to risk. At the same time, the household portfolio converges to her level of risk at higher levels of female control (as $\pi \rightarrow 1$). As this relationship results from a decentralized equilibrium in non-cooperative play, it is interesting in relation to the cooperative models cited above. However, the primary importance is in consideration of development policy, which if targeted to specific individuals within the household or for specific expenditure types (which may also vary by individual), will depend on differences in both risk preferences and relative access to resources.[26]

To consider the effect of gender inequality as it interacts with the level of uncertainty about the return on the risky asset, we solve for equilibrium portfolios across both levels of the sharing rule and variance of the risky return. The results of this procedure are presented graphically in figure 3.

Figure 3: Household Portfolio Risk vs. Variance and Sharing Rule



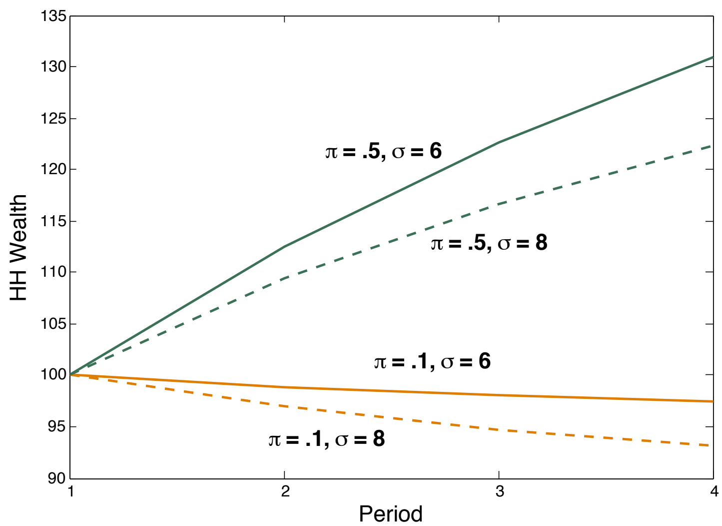
As we expect, investment in the risky technology is decreasing both in inequality and variance of the productivity parameter. For given levels of uncertainty, household investment is maximized in the case of equality, as before. What runs somewhat counter to expectations at this point (considering the interaction between policies and inequality in the analytical model) is that the reduction in variance has a similar effect across levels of equality (see

[26]We should also interpret the seemingly counterintuitive (eventual) fall in female portfolio risk as she has more control over the household asset base. Since we have made no assumptions about bargaining power per se, higher female investment in the risky technology reduces her marginal gains from additional transfers in the bargain relative to her partner, meaning that she must continually transfer more in his direction as the household maximizes the gains from cooperation. We have simulated a model including bargaining power in the traditional way and verified that the additional weighting of bargaining gains does produce the expected result that individual portfolio risk continues to increase with one's control. In doing so, the core relationship between unequal access to resources and household investment is unchanged. For this reason we continue to make no assumptions about relative skill at the bargaining table and focus on the role of the institutional parameter, π as we have.

Figure 9 in Appendix A for a side view of Figure 3, which holds the institutional rule constant at equal and unequal levels). This apparent contradiction is quickly resolved when we consider the indirect effect(s) of reducing the uncertainty about the risky technology. As the household becomes less uncertain they both invest more in the risky technology but also allocate more wealth to the safe asset (and consumption).

