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DECISION-MAKING IN COMPLEX HOUSEHOLDS

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ABSTRACT

Extremely rich data on farm households in Burkina Faso are used to test whether resource are allocated Pareto efficiently. The complexity of household structures, including multi-generation and polygynous households, is taken into account to developing tests from theoretical models of behavior. Credible measures of bargaining power are constructed exploiting the fact that individuals within a household have well-defined property rights over the plots they own. Using data on consumption choices, we establish that in farm households headed by a monogamous couple (with no co-resident adult sons), resource allocations are consistent with efficiency. In more complex household structures, including polygynous households, efficiency in allocations is not rejected in models that allow more than two household members to have agency in decision-making. In contrast, tests for efficiency based on whether the same farm households maximize profits by equating marginal products across plots are rejected for all household types. Further, these same tests indicate individuals do not equate marginal products across their own plots. We conclude, therefore, that tests of models of resource allocation based on production-side decisions are likely to be misleading. In contrast, the consumption-side tests provide novel insights into the nature of decision-making within complex households.

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A data appendix is available at see subdir of paper dir

1. Introduction

Understanding decision-making within households is an important scientific and policy issue. Consider, for example, the argument that female empowerment is key for economic development (Duflo, 2012). Without a clear conceptual understanding of the processes underlying decision-making, policies intended to improve the status of women may be ineffective and, in some cases, even backfire precisely because intra-household dynamics are ignored (Dey, 1981). While the unitary model of household decision-making, which assumes all members share the same preferences or one member dictates all choices, has been a powerful tool for understanding consumption behavior (Deaton and Muellbauer, 1980), the assumptions underlying that model have been shown to be overly restrictive in a broad array of settings.[1] Whereas no clear consensus has emerged around the general applicability of a specific alternative model, one important class of models that has received considerable attention in recent years assumes only that household allocations are collectively rational in the sense that resource allocations are Pareto efficient. The theoretical model was first described in seminal work by Chiappori (1988, 1992) and has been extended by Browning and Chiappori (1998), Chiappori and Ekeland (2006) and Cherchye et al (2012). From an empirical perspective, however, the extent to which household behavior is consistent with efficiency has not been resolved in the literature. This paper provides new evidence to fill that gap.

On the one hand, the vast majority of studies based on consumption choices of households fail to reject the hypothesis that household behavior is collectively rational (see, for example, Chiapppori and Meghir, 2015, for a review). These studies use data from across the globe including, for example, from Canada (Browning and Chiappori, 1998), France (Bourguignon et al., 1993), Indonesia (LaFave and Thomas, 2017), Mexico (Bobonis, 2009; Attanasio and Lechene, 2014), Taiwan (Thomas and Chen, 1994), Ghana (Rangel, 2004), the United Kingdom (Blundell et al, 2007; Dauphin et al, 2011) and the United States (Chiappori et al, 2002). On the other hand, seminal work by Udry (1996) and several follow-up studies of agricultural productivity and input usage among farm households in West Africa cast doubt on this conclusion. Udry (1996), Owens (2001) and Akresh (2008), for example, exploit the fact that in Burkina Faso and Senegal, household members farm independent plots of land and fail to maximize farm profits

[1] See, for example, Schultz (1990); Thomas (1990); Lundberg et al (1997); Rubalcava and Thomas (2000); Rangel (2006); Oreffice (2007) and Martinez (2013). See also Lafortune (2013) and Chiappori et al. (2017) for extensions that include marriage market impacts of female empowerment.

at the household level.[2] They conclude that holding all other inputs constant, reallocating land between husbands and wives would result in about a twenty to thirty percent increase in total agricultural output of the farm household. Corroborating evidence based on consumption behavior has been reported for Burkina Faso by Dauphin et al (2018). These important and widely cited results about inefficiency in resource allocation have been very influential in the development and population literatures. They have spawned several experimental and non-experimental studies of household dynamics emphasizing non-cooperation, asymmetric information and limited commitment, with some attention to polygynous and extended households (Akresh et al, 2012, 2016; Ahsraf, 2009; Barr et al., 2019; Guirkinger et al., 2015; Kazianga and Wahhaj, 2013, 2017; Robinson, 2012; Walther, 2018). At a broader level, it is a remarkable finding: it indicates that, even in environments in which resources are extremely constrained with households eking out a life of subsistence farming where survival is not assured, individuals in the same household fail to allocate resources on their plots to come even close to maximizing agricultural profits of the entire farm household. As Udry (1996) puts it, it is difficult to reconcile this behavior with Pareto efficiency in the allocation of resources in the farm household. Recent work suggests that at least part of the explanation of these results is likely due to contamination in the estimates arising from measurement error and unobserved heterogenity at the plot level (Goldstein and Udry, 2008; Gollin and Udry, 2019) or because of the failure of markets that differentially affects plots owned by a household (Jones et al, 2019).

Drawing on theoretical models of decision-making, we re-assess the evidence and, in so doing, extend empirical investigation of farm household decision-making to incorporate not only production but also consumption choices. Employing rich data collected from agricultural households in Burkina Faso we contrast inferences drawn across both domains about how resources are allocated within the household while also taking into account the complexity of living arrangements in our study setting (as it is in many countries across Africa). Specifically, using the 2014 *Enquête Multisectorielle Continue*, a Living Standards Measurement Survey conducted by the World Bank in collaboration with the Burkina Faso national statistical agency (INSD, 2016), we exploit detailed information about each plot of land, including individual plot ownership, to measure control over resources within the household. Since land is key for production, these measures are interpreted as indicative of agency in decision-making in the farm household and play a key role in the models. Following Udry (1996), we determine whether

[2] See also Duflo and Udry (2004), Goldstein and Udry (2008), Jones (1983), and Von Braun and Webb (1989).

allocations to plots owned by different household members are consistent with profit maximization. We then turn to the detailed consumption data to test whether demand behavior is consistent with predictions of the collective model emerging from the assumption of Pareto efficient allocations. Not only is it common for extended family members to coreside in Burkinabe farm households but about a third of households are polygynous. This complexity of household structure is key for advancing research on family decision-making as it provides opportunities to reach beyond empirical tests with households headed by one or two people.

We make three contributions to the literature. First, we replicate the finding that allocations to plots on the farm do not appear to be consistent with profit maximization at the household level: controlling observed characteristics of plots, those farmed by females are substantially less productive than those farmed by males in the same household, even after accounting for differences in crop choice. We also demonstrate, however, that following the same testing strategy and comparing yields of plots owned by an individual farmer leads to the conclusion that individual farmers fail to allocate resources efficiently. A more plausible interpretation is that the estimates are contaminated by plot-specific heterogeneity that the farmer exploits but is not observed in the survey data. We conclude that without an understanding of how specific plots are allocated among household members, and how those allocations are linked to time-varying innate productivity of each plot-holder combination, it is very difficult to rule out the possibility that estimates are contaminated by unobserved heterogeneity that is correlated with the identity of the plot owner/manager. This point has been made by Goldstein and Udry (2008) who document that plots managed by females are less likely to be fallowed and are, therefore, less productive even after adjusting for a broad array of observed plot characteristics including detailed measures of soil fertility. Indeed, in sharp contrast with the production-side tests, when we examine the consumption decisions of *exactly the same farm households*, we find no evidence that resource allocations are not efficient after taking into account household structure. A key advantage of consumption-based empirical tests is that contamination due to unobserved heterogeneity in plot-specific productivity is less of a concern relative its impact on production-side tests.