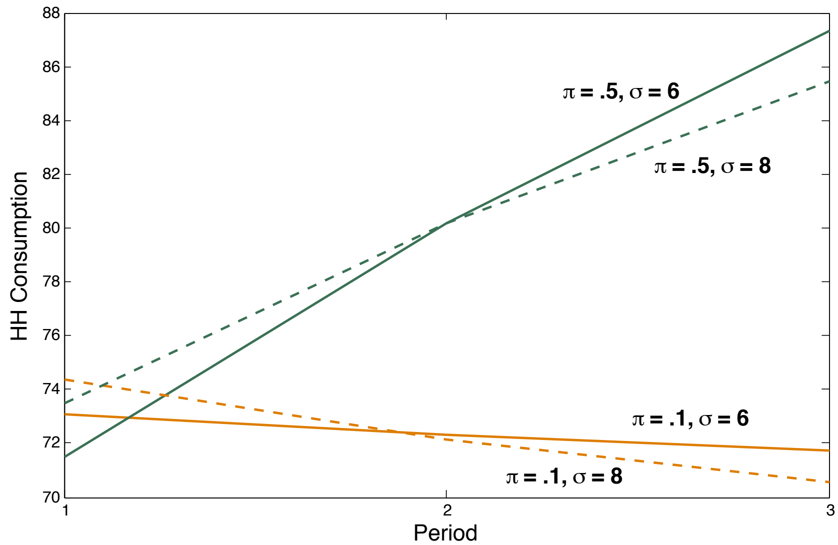
The full effect of reducing uncertainty over the risky return can be seen below in figures 4 and 5. Over the first four periods of production, the effect of reducing uncertainty grows stronger over time for households with egalitarian sharing rules. Although we do not model a subsistence thresholds as in Zimmerman and Carter (2003), we can surmise a similar importance here. For households operating against subsistence constraints, we can see that an equitable household will be more able to accumulate wealth and avoid falling below a threshold level of nutrition. Zimmerman and Carter show that poorer households continue to adopt safer portfolios due to this fear. Here, we add the compounding effect of intrahousehold inequality as a significant constraint to growth in a risky environment.

Figure 4: Household Wealth over Time



The interaction between inequality and uncertainty also has significant consequences in terms of the household consumption path. Figure 5 shows consumption growth over the first three periods. Although consumption mostly mirrors the growth in household assets, there are two important things to note. Firstly, initial period consumption is actually lowest in the case of equality and low variance. It is higher in the cases of inequality and under greater uncertainty. This initial result is expected as a low level of risky investment is complemented by higher consumption. However, this tradeoff quickly disappears over the second and third period, showing the potential gains from moving to a more equal sharing rule. While consumption in the first period falls, we can clearly see the potential Pareto improvement from a redistribution of assets by the second period. Secondly, the redistributive effect of lower variance on consumption is again lower for more unequal households as their consumption paths diverge less with variance relative to egalitarian ones. As wealth accumulation also showed less divergence for unequal households, we conclude that the redistributive gains are higher in terms of both savings in the safe asset and current period consumption under more equal sharing rules.

Figure 5: Household Consumption over Time



Although we have not considered the endogeneity of the institutional sharing rule, we can suggest here a potential reason why an inefficient institution might persist over time. A shift to a more equal sharing rule would necessarily reduce indirect utility of the individual giving up say (as well as the household in sum) in period t. While our model projects that total consumption would be higher in future periods from such a shift, the promise of future repayment may not be satisfactory, especially given the lack of binding contracts to ensure such a payment. As individual objectives are strictly increasing in controllable wealth, an autonomous shift in the household sharing rule would be unlikely without an enforceable agreement.

5 Testing Predictions of the Model

We now return to the data that motivated our model to test its core hypotheses, namely that: (i) Post-harvest transfers are inversely related to one's control over the household asset base, and (ii) Risk of the household portfolio is decreasing in inequality.[27] To test these hypotheses we utilize data collected over 15 rounds (during 1997/1998) from 200 households in 4 villages in rural Ghana in the Agricultural Innovation and Resource Management survey (Goldstein and Udry, 1999). As an intrahousehold panel, this data set provides a unique opportunity to explore the allocation of inputs across individuals within households. Furthermore, since females and males often farm similar crops in the same year, we can compare household choices with individual resource allocations.[28]

We test the first hypothesis that intrahousehold transfers are negatively related to one's control over household wealth, formalized in Proposition 1 of section 3.3. We do this by estimating the following model:

$$\Theta_{ivt} = \beta_0 + \beta_1 \pi_{ivt} + \beta_2 X(f)_{ivt} + \beta_3 X(m)_{ivt} + u_{ivt}, \tag{17}$$

where the actual male-to-female transfer by household i in village v and year t is a function of the household sharing rule, π and individual investments, $X(f)$ and $X(m)$, and a random shock, u_{ivt}.[29] The results of this estimation are below in Table 1.[30]

[27]While there are many testable hypotheses to be considered here, the data limit our ability to test the more detailed relationships between intrahousehold characteristics and outcomes.