Second, a key element of models of decision-making is indicators of individual-specific bargaining power that provide leverage so individuals may assert their preferences over others in the distribution of resources within the household. A major challenge in the empirical literature on household decision-making is the identification of "distribution factors" that are indicative of resources under the control of each individual within the household. We directly address this challenge exploiting the Burkinabe cultural setting in which individual males and females control specific plots of land in conjunction with detailed information collected in the survey about the characteristics of each plot including size and type of ownership. This unusually rich set of information provides well-measured individual-specific distribution factors that provide credible identification in our models. Drawing on the theory underlying distribution factors, we use the amount of land an individual owns with a title or through inheritance as our primary indicator of power within the household since this is the land over which the individual has greatest control and should retain ownership in the event of household dissolution.

Finally, if households are collectively rational, then theory provides predictions about consumption behavior in response to price variation that shed light on the minimum number of active decision-makers within the household. Exploiting these predictions, we establish that single-headed households involve one decision-maker, monogamous couples with no adult sons involve two decision-makers but other households, including males with multiple wives, involve up to three decision-makers. These results underscore the richness of the theory of collective rationality and the importance of taking the complexity of household structure into account in testing models of household behavior.

Dauphin et al (2018) draw a different conclusion based on tests using consumption data they collected from about 500 households in Passoré, a province in northern Burkina Faso. They do not have data on prices and so only test the implications of the collective model for distribution factors. Moreover, because of data constraints, they impose the restriction that leisure and consumption are separable and treat individual labor income as distribution factors. As they note, this is not an appealing restriction, even if it is the standard in the literature. It is possible that individual-specific preferences for substitution between time and consumption contaminate the tests of the collective model and so we do not impose that restriction. We exploit the rich plot-level ownership collected at the individual level in the survey of Burkinabe farm households to constuct distribution factors that are plausibly exogenous. Our tests also exploit market-level variation in prices. While our conclusion regarding the behavior of West African households is in keeping with the recent empirical literature on household resource allocation in other countries across the globe, it is important to note that our results do not imply that improving the status of women is either infeasible or undesirable. Rather, the evidence suggests that thinking about these issues in the context of a model of collective rationality is likely to be profitable both to policy makers and to science.[3] The results regarding decision makers within the extended family also has important

[3] To this end, the theory has laid the foundation for recent advances in the development of equivalence scales

implications for understanding families in a broader context in developing countries and more advanced economies. In the U.S., for example, little is known about how parents and their non co-resident adult children negotiate resource-sharing and whether those allocations are efficient in an economic sense.

2. Conceptual framework

A distinguishing feature of farm households is that production and consumption decisions are inter-linked because they produce agricultural goods both for sale and for their own consumption. Whereas empirical studies based of these models have advanced understanding of a wide array of issues including, for example, the relationships between health and productivity, welfare impacts of changes in prices, technological innovation and public policies and the functioning of product, credit and labor markets (Strauss, 1986; Singh et al., 1986; Benjamin, 1998; Jayachandran, 2006; LaFave and Thomas, 2016; Dillon et al., 2019 and Kaur, 2019; for example), there is little evidence in the economics literature about how farm household members co-ordinate decisions among themselves.

In the literature, the farm household is typically assumed to be unitary. That is, one member (a dictator) makes all decisions (Becker, 1991) or there is consensus among all decision-makers in which case they behave as if they have common preferences (Samuelson, 1956). However, studies in anthropology have documented examples of farm household responses to policy and technological changes that suggest within households dynamics are important (Guyer, 1997). For example a government intervention in the Gambia sought to improve the economic status of women by introducing technology to raise the productivity of rice which had traditionally been cultivated by women and was largely consumed by her family. As rice turned from subsistence to a cash crop, males took over cultivation, marketing and, apparently, funds from sales (Dey, 1981). Clearly, the program did not have the intended direct impact on the status of women and persistently low levels of rice production suggest little improvements in family welfare. Similarly, potential benefits of public-policy-induced innovation in cotton production in Tanzania, a crop controlled by men, were not fully realized as women did not tend the cotton plants but continued to cultivate maize (Fortman, 1986). These types of studies have been interpreted as providing *prima facie* evidence that the dynamics of the allocation of time and financial resources within farm households is not consistent with the unitary model and unlikely to

(Browning et al, 2013, for example), defining sharing rules (Laurens et al., 2015), and the analysis of individual-specific poverty (Dunbar et al., 2013).

be efficient.

This conclusion has particular appeal in the African context where, in many cases, a farm household is headed by a male with multiple wives, each of whom manages their own plots. Moreover, ethnographic studies indicate that it is neither the custom nor the practice for husbands and wives to pool their resources in much of West Africa. Many of these studies document that husbands and wives take responsibility for different domains of decision-making and resource allocation, although the precise domains vary across cultures and societies (See Guyer, 1980; Mook, 1986 and Orubuloye et al., 1991; Hill, 1975).

Taking these insights into account, our integrated model of the farm household is general in that it allows for heterogeneity in the preferences of individual members and permits each member to have agency in decision-making about resource allocation in both production and consumption. We assume each decision-maker in the household maximizes their own utility which depends on own consumption and time allocation, as well as, in general, consumption and time allocation of all other household members and consumption of public goods. Individual choices are limited by a time and a money budget constraint that depends on that individual's claims on total farm household resources; the individual budget constraints sum to the household budget constraint which is given by the value of profits from all farm plots, income from household labor on the farm, off farm labor of household members and non-labor sources. Decisions inherent in maximizing individual felicity functions are aggregated into a household welfare function where the weights assigned to each felicity function depend on total household resources, prices of goods and services and "distribution factors" influencing the bargaining power of each member in asserting their own preferences.

Farms are made up of distinct plots, some of which are jointly owned while others are individually owned. Since land is critical for agricultural production, and plot ownership conveys a claim to the profits of that plot and, therefore, to household resources, land owned by an individual household member is an ideal candidate for a distribution factor that reflects agency in decision-making. In line with this reasoning, we focus primarily on plots that are individually owned either with a title or through inheritance. In these cases, ownership is widely recognized within the community, unlikely to be disputed and does not vary over the short or medium term. In contrast, the amount of land managed by an individual is unlikely to be an appropriate distribution factor. It likely reflects the outcome of bargaining over resources within the household including time allocated to farming, off-farm work and production of services in the home and is not, therefore, plausibly exogenous in the allocation of household resources. These concerns apply to rented and communal land farmed by the household and would apply to assigning control over jointly owned land to the individual who manages the plot.

2.1 Efficiency in production

Farmers combine inputs to produce food and non-food crops on their plots; part of the product is sold on the market and part is consumed by the household. Output on each plot, Q, depends on land area, *A*, a set of variable inputs, *V*, that include labor, seed, fertilizer and water as well as fixed inputs, *Z*, such as soil type and topography. Other inputs that are not measured, are included in ϕ; these include soil fertility, farmer expertise and other dimensions of plot and farm quality as well as environmental factors such as weather. Transformation of inputs to output is constrained by the available technology.

If a farm household faces parametric prices for all farm inputs and outputs, and allocates resources efficiently, the farm household will maximize profits on the farm enterprise by setting the marginal value product of each input, i, to equal its price, p_{V_i},

$$\frac{\partial Q^*\left(A, V, Z, \phi\right)}{\partial V_i} = p_{V_i}$$

However, empirically establishing that profits are maximized is not straightforward for several reasons. For example, the productivity of an input is likely to be correlated with many dimensions of farm quality as indicated, for example, by the fertility of the soil. It is also likely to depend on the characteristics of the farmer. These characteristics of the farm and farmer are difficult to measure and are typically not observed in farm survey data and, therefore, potentially contaminate estimates of marginal value products.

In households with multiple plots, however, an immediate implication of profit maximization is that the marginal value product of each input, including labor, should be equal across all plots, *l* and *m*,

$$\frac{\partial Q_l^*\left(A, V, Z, \phi\right)}{\partial V_{li}} = p_{V_i} = \frac{\partial Q_m^*\left(A, V, Z, \phi\right)}{\partial V_{mi}}$$

so that

$$\frac{\partial Q_l^*\left(A, V, Z, \phi\right)}{\partial V_{li}} - \frac{\partial Q_m^*\left(A, V, Z, \phi\right)}{\partial V_{mi}} = 0 \qquad (0)$$

yielding a test that is not contaminated by unobserved heterogeneity at the farm household level. This key insight is the foundation of the empirical tests in Udry (1996) and related studies, which determine whether the marginal product varies with the identity of the plot owner or manager to draw conclusions about whether household behavior is consistent with Pareto efficiency.

Several additional assumptions are necessary to draw such inferences. First, all decision-makers in the farm household must face the same parametric prices for all goods and services including farm inputs, outputs and consumption goods. This includes the value of time, or shadow wage, of each household member which, by assumption, must be the same irrespective of whether the person is working on their own plot, another member's plot, a jointly owned plot or a plot that is rented or provided out of the communal stock in the village. This is not an innocuous assumption. For example, it rules out household members exerting greater effort on their own plot or shirking on other plots. The key point is that rejection of the equality of marginal products across plots within a farm household does not necessarily imply that households are not collectively rational. To draw that inference requires additional assumptions that need to be subjected to empirical scrutiny.[4]

Second, it is necessary to assume there are no unobserved characteristics of plots that are correlated with the marginal product of inputs that differ systematically with the identity of the plot owner. This rules out a farmer having comparative advantage working on his/her own plot that is not controlled in the empirical model. This might arise because of, for example, plot-specific managerial skill, knowledge or learning from experience working on that plot. It is plausible that farmers have a comparative advantage working on plots they own, because, for example, of experience with those plots. This substantially complicates interpretation of comparisons of productivity on plots managed by the farmer that are rented or from a communal pool.

More generally, unobserved heterogeneity at the plot level has been shown to be a substantively important concern in the literature comparing plots managed by males and females. Across Africa, part of the land cultivated by farmers is communal and allocated by village leaders. If a farmer has been granted the right to cultivate a communal plot and fails to do so, the farmer is at risk of losing that right. As a result, relative to privately-owned plots, communal plots are less likely to be fallowed at any time, and, since fallowing enhances soil fertility, communal plots are also less productive than other plots. Goldstein and Udry (2008) document these patterns in Ghana where plots managed by females are more likely to be drawn from the common pool. Failure to take into account land tenure rights in productivity comparisons results in female plots being

[4] For example, it is necessary that the choice of effort on a plot to affect bargaining power in resource allocation decisions. This is difficult to test because of, inter alia, the endogeneity and lack of observability of effort as well as the possibility that decisions about effort are made as part of the contract struck at the time of marriage and there may be difficulties enforcing that contract.

measured as less productive than male plots, even after controlling for a very rich set of measured plot and soil characteristics. Without a model of the allocation of communal and privately-owned plots managed by household members, it is extremely difficult to rule out the possibility that unobserved plot-specific heterogeneity seriously compromises inferences about whether farm households maximize profits based on comparisons of the productivity of plots. Moreover, such comparisons are not likely to be informative about whether farm households are collectively rational.[5]

To summarize, if a household fails to increase total profits by shifting inputs from one plot to another, it seems reasonable to infer that the household is unable to allocate resources Pareto efficiently. There are, however, at least two key assumptions that must be true in order to draw conclusions from comparisons of the productivity of plots about whether farm households maximize profits. First, all household members must face the same parametric prices, including the shadow wage of each member. Second, there can be no unobserved plot-specific characteristics that are related to productivity and the identity of the plot owner (or manager in studies that draw such comparisons). There are plausible conditions under which one or both of these assumptions will be violated. We turn next to discuss consumption-based tests for whether household behavior is consistent with Pareto efficiency for two reasons. First, the sources of unobserved heterogeneity that influence results in production-side tests are not likely to be salient sources of contamination in consumption-side tests. Second, the consumption-side tests provide direct tests of efficiency that have a foundation in consumer demand theory which is a key advantage over indirect tests based on production choices.

2.2 Efficiency in consumption

Assume a farm household comprises individuals with heterogeneous preferences who make decisions collectively. A theoretically appealing class of models proposed and developed by Chiappori (1988, 1992, 1997) and Browning and Chiappori (1998) assumes that household behavior is "collectively rational" in the sense that allocations are Pareto efficient. Although the model is quite general and includes, for example, co-operative bargaining models (Manser and Brown, 1980; McElroy and Horney, 1981), models with separate spheres of interest (Lundberg and Pollak, 1993), it excludes a broad class of non co-operative bargaining models (Leuthold, 1968; Ulph, 1988). Anthropological studies have highlighted gender-differentiated domains of

[5] To assure the empirical analyses discussed below are not subject to this concern, we focus on plots that are owned by household members.

control in decision-making in many African contexts and some studies have concluded that polygynous households fail to achieve co-operative outcomes. Rigorous testing of whether farm households with complex structures behave as if they are collectively rational is of substantial interest, in general, and in this context.

If resources are allocated efficiently within the farm household, the household welfare function can be written as a weighted average of the individual-specific felicity functions, u, one for each household decision-maker indexed by superscripts[6]

$$W = \left(1 - \sum_{j=1}^{J} \mu^j\right) \cdot u^0\left(\mathbf{C}; \mathbf{X}, \epsilon\right) + \sum_{j=1}^{J} \mu^j \cdot u^j\left(\mathbf{C}; \mathbf{X}, \epsilon\right) \tag{1}$$

where **C** is total household consumption, **X** are observed individual and household characteristics that affect consumption choices and ϵ are unobserved taste shifters. u^0 is the utility function of a reference decision-maker in the household (e.g.: the household head). The Pareto weights, μ^j, play a key role in the model. They depend on distribution factors, λ, which is a $(J+1)\times 1$ vector that, at an intuitive level, reflects the bargaining power of each individual in the farm household resource allocation decision. Bargaining power is likely to depend on productive resources that the individual would control if he/she split from the household; in this context, land owned by each individual is ideally suited to serve as an empirical counterpart of the distribution factors. The weights also vary with prices, **P**, observed household characteristics, **X**, and total household expenditure, e.

$$\mu^j = \mu^j\left(\boldsymbol{\lambda}, \mathbf{P}, \mathbf{X}, \epsilon, e\right) \tag{2}$$

In our static framework, the household chooses consumption given resource and time budget constraints so Marshallian demand is

$$\mathbf{C} = \mathbf{C}\left(\mathbf{P}, e, \boldsymbol{\mu}; \mathbf{X}, \epsilon, \mathbf{A}, \mathbf{Z}, \boldsymbol{\Phi}\right)$$

where $\boldsymbol{\mu}$ is a $J \times 1$ vector. In reduced form, demand is

$$\mathbf{C} = \mathbf{C}\left(\mathbf{P}, e, \boldsymbol{\lambda}; \mathbf{X}, \epsilon, \mathbf{A}, \mathbf{Z}, \boldsymbol{\Phi}\right) \tag{3}$$

Under the assumption that all current and future markets are complete, then farm profits will only affect demand through total resources, e (LaFave, Peet and Thomas, 2019). Rather than impose that strong assumption, we allow demand to be directly affected by the determinants of profits: the amount of land owned, $\mathbf{A}$, plot-specific observed characteristics, $\mathbf{Z}$ and plot-specific unobserved characteristics, $\boldsymbol{\Phi}$.