[28]Since individuals in surveyed households were interviewed separately (by persons of similar gender) we can also assume that reports of intrahousehold transfers and input sharing are not biased by fears of repercussion resulting from incriminating reports. However we later conclude that reports of cash transfers are biased in some way, specifically by over- and underestimations of benefactors relative to recipients

[29]We sum total investments as there are not enough observations of female investment in Pineapple to accommodate a comparison of strictly risky investments.

[30]We also control for village and year fixed effects to account for variation across geographical space and period specific endogeneity.

Table 1: Actual Transfers as a function of Sharing Rule

Dependent Variable: Θ (1000's GH)	
π	-141.161**
	[40.388]
$X(f)$	0.263***
	[.078]
$X(m)$	0.075***
	[.022]
Constant	225.092***
	[28.00]
Observations	231
R-squared	0.223

standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

Controlling for individual investments and relevant fixed-effects, we reject the null that the household sharing rule is unrelated to the intrahousehold transfer, and conclude that the level of transfer is negatively related to the sharing rule. Although the division of household assets is largely male biased (see distribution of sharing rules in figure 7 below), the positive and significant intercept implies that at the mean of the data, the expected transfer would be towards the female even without any investment. This could reflect a combination of two things: (i) The systematic over reporting of transfers, or (ii) The possibility that our model underestimates the flow of intrahousehold transfers since in the case of the Ghana survey, very few females invest in Pineapple production.[31] Given the phenomena described in footnote 31, we can at least support the former, which suggests that there is imperfect information about transfers between agents. While we could model this effect here, we continue to focus on the distribution of resources under cooperation and competition and leave information problems for later work.

Next, we test the hypothesis that inequality has no relationship to the household's level of portfolio risk. At the time of the survey, Ghana was in the middle of a major transformation to production of the cash-crop Pineapple for export. Investment in the new crop entailed uncertainty about the process itself, and also regarding fertilizer commonly

[31]The sum of male reported transfers (net male to female) minus the sum of female transfers (net male to female) should equal zero, however this is not so in the data. Actually, there is an average over reporting of the transfer of 245,000 GH, which is statistically significant at the 1% level (see Figure 8 in Appendix A). Subtracting this average over-reporting of Θ from each household and estimating equation (17) again gives an estimated intercept which is not significantly different than zero.

used in its production.[32] To test this hypothesis, we use maximum likelihood techniques to estimate a generalized linear model with a logistic distribution of portfolio risk, ρ_{hh}:

$$\ln\left\{\frac{\rho_{ivt}}{1-\rho_{ivt}}\right\} = \beta_0 + \beta_1 Ineq_{ivt} + \beta_2 X(hh)_{ivt} + u_{ivt} \tag{18}$$

Where $\rho \in (0,1)$ is the household's level of portfolio risk, defined as the portion of total agricultural expenditure applied to pineapple production, $Ineq$ is the difference between the actual sharing rule and equality ($|\pi - .5|$), multiplied by two so that $Ineq \in [0,1]$ represents a range between equality and total inequality, and X is the level of total household expenditure (in $1000's$ GH) of household i in village v in year t. Linear (un-exponentiated) coefficients of this estimation are given in table 2 below.[33]

Table 2: Household Portfolio Risk

Dependent Variable: Household Risk, $\rho \in (0,1)$	
Inequality	-0.329*
	[0.187]
HH Expenditure	0.012***
	[0.002]
Constant	-1.047***
	[0.172]
Observations	1618
standard errors in brackets	
* significant at 10%; ** significant at 5%; *** significant at 1%	

As the household sharing rule deviates from equality, the average level of portfolio risk falls to a significant degree (statistically and economically). We reject the null that inequality is unrelated to household portfolio risk and conclude that there is a significantly negative relationship between the two. Specifically, as the household sharing rule deviates from equality to full inequality, the logit function, $\ln\left\{\frac{\rho_{hh}}{1-\rho_{hh}}\right\}$ decreases by .33 on average. In