6 Weights are normalized to sum to one with individual-0 defined as the reference decision-maker.

Unitary households

The unitary model of the household is a special case of the collective model since distribution factors play no role in resource allocation decisions in the unitary model. Thus, one immediate and testable implication of the unitary model is

$$\frac{\partial c_s}{\partial \lambda^j}=0 \qquad \forall \text{ goods } s \text{ and individuals } j \tag{4}$$

The unitary and collective models also have different implications for the effects of prices on demand. Let ψ_{sr} be the effect of a change in the price of good r on demand for good s in the collective model

$$\begin{aligned}\psi_{sr} &= \frac{\partial c_s}{\partial p_r}+\frac{\partial c_s}{\partial e}c_s \\ &= \left[\frac{\partial c_s}{\partial p_r}+\frac{\partial c_s}{\partial \boldsymbol{\mu}'}\frac{\partial \boldsymbol{\mu}}{\partial p_r}\right]+\left[\frac{\partial c_s}{\partial e}+\frac{\partial c_s}{\partial \boldsymbol{\mu}'}\frac{\partial \boldsymbol{\mu}}{\partial e}\right]c_r \\ &= \left[\frac{\partial c_s}{\partial p_r}+\frac{\partial c_s}{\partial e}c_r\right]+\left[\frac{\partial c_s}{\partial \boldsymbol{\mu}'}\frac{\partial \boldsymbol{\mu}}{\partial p_r}+\frac{\partial c_s}{\partial \boldsymbol{\mu}'}\frac{\partial \boldsymbol{\mu}}{\partial e}c_r\right] \qquad \forall\ r=1,\ldots,S\end{aligned} \tag{5}$$

Holding the vector of Pareto weights constant and holding total household welfare, W, constant, the compensated price effects in the unitary model are

$$\sigma_{sr}=\left.\frac{\partial c_s}{\partial p_r}\right|_{dW=0,d\boldsymbol{\mu}=0}=\frac{\partial c_s}{\partial p_r}+\frac{\partial c_s}{\partial e}c_r \qquad \forall\ r=1,\ldots,S \tag{6}$$

Substituting (6) into (5)

$$\psi_{sr}=\sigma_{sr}+\left[\frac{\partial c_s}{\partial \boldsymbol{\mu}'}\frac{\partial \boldsymbol{\mu}}{\partial p_r}+\frac{\partial c_s}{\partial \boldsymbol{\mu}'}\frac{\partial \boldsymbol{\mu}}{\partial e}c_r\right] \tag{7}$$

a compensated price response in the collective model comprises both the compensated (or substitution) effect in the unitary model, σ_{sr} plus the effects in the square brackets which capture the impact of the price change on the Pareto weights in the household optimization program. The terms in the square brackets parallel an income effect as they effectively amount to the impact on demand of shifting resources from a member whose Pareto weight declines with the price change to a member whose Pareto weight increases.[7] The key insight from (7) is that, in contrast with the

[7] The household optimization program in the collective model can be interpreted in terms of two stage budgeting. In the first state, total household resources are distributed among household members with shares depending on their Pareto weight; in the second stage, each member maximizes their own felicity function given their own budget constraint. The impact of changes in prices on Pareto weights only affects the first stage when

unitary model (6), in general, the compensated price effects are not necessarily symmetric in the collective model precisely because the price effect has an additional income effect through the redistribution of resources. Thus, symmetry of the Slutsky matrix is a second testable implication of the unitary model that is not a restriction imposed by the collective model:

$$\psi_{sr} - \psi_{rs} = 0 \quad \forall s, r \tag{8}$$

Rejection of the unitary model says nothing about how decisions by individuals with different preferences are made within a household. We turn, next, to test specific implications of the model of collective rationality.

Collectively-rational households

First, if allocations are efficient then distribution factors only affect resource allocation decisions by shifting outside options (or bargaining power) of each household decision-maker. That is, each element of λ is restricted to only affect demand through its impact on μ which is constant across all goods. Intuitively, the shift in bargaining power plays the same role as a shift in the distribution of exogenous income in the household. This weak separability restriction implies that the ratio of marginal propensities to consume with respect to two decision-makers, as indicated by each having their own distribution factor, λ^0 and λ^1, respectively, should be the same for any pair of goods, r and s

$$\frac{\frac{\partial c_s}{\partial \lambda^0}}{\frac{\partial c_s}{\partial \lambda^1}} = \frac{\frac{\partial c_s}{\partial \mu^1}\frac{\partial \mu^1}{\partial \lambda^0}}{\frac{\partial c_s}{\partial \mu^1}\frac{\partial \mu^1}{\partial \lambda^1}} = \frac{\frac{\partial \mu^1}{\partial \lambda^0}}{\frac{\partial \mu^1}{\partial \lambda^1}} = \frac{\frac{\partial c_r}{\partial \lambda^0}}{\frac{\partial c_r}{\partial \lambda^1}} \quad \forall s \neq r \tag{9}$$

which simplifies to

$$\frac{\partial c_s}{\partial \lambda^0}\frac{\partial c_r}{\partial \lambda^1} - \frac{\partial c_r}{\partial \lambda^0}\frac{\partial c_s}{\partial \lambda^1} = 0 \quad \forall s \neq r \tag{10}$$

If there are two decision-makers in a household, these proportionality restrictions amount to cross-equation restrictions in the demand system that are straightforward to test. It is important to note that if there are more than two decision-makers then the equality of ratios in (10) is not implied by the collectively rational model. Take, for example, the case of three decision makers, 0, 1 and 2. Household demand is

$$\mathbf{C} = \mathbf{C}\left(\mathbf{P}, e, \mu^1, \mu^2; \mathbf{X}, \epsilon, \mathbf{A}, \mathbf{Z}, \mathbf{\Phi}\right)$$

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total resources are shared and thus has only an income effect on household demand.

so that the effect of a change in λ^0 is

$$\frac{\partial c_s}{\partial \lambda^0} = \frac{\partial c_s}{\partial \mu^1}\frac{\partial \mu^1}{\partial \lambda^0} + \frac{\partial c_s}{\partial \mu^2}\frac{\partial \mu^2}{\partial \lambda^0} \qquad (11)$$

and the effect of a change in λ^1 is

$$\frac{\partial c_s}{\partial \lambda^1} = \frac{\partial c_s}{\partial \mu^1}\frac{\partial \mu^1}{\partial \lambda^1} + \frac{\partial c_s}{\partial \mu^2}\frac{\partial \mu^2}{\partial \lambda^1} \qquad (12)$$

It is clear from inspection of (11) and (12) that, in general, the proportionality restriction, (10), only holds when there is one independent Pareto weight because each of the distribution factors, λ, affects all the Pareto weights, in this case, μ^1 and μ^2, and thus $\mu^0 = 1 - (\mu^1 + \mu^2)$. Therefore, tests based on (10) are interpreted as testing the joint hypothesis that household behavior is consistent with collective rationality and that there are no more than two decision-makers in the household. This is an unappealing restriction in many developing country contexts; it is particularly unappealing in our West African context where household structures are complex and polygeny is practiced.

It turns out that under the assumption of collective rationality, the compensated price effects are well suited to examine efficiency in those contexts. Let the matrix of price responses under the collective rationality assumption be defined as $\mathbf{\Psi}$, the pseudo-Slutsky matrix. Its counterpart under the unitary assumption is the traditional Slutsky matrix, $\mathbf{\Sigma}$. Define

$$\mathbf{\Psi} = \mathbf{\Sigma} + \mathbf{\Omega} \qquad (13)$$

where the matrix $\mathbf{\Omega}$ collects the terms associated with the changes in the distributional weights in (5) that are not in (6).