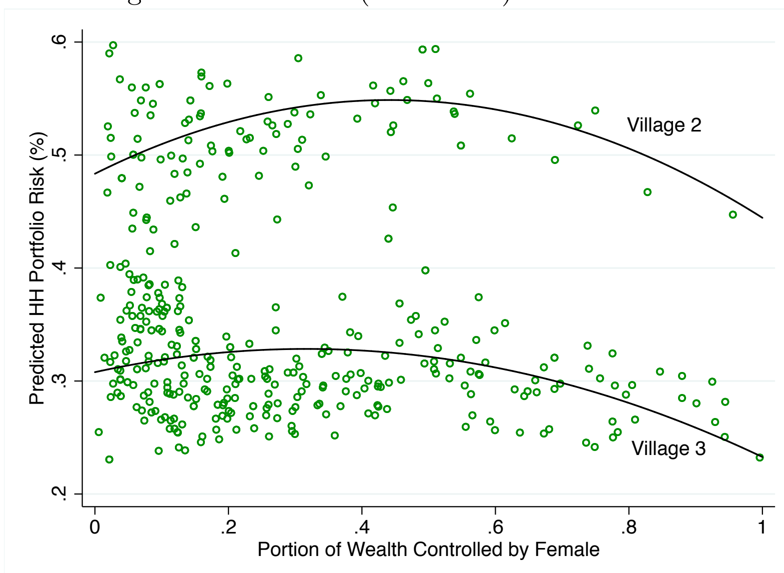
[32] Although we have used the terms risk and uncertainty interchangeably, we have operationalized randomness as Knight (1921) would define risk. Here, decision makers know the probability distribution defining their expectation of outcomes. Alternatively, uncertainty would in Knight's terms reflect less than perfect information about the distribution itself. While we have assumed agents know the distribution of *risk*, anecdotal reports in the data reflect uncertainty as well. Specifically, many farmers avoided investment in the new crop due to perceptions of scale effects, which are not confirmed in empirical analysis (Goldstein and Udry, 1999).

[33] We also estimate a tobit model truncated at zero and full risk and receive similar results.

other words, the level of household portfolio risk changes on average by $\exp\{\beta_1\} - 1 = \exp\{-.33\} - 1 = -.28$, or falls by 28.0% (Agresti, 1996).

Estimated portfolio risk (controlling for total expenditure and village and year fixed effects) falls from 41.0% in the case of equality to between 23.8% and 18.6% in the cases where $\pi = 0$ and $\pi = 1$ respectively, reflecting the predicted drop in portfolio risk associated with a shift from equality to pure inequality in table 2. Figure 6 presents the distribution of predicted portfolios against the household sharing rule, including a quadratic best fit line revealing this relationship and that predicted theoretically in Figure 1 of section 4.

Figure 6: Predicted (Household) Portfolio Risk



6 Discussion

For the agricultural households considered here, gender inequality and uncertainty interact crucially to affect investment and prospects for growth. While risk certainly lowers rates of investment and household wealth accumulation, we conclude that gender inequality is an overarching constraint that unless removed will continue to limit the gains from policies aimed at limiting the deterrence of risk's downside. Although we have treated the institution of gender bias as an exogenous variable, we have suggested gains from a more egalitarian rule and generated multiple testable hypotheses to apply to similar contexts.

By unpacking the household and treating it simultaneously as a site of cooperation and conflict amongst individual members, we have shown the binding effect of unequal access to resources and how it operates through its impact on optimal investment strategies. Here we offer theoretical contributions of combining intrahousehold processes with stochastic growth. While mirroring results of fully cooperative models, we also incorporate noncooperative play to allow for inferior outcomes suggested by empirical work.

Furthermore, we have addressed important considerations for development policies as they interact with a more realistic intrahousehold process supported by both theoretical and empirical results. As females have less say over the returns to cash crop production, they accordingly adjust their portfolios, thus limiting their ability to accumulate assets and improve their future bargaining position. While we have also explored the interaction between uptake policies and the institution of gender bias in this way, we have not offered claims regarding how to reverse this cycle.

Explicit description of endogeneity of the institutional norm will certainly allow us to consider the ability of policies to help households achieve higher rates of investment through more equal sharing rules. As far as individual outcomes drive changes in the distribution of resources through bargaining, policies may be able to simultaneously support investment, food security, and endogenous shifts towards intrahousehold equity.