Browning and Chiappori (1998), show that this "symmetry perturbation matrix" has to obey specific rank conditions under the assumption of collective rationality. In the collective model, the matrix $\mathbf{\Omega}$ has rank equal at most to the number of decision-makers minus one. That is, if there are two decision-makers, the rank of $\mathbf{\Omega}$ is one. They called this the SR_J restriction over $\mathbf{\Psi}$ ("symmetric matrix plus a rank J matrix"). The restriction arises because, as shown in (11) and (12), bargaining power effects depend on the dimension of the vector of weight functions $\boldsymbol{\mu}$, and this is reflected in the number of rows (or columns) in $\mathbf{\Omega}$ that are linearly independent.[8] As discussed in more detail below, this insight provides an opportunity to infer the number of household members with agency in the allocation of resources in the farm household. This is a

[8] See, also, Chiappori and Ekeland (2006) and Dauphin et al. (2011).

powerful insight that is especially important in our context.

In practice, $\mathbf{\Sigma}$ and $\mathbf{\Omega}$ cannot be identified in this general formulation. However, Browning and Chiappori (1998) show the collective rationality restrictions can be indirectly tested. In particular, consider the matrix

$$\mathbf{\Delta} = \mathbf{\Psi} - \mathbf{\Psi}' = \mathbf{\Omega} - \mathbf{\Omega}' \qquad (14)$$

It follows that, if the unitary model is valid, $\mathbf{\Delta} = 0$ and $\mathbf{\Psi}$ inherits the symmetry property of $\mathbf{\Sigma}$. Under the assumption of collective rationaloty, the matrix $\mathbf{\Delta}$ is antisymmetric (or "skew symmetric"),[9] which implies that its eigenvalues are imaginary and its rank is an even number. Browning and Chiappori (1998) suggest a sequential approach to testing collective rationality using price sensitivity of households' consumption decisions. First, test whether the pseudo-Slutsky matrix is symmetric by testing whether the rank of $\mathbf{\Delta}$ is zero. If that restriction is not rejected, behavior is consistent with the unitary model. If that restriction is rejected, then proceed to sequentially test whether $rank(\mathbf{\Delta})=2$ x J where $J+1$ is the number of decision-makers in the household. For example, failure to reject the restriction $rank(\mathbf{\Delta})=2$ indicates behavior is consistent with collective rationality and there are 2 decision-makers; failure to reject $rank(\mathbf{\Delta})=4$ indicates there are 3 decision-makers and behavior is collectively raitionally. If, however, $rank(\mathbf{\Delta}) > 2 \times J$, the collective model is rejected and we conclude that household behavior is not consistent with efficient allocations, including co-operative bargaining equilibria.

3. Description of the data

Few household surveys collect detailed information on both production and consumption in the same farm households, prices faced by these households and sufficient information to construct measures of distribution factors that plausibly affect bargaining power within the household. We use data from *Enquête Multisectorielle Continue*, a nationally-representative household survey conducted in Burkina Faso in 2014, which is ideally suited for this research. There are five features of the survey that are key.

First, detailed information is reported about each plot farmed by the household including crops planted, the quantity and value of output, quantity and value of inputs used, plot size measured by GPS, plot location relative to the homestead and indicators of land quality including soil type and typography. Second, the identity of the owner(s) of each plot is recorded along with whether each plot is held with a formal title or whether it was inherited. Title or inheritance

[9] A matrix M is antisymmetric if M′=-M.

conveys clear property rights and forms the basis for our construction of distribution factors that are linked to control over resource allocation decisions within the household. Other plots are owned without a title or use-rights are assigned by the local chief, usually from the village communal pool. Most of the analyses are restricted to 4,664 farm households headed by a man and at least one woman who own one or more productive plots of agricultural land.[10] Third, production and consumption information was collected in each of four rounds over 12 months. Combining data across rounds, we construct annual measures of inputs, outputs and consumption in order to put aside the important issue of seasonality in an agrarian economy. Fourth, consumption measures in the survey include not only expenditures but also the value, at market prices, of consumption from own production. Fifth, to estimate price effects in the demand system, we use prices for consumption goods, farm outputs and inputs collected at local markets for specific homogeneous goods and thereby avoid problems with using unit prices that reflect the combination of household choices, quality variation and potential quantity discounts.

Table 1 provides an overview of land ownership and household structure in the analytical sample. As shown in the first column, the average farm household owned almost 5 Ha of land that spanned 3.37 plots. Almost every male head owns land with the average male owning 4.84 Ha on 3.18 plots. In households headed by monogamous couples, we refer to the wife of the male head as the female head; in polygynous households, all wives are referred to as female heads. Slightly over one in twelve female heads own land, they own 1.54 Ha and 1.81 plots on average. On average, female plots are slightly larger than half the size of male plots.

The complexity of household structures in Burkina Faso is another important reason to investigate household decision-making in this context. As shown in columns 2 through 5 of Table 1, we have stratified households into four types. Households headed by a male and female couple with no other adults (column 2) have played a central role in studies of household decision-making; they are unlikely to have more than two decision-makers. We have separated households headed by a couple with another adult who is not a son (column 3) from those with an adult son (column 4). Both of these household types potentially have more than two decision-makers particularly in the latter household type. Since a co-resident adult son is likely to work in the farm enterprise and inherit land ownership rights from his parents, he is also likely to play a significant role in decision-making. Polygynous households (column 5) are interesting because, at one extreme, it is possible their behavior is consistent with the unitary model, if one

[10] Plots that use some labor input and produce output that is consumed or sold.

household member dictates all decisions and, at the other extreme, the household may have difficulty achieving a co-operative equilibrium.

On average, the amount of land owned and number of plots owned tends to increase with household complexity. On average, monogamous couples and no cohabiting adults have the least land and fewest plots while polygynous households have the most land and largest number of plots. A female owns at least one plot in 9.4% of polygynous households and together they own far more plots than females in monogamous households.

While the differences in land ownership across household types are modest, there are very large differences in household size and composition, as shown in panel B of Table 1. Overall, there are 8.9 members in the average household with 2 male adults, slightly more female adults and 4.5 children. Monogamous couples with no other adults are much smaller because, by definition there is only one male and one female adult in the household and because there are fewer children. Other households headed by a monogamous couple are very similar to the average household and polygynous households are much larger with 12.9 members, on average of whom 2.4 are male adults, 3.6 are female adults and 6.8 are children. Male heads are younger in monogamous couples without an adult son and there is little variation in literacy and religion of household heads across the household types except that polygynous households are more likely to be Muslim.

Consumption includes both purchases in the market and consumption out of own production. Food consumption over the previous 7 days and non-food over the previous 90 days from each of the four survey rounds are converted to annual values. In our central analysis results are reported for seven semi-aggregates which have been chosen in an effort to group similar goods together while avoiding the complexities that arise with estimation and interpretation of models of budget shares that include large fractions of households who report zero consumption of a semi-aggregate.[11]

4. Empirical implementation and results

Our investigation of whether the behavior of Burkinabe farm households is consistent with collective rationality, we begin with production-side tests as implemented by Udry (1996) and others. Consistent with that literature, profit maximization is rejected. Recall from Section 2 that we argue that failure of collective rationality is not the only potential explanation for this result.

[11] Among our seven semi-aggregates only three have incidence of zero expenditures. Specifically, 0.19% of the households do not report any housing expenditures; 2.94% of the households transportation expenditures, and; 1.65% of households recreation expenditures.

We therefore turn next to the consumption-side tests. If the restriction that there are no more than two decision-makers in each farm households is imposed on the data, collective rationality is rejected. There is, however, no a priori reason to impose that restriction given the complexity of Burkinabe farm household structures described above. This turns out to be key: allowing the number of decision-makers to differ across household types, collective rationality is not rejected for any of the household types. With this result, we return to production-side choices and assess whether behavior is consistent with profit maximization within any of the household types described in the previous section.

4.1 Production-side tests

If a farm household maximizes profits, then the marginal value product of any inputs should be equal across all plots farmed by that household, (0), which implies that the marginal value product of a plot should not depend on the identity of the plot owner. Marginal products are difficult to estimate and so, following Udry (1996), we take a Taylor series approximation and compare the average yield per hectare of plots owned by males with the yield on female owned plots. In order to compare of yields of plots owned by males and females within each farm household, we translate such notion into a regression framework and estimate

$$R_{ht} = \gamma_1 female_{ht} + \gamma_2 A_{ht} + \mathbf{Z}'_{ht}\gamma_3 + \eta_h + \sum_{g=1}^{G} \omega_g + \phi_{ht} \qquad (15)$$

where R_{ht} is the yield per hectare on plot t, owned by a member of household h and $female$ is an indicator variable for a female-owned plot. The model includes a farm household fixed effect, η_h to assure comparisons are made between plots owned by males and females in the same farm household. Further, the model includes an indicator variable for the primary crop planted on the plot, ω_g, for G crops to assure comparisons across plot owners are not contaminated by crop choice. Since plot productivity is typically inversely correlated with plot size, the model includes an indicator for each quantile of land area, A_{ht}, and, to adjust for plot-specific quality differences, the model semi-parametrically includes measures of plot topography, soil type and distance from the homestead, Z_{ht}.

Results from estimation of (15) are reported in Table 2. As shown in the first row of panel A, taking all plots owned by the male or female household head, on female-owned plots, the ln(yield per Ha) evaluated at market prices is 10.17 (about CFAF 26,000 or \$50) but only 9.96 on male plots, a 21% gap that is large and statistically significant. Drawing comparisons between men and women in the same household by including a farm household fixed effect, η_h, the gap is reduced to 11% and it is not significant. However, female-owned plots are about half the size of male plots (panel C, row 1) and, in general, there is a negative correlation between plot size and productivity. Further, females are more likely to grow peanuts which are higher value than millet which is grown by males. Adjusting for plot size and including indicators for crops, male-owned plots are 25% more productive than female-owned plots (row 3, column 3). Adding plot characteristics to the model does not change the estimated effect or inference. This is not surprising since, as shown in panel C.3 of the table, the differences in observed plot characteristics of males and females are small. Restricting attention to households in which both the male and a female head own land, the gender gap increases to 32% (column 4) and further restricting to plots that grow the same crop, the gap is 29% (column 5).

Goldstein and Udry (2008) document that plots managed by females are less frequently fallowed because many are communally owned) which affects the fertility of the soil and productivity of the plots. We avoid this source of unobserved heterogeneity by examining only plots that are owned by the individual and, as shown in panel C.4 of Table 2, only 3% of plots are fallowed and there is no difference by gender of the owner.

Key for the tests of collective rationality is measurement of individual-specific indicators of control over resources (or bargaining power). It is possible that not all land owned conveys control over the resource which may depend on the nature of the ownership and how the land is likely to be allocated if the household splits. We restrict attention to plots for which the individual has a title or plots that were inherited by the individual. As shown in panel C.5, almost all land owned by male heads carries a title or is inherited whereas only about two-thirds of the plots owned by female heads are secured in this way. Nonetheless, results reported in panel B of the table, are almost identical to the broader measure: adjusting for plot characteristics and comparing the same crops within households, female plots are 27% less productive than male plots and restricting to households that have both male and female owned plots with titles or through inheritance, the gap is 36%.

This evidence replicates the central empirical finding in the literature: plots owned by females are substantially and significantly less productive than plots owned by males. The result has been interpreted as inconsistent with efficient resource allocations by households (Udry, 1996 and others) and evidence of co-operation failure between husbands and their wives (Akresh et al, 2016). The validity of this interpretation depends critically on assuming that the plots owned by males and females are exchangeable. As discussed above, this is a strong assumption that is difficult to establish empirically. More generally, it is difficult to rule out gender-specific unobserved heterogeneity in the productivity of inputs in these models particularly in models that ignore inter-temporal dynamics and how plots are allocated between male and female heads (Chiappori and Mazzocco, 2017).

One approach to assess the empirical importance of contamination in the estimates of productivity due to unobserved heterogeneity across plots is to estimate the models comparing plots that are owned by a single individual. There is no reason for this farmer to not maximize profits and so the only reason productivity will differ across plots is because the assumptions underlying the empirical specification are violated. Restricting attention to 1,481 individuals who report owning multiple plots (with a title or through inheritance), we have re-estimated (15) for ln(yields/Ha) replacing the indicator for gender of the owner with an indicator for whether the plot was the last to be listed on the individual's plot roster. There are 4.594 plots so the average farmer owns slightly over 3 plots. The survey provided no instructions on the order in which plots should be listed by the respondent and, the plot listed last on the roster is 1.4% more productive (s.e.=2.9%) overall and 0.5% more productive (s.e.=3%) if comparisons are drawn within plots owned by an individual (i.e. including plot owner fixed effects). However, taking into account crop choice and plot characteristics, on average, the productivity of the plot listed last is 9.2% lower than all other plots owned by the farmer; this gap is both large and statistically significant (se=2.5%). Following Udry (1996), this indicates that the individual farmer fails to maximize profits and is, thereby, not Pareto efficient. A more plausible interpretation is that farners allocate resources to plots that are more productive and this plot-specific heterogeneity which is unobserved in the data contaminates the estimates.[12] This seriously compromises inferences about efficiency in resource allocations based on production-side tests. Therefore, to empirically assess whether Burkinabe farm households allocate resources Pareto efficiently, we turn to consumption-based tests.

4.2 Heterogeneity of preferences and consumption decisions

In each of the four survey rounds, detailed consumption is collected for food items (over the previous 7 days) and non food items (over the previous 90 days) taking into account both purchases in the market and consumption out of own production. The four rounds of data are

[12] One indicator of the extent of contamination due to unobserved heterogeneity is provided by drawing comparisons between a farmers highest and lowest yielding plots: the productivity gap is 60% (s.e.=4.2%) after controlling individual farmer fixed effects, crop fixed effects and observed plot characteristics.

combined and converted to annual consumption which we have aggregated to create budget shares for seven semi-aggregates. The average shares are displayed in panel A of Table 3. The staples, cereal (millet, corn and rice), accounts for one-quarter of the budget, meat, fish and vegetables account for about one-sixth and other foods another one-sixth. On average, food accounts for 55% of the budget. Household and personal goods accounts for one-fifth of the budget and includes household furniture and semi-durables, clothing, health and education spending. The shares of the budget allocated to housing and transport are small. Recreation accounts for about one-tenth of the budget and includes leisure-related spending and spending on festivals and holidays.

The semi-aggregates have been chosen so that similar goods are grouped together (such as all cereals). We selected a demand system with seven shares as the tests for collective rationality lack power when income effects are poorly determined.[13] To test the theoretical predictions on demand behavior of collective rationality, we estimate (3) a flexible Almost Ideal Demand type of specification that is extended to include distribution factors. Specifically,

$$w_{hl}^{s}=\sum_{q=1}^{4}\alpha_{q1}^{s}lnPCE_{qhl}+\theta^{s}ln\left(P_{l}\right)+\sum_{g=1}^{G}\psi_{g}^{s}ln\left(p_{l}^{g}\right)+\mathbf{X}_{hl}^{'}\alpha_{2}^{s}+\beta_{1}^{s}\boldsymbol{\lambda}_{hl}^{m}+\beta_{2}^{s}\boldsymbol{\lambda}_{hl}^{f}+\varepsilon_{hl}^{s} \qquad (16)$$

where w_{hl}^{s} is the share of the budget spent on semi-aggregate s by household h living in locality l. Budget shares depend on the logarithm of per capita expenditure (PCE) specified as a spline with knots at each quartile of the PCE distribution to allow flexibility in the shape of the income effects, household characteristics, $\mathbf{X}$,[14] an overall price index, P, and the relative price of each semi-aggregate, p. Market prices, collected in each survey round at the locality level, are used to create locality-specific share-weighted price indices where the weight is the locality area mean budget share for each good in the sub-aggregate and all price indices are specified in logarithms.