As uptake policies have different impacts on individual portfolios, they must consider not only unequal improvements in individual prospects, but also the strategic responses of other household members. If males maintain control over the household asset base, the household portfolio will react to policies in a similar fashion to his own. As females expect more revenue transfers from male production, policies that increase investments on male plots may actually decrease the willingness of females to make greater investments. As far as this continues to affect relative bargaining positions over time, it may unfortunately serve to sustain a given institutional rule and deter gains in both investment and intrahousehold equality. If the pooling of risk implied by our bargaining process is in reality less concerned with cooperative gains, individual consumption possibilities targeted by policies may also be limited by the extent of inequality.

While we have highlighted the dynamic links between agents in separate spheres households and the resulting impact on development goals, we have also left important considerations for future work. Although our relatively benign form of cooperation assumes away additional inefficiencies that may affect technology adoption, we have underlined the core relationship between gender and the household's choice problem. Extension of the bargaining stage to include context specific realities such as bargaining breakdowns, imperfect information, and a stricter form of power may allow deeper insight into the strategic responses of household members to investment policy and the resulting effects on growth. Similarly, considering the evolution of the institutional rule as a result of individual strategies and outcomes will allow additional policy leverage in dealing with inequality proactively.

While this paper makes important connections between the dynamics of risk and realities of the household, there is much more to be done. In building an initial framework linking these previously isolated problems, we hope to have suggested a relevant avenue for approaching the dual concerns of social equality and economic development.