The distribution factors are measured by the amount of land that is individually owned with a title or through inheritance by the male head, $\boldsymbol{\lambda}^{\mathbf{m}}$, and by the female head(s), $\boldsymbol{\lambda}^{\mathbf{f}}$.[15] Each model includes an indicator for whether any land is owned and the quartic root of the amount of land owned, separately for females and males.[16]

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[13] We examine the robustness to this choice below.

[14] Specifically, ln(household size), the share of members that are children, adult males adult females and senior males, the age, literacy and religion of the male head and female head (the senior female head in polygynous households) and indicator functions for province of residence.

[15] In the case of polygynous households, holdings across all wives are aggregated in order to mimic the gender differential highlighted in the exercise focused on data from production decisions.

[16] The quartic root function closely approximates the logarithmic function for all values other than 0 and has the advantage of being defined at zero; results using the inverse hyperbolic sine function are substantively the same.

Estimates of the coefficients on the distribution factors, β, are reported in panel B of Table 3 for each of the 7 semi-aggregates. Tests for the joint significance of land owned by females, by males and land owned by all household heads are reported in panel C, with associated p-values. Since lnPCE enters the demand functions very flexibly, the estimates of β s can be interpreted as conditional on taking into account the effects of total resources on demand and are indicative of the effects of resource control or bargaining power. Under the assumptions of the unitary model, they play no role in the allocation of the budget.

$$\beta_1^s = \beta_2^s = 0 \quad \forall s \tag{17}$$

The restriction is rejected. For example, in the first column of the table, a greater share of the budget is allocated to cereals as females own more land and the female land ownership coefficients are jointly significant. Although male land ownership is not significantly related to cereal shares, taken together, male and female land ownership are significant predictors of cereal shares. This is not consistent with the unitary model. Overall, the restriction of the unitary model is rejected for five of the 7 goods at a 5% size of test. (It is not rejected for household and personal goods and for housing) with rejections for two and five of the shares for female and male land ownership, respectively. Panel D.1 displays p-values for tests of the unitary model for the entire demand system. The tests for no effects of land ownership are rejected for female ownership, male ownership and ownership by all household heads.

Whereas many studies have tested whether resource control predicts outcomes, there are relatively few tests of the unitary model based on price effects in the literature on intra-household resource allocation. Panel D.2 tests the 21 cross-equation restrictions that the pseudo-Slutsky matrix is symmetric: it is rejected. Taking each pair of price effects at a time, 52% are significantly different at a 5% size of test and 71% at a 10% size of test. Taking all of the pairs together, the symmetry restriction is rejected (p-value < 0.001).

It is possible that rejection of the unitary model is driven by model mis-specification. To assess this concern, the models are re-estimated for households with a single head since the behavior of those households should be consistent with the unitary model.[17] Results are reported in column 1 of Table 4. Conditional on household resources, neither of the predictions of the unitary model is rejected. As shown in panel A, female land ownership does not predict budget

[17] Attention is restricted to households with a female head, many of whom co-reside with children and other adults. These households are not combined with households headed by a single male because the latter tend to be old, live alone and have different budget allocations from female-headed households. There are too few single male heads to reliably estimate demand functions for those households alone.

shares at a 5% size of test and, in panel B, Slutsky symmetry is not rejected. These results provide reassurance regarding the empirical specification of the model.

Results from Table 3 for households with a male and at least one female head are repeated in column 2 of Table 4. These households are stratified into the four household types described in Table 1. Monogamous couples are stratified into those with no other adult household members (in column 3), those living with other adults, none of whom is an adult son (in column 4) and those co-residing with at least one adult son (in column 5). Polygynous households (column 6) are separated from monogamous couples.

As shown in panel A of the table, for polygynous households and those monogamous households with more than 2 adults (columns 4-6), male land ownership and female land ownership are significant predictors of budget shares alone and taking land owned by all heads together. For monogamous couples with no co-resident adults (column 3), land owned by the male head and the joint test for the male and female head indicate they are significant predictors of budget shares whereas female land ownership alone is not. Thus, for all households headed by a male and at least one female, the restriction of the unitary model that the distribution of land ownership does not affect resource allocation is rejected. Further, as shown in panel B of the table, for all four household types, Slutsky symmetry is also rejected. We conclude that the unitary model is soundly rejected for all households other than those headed by a single female.

Testing the collective model: Proportionality

Turning to the empirical implications of the collective model for consumption behavior, we begin by testing the proportionality restriction. When resource allocations are collectively rational, the ratio of the effects of distribution factors should be the same for all goods in the demand system

$$\frac{\beta_1^s}{\beta_1^r} - \frac{\beta_2^s}{\beta_2^r} = 0 \tag{18}$$

These ratios vary in ways that are economically meaningful and substantively important.From the estimates in panel B of Table 3, taking all household types together, the ratio of the effect of the amount of land owned by females, relative to males, on the share of the budget allocated to household and personal goods is 8.8 (s.e.=1.0). These goods are likely to more highly valued by females relative to males. In contrast, the ratio is negative for the share spent on transport (-0.28, s.e.=0.02): shares rise with the amount of land owned by males and decline with the amount of land owned by females. It is likely that males value higher cost transport (motor bikes, for example) more than females.

In order to formally test the cross-equation restrictions (18), it is useful to recast the restrictions in product form

$$\beta_1^s \beta_2^r - \beta_1^r \beta_2^s = 0 \quad \forall s, r \tag{19}$$

as the resulting non-linear Wald test statistic has improved numerical properties (Gregory and Veall, 1985). The chi-squared test statistics and associated p-values for the demand system are displayed in the first panel of part A of Table 5 for households headed by a male and one or more females (column 1) and for each of the four households types (columns 2 through 5). Collective rationality is not rejected for any of the four household types. There are, however, legitimate questions about the power of tests based on the entire demand system. As an example, the impact of a small number of poorly determined coefficients may be propagated across the entire test rendering failure to reject the test uninformative. In panel A.2 of the table, therefore, we summarize results for pair-wise tests of equality and display the number of pairs that are not equal at a 5 and 10% size of test. Of course, by design, we expect 5% and 10% to not be equal, respectively.

Taking all households together (column 1), the pair-wise results are ambiguous: the restriction is rejected for 2.4% of pairs at a 5% size of test but for 14.3% of pairs at a 10%. It turns out this ambiguity is due to heterogeneity across households which is clear from the remaining columns in the table. For monogamous couples with no other adult household members (in column 2), there is no evidence that the proportionality restriction is rejected. However, for all other monogamous couples and for polygynous households (columns 3 through 5), the proportionality restriction is rejected for both the 5 and 10% test sizes. The second and third panels of the table report pair-wise tests for the coefficients on the intensive margin (amount of land owned) and extensive margin (whether or not land is owned) respectively. It is clear that rejection of the proportionality restriction is driven by variation in the amount of land owned (panel A.2.2) and not at the extensive margin (panel A.2.3).[18]

[18] It is useful to note that these results have implications for the unitary model when the distribution factors, or plot characteristics in our case, are measured with error. Error that is common across all plots is unlikely to be a concern because it will be absorbed by the farm household fixed effect under reasonable conditions. Error that is correlated with the gender of the owner is a potential concern. Since most of the plot sizes are calculated from GPS measures taken by the enumerator, measurement error is likely to be modest and is unlikely to be related to the gender of the owner. However, other observed characteristics are reported by the household, typically the male head and if knows more about his own plots, there is a potential for gender-specific measurement error. Moreover, plot productivity, conditional on observed characteristics, is not measured but is likely to be known to the household members and it is possible that it is correlated with gender of the owner. In general, if

Testing the collective model: Rank of the pseudo-Slutsky matrix

We turn next to empirically assess the restrictions on the pseudo-Slutsky matrix under the assumption that allocations are collectively rational first described by Browning and Chiappori (1998). Allowing the distribution factors to affect price effects, the pseudo-Slutsky matrix comprises the usual symmetric matrix and another matrix, the rank of which is directly related to the number of decision-makers in the household.