Appendix A Additional Figures

Figure 7: Distribution of Household Sharing Rules

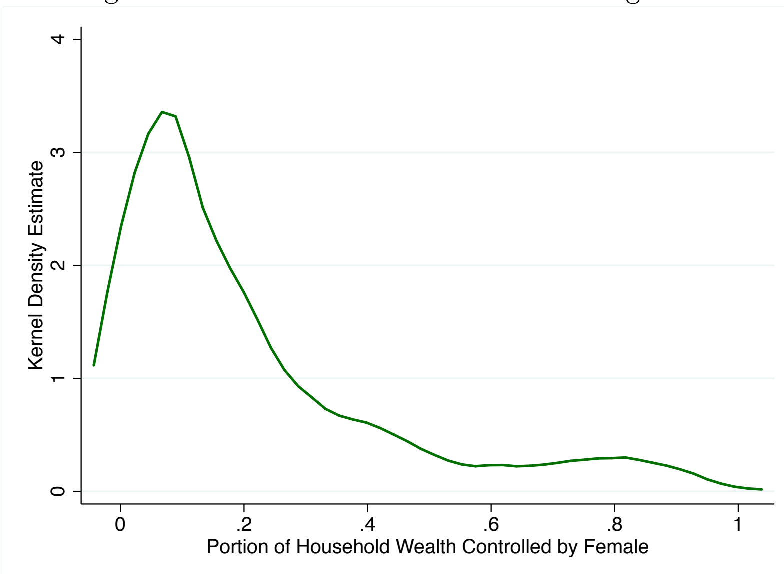


Figure 8: Bias in Reported Transfers

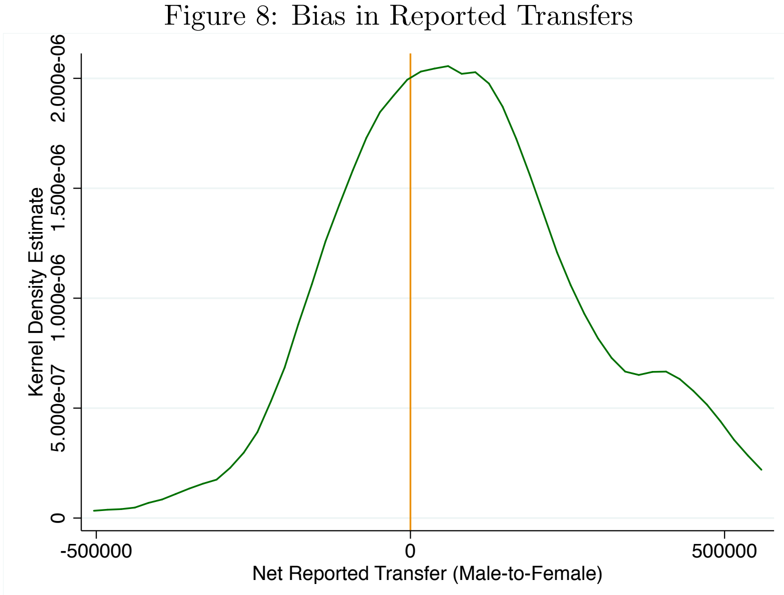
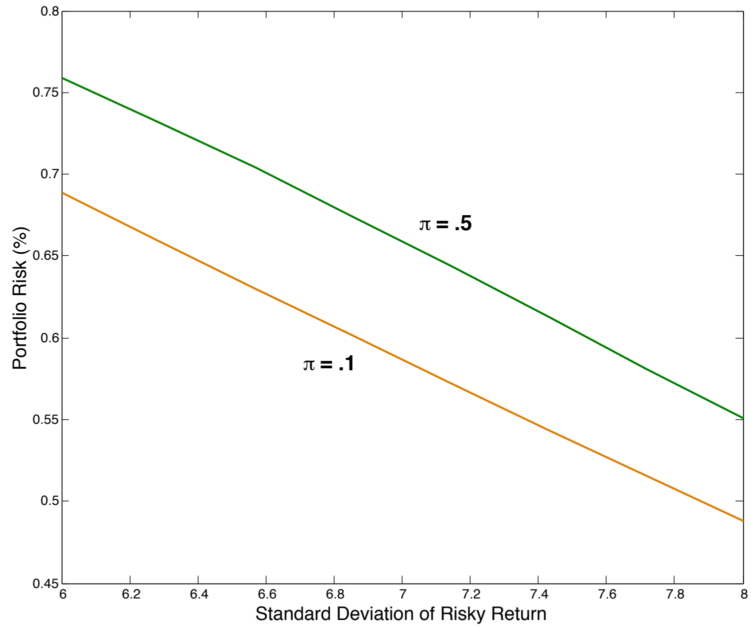


Figure 9: Household Portfolio Risk as a function of Variance



Appendix B Derivations and Proofs

Derivation of equation (6), the optimal post-harvest transfer, Θ^*
The level of male-to-female transfer that will maximize the gains from cooperation will satisfy the following first order condition:

$$\frac{\partial N}{\partial \Theta} = \frac{ln\big(\pi R[x_f + x_m] + \Theta\big) - ln\big(Rx_f\big)}{\pi R[x_f + x_m]} - \frac{ln\big((1-\pi)R[x_f + x_m] - \Theta\big) - ln\big(Rx_m\big)}{(1-\pi)R[x_f + x_m]} = 0 \tag{B.1}$$

This condition is only satisfied when:

$$\begin{aligned} & ln\big(\pi R[x_f + x_m] + \Theta\big) - ln\big(Rx_f\big) = ln\big((1-\pi)R[x_f + x_m] - \Theta\big) - ln\big(Rx_m\big) = 0 \\ & \Theta = R\big[(1-\pi)x_f - \pi x_m\big] \end{aligned} \tag{B.2}$$

From the concavity of the Nash objective in transfers, we can conclude that the solution to the first order condition above is indeed a maximum.

Proof of Proposition 1
Holding investments fixed, the optimal transfer is decreasing in the value of π:

$$\frac{\partial \Theta^*}{\partial \pi} = -R[x_f + x_m] < 0. \tag{B.3}$$

As the transfer is a net male-to-female transfer, equation (B.3) shows the balance of the transfer is in the male's favor as his control of household wealth decreases. Likewise, a decrease in π which represents more male control would cause the optimal transfer to increase, or shift in the female's favor.

Derivation of equations (11), female and male best response functions

Individuals choose optimal investments taking the behavior of their spouse as given according to the first order necessary conditions:

$$\begin{aligned} \frac{\partial V_f}{\partial x_f} &= -\frac{p}{\pi W - px_f} + \beta\frac{(2-\pi)R}{Rx_f + R\big[(1-\pi)x_f - \pi x_m\big]} = 0 \\ \frac{\partial V_m}{\partial x_m} &= -\frac{p}{(1-\pi)W - px_m} + \beta\frac{(1+\pi)R}{Rx_m - R\big[(1-\pi)x_f - \pi x_m\big]} = 0 \end{aligned} \tag{B.4}$$

Again, with the concavity of the objective functions in the choice variables, we know that the second order conditions will hold and the first order conditions indeed give maxima. While individual investments are increasing in one's say, they do so at a diminishing rate:

$$\begin{aligned}
\frac{\partial x_f^{NE}}{\partial \pi} &= \frac{\beta\Big(2(1+\beta)^2(3+2\beta)+4(1+\beta)^3\pi-(2+\beta)\Big(6+\beta(8+3\beta)\Big)\pi^2 -2\beta(2+\beta)^2\pi^3+\beta(2+\beta)^2\pi^4\Big)W}{p\Big(2+\beta(2+\beta)(2+\pi-\pi^2)\Big)^2} > 0 \\
\frac{\partial x_m^{NE}}{\partial \pi} &= -\frac{\beta\Big((4(5-3\pi)\pi-2+\beta^3(2+\pi-\pi^2)^2+2\beta^2(\pi-2)^2\Big(1+2\pi(2+\pi)\Big) +\beta\Big(2+2\pi\Big(20+\pi(2(\pi-2)\pi-11)\Big)\Big)\Big)W}{p\Big(2+\beta(2+\beta)(2+\pi-\pi^2)\Big)^2} < 0
\end{aligned} \tag{B.5}$$

$$\begin{aligned}
\frac{\partial^2 x_f^{NE}}{\partial \pi^2} &= -\frac{4\beta(1+\beta)\Big(\beta^2+\beta^3-2-2\beta+3(1+\beta)(2+\beta)^2\pi +3\beta(1+\beta)(2+\beta)\pi^2+\beta(2+\beta)^2\pi^3\Big)W}{p\Big(2+\beta(2+\beta)(2+\pi-\pi^2)\Big)^3} < 0 \\
\frac{\partial^2 x_m^{NE}}{\partial \pi^2} &= \frac{4\beta(1+\beta)\Big(2(6\pi-5)+\beta(\beta^2(\pi-2)^3-32+2\pi(24+\pi(2\pi-9)) +\beta(\pi(45+\pi(4\pi-21))-29))\Big)W}{p\Big(2+\beta(2+\beta)(2+\pi-\pi^2)\Big)^2} < 0
\end{aligned} \tag{B.6}$$

Proof of Proposition 2 From the individual equilibrium investments in equations (12), total household investment is given by:

$$x_{hh}^{NE} = x_f^{NE} + x_m^{NE} = \frac{\beta W\Big(4\pi(\pi-1)+\beta(\pi-2)(1+\pi)-2\Big)}{p\Big(\beta(2+\beta)(\pi-2)(1+\pi)-2\Big)} \tag{B.7}$$

Supposing a social planner could choose the institutional sharing rule π with the goal of maximizing total investment, her problem would be to:

$$\max_{\pi\in[0,1]} x_{hh}^{NE} = \frac{\beta W\Big(4\pi(\pi-1)+\beta(\pi-2)(1+\pi)-2\Big)}{p\Big(\beta(2+\beta)(\pi-2)(1+\pi)-2\Big)}, \tag{B.8}$$

which would be done according to the following first order condition:

$$\frac{\partial x_{hh}^{NE}}{\partial \pi} = -\frac{2\beta W(1+\beta)(4+3\beta)(2\pi-1))}{p\big(2+\beta(2+\beta)(2+\pi-\pi^2)\big)^2} = 0, \tag{B.9}$$

which is met when

$$\begin{aligned} &2\beta W(1+\beta)(4+3\beta)(2\pi-1)) = 0 \\ &\pi = .5. \end{aligned} \tag{B.10}$$

An equal sharing rule of $\pi = .5$ is indeed a maximum as the second derivative of household investment with respect to π is negative under equality:

$$\left.\frac{\partial^2 x_{hh}^{NE}}{\partial \pi^2}\right|_{\pi=.5} = -\frac{4\beta W(1+\beta)(4+3\beta)}{p\big(2+2.25\beta(2+\beta)\big)^2} < 0 \tag{B.11}$$

Proof of Proposition 3 Household growth as defined in equation (13) is increasing in the productivity of the production technology and decreasing in its price:

$$\begin{aligned} \frac{\partial g}{\partial R} &= \frac{\beta\big(4(\pi-1)\pi+\beta(\pi-2)(1+\pi)-2\big)}{p\big(\beta(2+\beta)(\pi-2)(1+\pi)-2\big)} > 0 \\ \frac{\partial g}{\partial p} &= \frac{\beta R\big(2(1+\beta)+\pi(4+\beta)-\pi^2(4+\beta)\big)}{p^2\big(\beta(2+\beta)(\pi-2)(1+\pi)-2\big)} < 0 \end{aligned} \tag{B.12}$$

While these conditions hold over the range of sharing rules, they have their largest effect in the case of equality. This is confirmed when the comparative static results derived in equations (B.12) are compared over the range of π. In regards to the productivity parameter, the effect of a productivity increase on growth is largest in the case of equality, as the derivative of the growth effect with respect to π is 0 in the case of equality while the second derivative with respect to π is negative:

$$\frac{\partial^2 g}{\partial R \partial \pi} = -\frac{2\beta(1+\beta)(4+3\beta)(2\pi-1)}{p\big(2+\beta(2+\beta)(2+pi-\pi^2)\big)^2} = 0$$

$$2\beta(1+\beta)(4+3\beta)(2\pi-1) = 0 \tag{B.13}$$

$$\pi = .5$$

$$\left.\frac{\partial^3 g}{\partial R \partial \pi^2}\right|_{\pi=.5} = -\frac{4\beta(1+\beta)(4+3\beta)}{p\big(2+2.25\beta(2+\beta)\big)^2} < 0 \tag{B.14}$$

While a price increase lowers the growth rate as in equation (B.12), and therefore a subsidy increases it, this effect is strongest in the case of equality as the growth effect from price with respect to the sharing rule is maximized (it's most minimum) when $\pi = .5$:

$$\frac{\partial^2 g}{\partial p \partial \pi} = \frac{2\beta(1+\beta)(4+3\beta)R(2\pi-1)}{p^2\Big(2+\beta(2+\beta)\big(2+\pi-\pi^2\big)\Big)^2} = 0$$

$$2\beta(1+\beta)(4+3\beta)R(2\pi-1) = 0 \tag{B.15}$$

$$\pi = .5$$

$$\left.\frac{\partial^3 g}{\partial p \partial \pi^2}\right|_{\pi=.5} = \frac{4\beta(1+\beta)(4+3\beta)R}{p^2\big(2+2.25\beta(2+\beta)\big)^2} > 0 \tag{B.16}$$

First order necessary conditions for maximization of stochastic portfolios

Each agent chooses their levels of investment in the safe and risky technologies in order to maximize the objectives in equations (16) so that the following conditions are met (two for each agent):

$$
\begin{aligned}
\frac{\partial V_f}{\partial x_f} &= -p(\pi W - px_f - z_f)^{-\alpha_f} + \beta E_{\tilde{R}}\Big((2-\pi)d\tilde{R}x_f^{d-1}\Big)\Big((2-\pi)\tilde{R}x_f^d - \pi\tilde{R}x_m^d + Gz_f^h\Big)^{-\alpha_f} = 0 \\
\frac{\partial V_f}{\partial z_f} &= -(\pi W - px_f - z_f)^{-\alpha_f} + \beta Ghz_f^{h-1}E_{\tilde{R}}\Big((2-\pi)\tilde{R}x_f^d - \tilde{R}x_m^d + Gz_f^d\Big)^{-\alpha_f} = 0 \\
\frac{\partial V_m}{\partial x_m} &= -p((1-\pi)W - px_m - z_m)^{-\alpha_m} + \beta E_{\tilde{R}}\Big((1+\pi)d\tilde{R}x_m^{d-1}\Big)\Big((\pi-1)\tilde{R}x_f^d + (1+\pi)\tilde{R}x_m^d + Gz_m^h\Big)^{-\alpha_m} = 0 \\
\frac{\partial V_m}{\partial z_m} &= -((1-\pi)W - px_m - z_m)^{-\alpha_m} + \beta Ghz_m^{h-1}E_{\tilde{R}}\Big((\pi-1)\tilde{R}x_f^d + (1+\pi)\tilde{R}x_m^d + Gz_m^h\Big)^{-\alpha_m} = 0
\end{aligned}
\tag{B.17}
$$

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