These tests can be formulated in terms of the rank of an antisymmetric matrix formed by the difference between the matrix of price responses and its transpose. Tests of rank two and rank four have direct counterparts in terms of non-linear restrictions over the parameters of the demand system, as shown in Browning and Chiappori (1998) and Dauphin et al. (2011), respectively. On the other hand, there is no direct parametric restriction when testing higher rank conditions. Moreover, since estimated matrices are subject to statistical errors and the discreteness of the rank function, their ranks will most likely not correspond to the rank of the matrix of interest. This rules out simple comparisons of ranks directly computed from estimates of Δ.

Following Browning and Chiappori (1998), we take a sequential approach to testing. Beginning with $SR_{(1)}$, we test the null hypothesis that $rank(\Delta) = 2$ against the alternative that $rank(\Delta) > 2$. This is the case if Δ has $S-2$ of its rows as linear combinations of the other two. Browning and Chiappori (1998) show that this corresponds to testing $\frac{(S-2)\times(S-3)}{2}$ restrictions of the form

$$\delta_{sr}\delta_{12} - \delta_{1s}\delta_{2r} + \delta_{1r}\delta_{2s} = 0 \qquad \forall \quad r > s > 2$$

If $SR_{(1)}$ is rejected, we proceed to test whether the rank is higher order and test the null hypothesis that $rank(\Delta) = 4$ against the alternative that $rank(\Delta) > 4$. Following Dauphin et al. (2011), this test relies on a non-linear combination of parameters that yields the non-linear Wald-statistic

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measurement error in λ is additive, then, under the assumptions of the unitary model, the ratio of the effects of the distribution factors will be constant across goods (Thomas, 1990; see, also, Black et al, 2000, who show the result holds making other assumptions about the nature of the measurement error). This is exactly the same as the proportionality restriction under the assumption that allocations are collectively rational. We conclude, therefore, that allowing for measurement error in the distribution factors, the unitary model is rejected for all but monogamous couples with no other adults. Tests of the symmetry of the compensated price effects is not affected by this type of measurement error and, for those tests, our conclusion that the unitary model is rejected for all four types of households remains.

$$
\begin{aligned}
&\delta_{sr}(\delta_{12}\delta_{34} - \delta_{13}\delta_{24} + \delta_{14}\delta_{23}) - \delta_{12}(\delta_{3s}\delta_{4r} - \delta_{3r}\delta_{4s}) \\
&\quad - \delta_{13}(\delta_{2r}\delta_{4s} - \delta_{2s}\delta_{4r}) - \delta_{14}(\delta_{2s}\delta_{3r} - \delta_{2r}\delta_{3s}) \\
&\quad - \delta_{1s}(\delta_{23}\delta_{4r} - \delta_{24}\delta_{3r} + \delta_{2r}\delta_{34}) + \delta_{1r}(\delta_{23}\delta_{4s} + \delta_{24}\delta_{3s} + \delta_{2s}\delta_{34}) = 0 \quad \forall\, r > s > 4
\end{aligned}
$$

The non-linear Wald test is complemented with a test based on the singular values of the pseudo-Slutsky matrices (i.e., the norm of their eigenvalues). We calculate the number of non-zero singular values which correspond to the rank of the matrix[19] and estimate variability of that estimate using the boostrap.[20] Details are presented in the Technical Appendix.

These tests of the restrictions on the pseudo-Slutsky matrix are presented in panel B of Table 5 beginning, in the first row, with Browning and Chiappori's SR_1 test which is test for rank 2. It is rejected for all households with more than one head (in column 1). This result is, again, driven by heterogeneity among households. Restricting attention to monogamous households with no other adults (column 2) and those with no adult sons (column3), the restriction is not rejected. For these household types, consumption behavior is consistent with collective rationality and two decision-makers. The restrictions are rejected for monogamous households with an adult son (column 4) and also for polygynous households (column 5). This may be because allocations are not Pareto efficient or because the number of decision makers is greater than two, or both. To distinguish between these explanations, the second row in the panel reports results of the tests that the pseudo-Slutsky matrix has rank 4 for these two types of households. It is not rejected in either case and the evidence is consistent with the allocations of these households being Pareto efficient and that there are 3 decision-makers in the households.

A key strength of this paper, and an important advantage of the farm household context, is that the amount of land owned is a plausible distribution factor which is likely to be indicative of bargaining power of the owner in household allocation decisions. The consumption side tests have included the amount of land that is owned with a formal title or through inheritance. This has the advantage of identifying land that the owner is likely to control even if the household dissolves and is, therefore, indicative of an individual's threat point bargaining position. This definition accounts for almost all land owned by males but only two-thirds of the land owned by females. All of the consumption-side tests are repeated in Appendix Table 1 using any land owned, with or without a title. None of the conclusions regarding rejection of the unitary model or failure to reject Pareto efficiency described above is changed using this broader definition to identify the effects of the

[19] Leon (1990).
[20] Eaton and Tyler (1994), Bullock (1995) and Ratsimalehelo (2003).

distribution factors.[21]

The power of the consumption-side tests likely varies with the number of sub-aggregates and price indices included in the demand system. This is likely to be particularly important in tests of income ratios and tests based on estimated price effects. As the number of sub-aggregates is increased, the number of zero shares also increases; we have limited attention to demand systems with 9 and 8 sub-aggregates and also report results for systems with 6 and 5 sub-aggregates. Results using the more narrow definition of land ownership are presented in Appendix Tables 2a-2d, respectively. In none of these cases do our conclusions differ from those described above for the demand system with 7 sub-aggregates. We conclude our results are robust to varying the number of sub-aggregates, at least within this range.

Taken together, these results based on consumption behavior are striking. Not only do they establish that resource allocations among Burkinabe farmers are consistent with Pareto efficiency but they are also informative about how decision-making varies with the complexity of the household composition. Specifically, households headed by a man and a woman with no adult sons behaves as if there are two decision-makers whereas polygynous households and monogamous households with at least one son in the household behaves as if there are three decision-makers.

Production efficiency and household structure

The consumption-side tests have highlighted the importance of heterogeneity across the four household types for understanding decision-making within households. With this in mind, we return to the production side of the farm household and examine whether the gender-specific productivity differentials vary with household type. Results are reported in Table 6. The (female-male) gender gap in ln(yields/Ha) are displayed in panel A for plots owned with a title or by inheritance in the first row and for all land owned in the second row. All models include farm household and crop fixed effects along with measures of plot quality. All farm households are included in the models reported in the first column which repeats results from Table 2: plots owned by females are 25 to 27% less productive than plots owned by males. Among monogamous couples with no other adults in the households, the productivity differential is cut by half to 14% and is not statistically significant. The gap is largest for couples with a co-resident adult son

[21] There are relatively few households in which land is owned by a third member. In households with an adult son, for example, few of the sons own land although it is very likely they will inherit the land in the future. As a result, this study is not powered to implement tests based on the rank of the matrix of the effects of three distribution factors on consumption (or the relationship between its columns and those of the antisymmetric matrix Δ)

(36-39%) and significant for both those households and polygynous households. However, none of the gaps across household types is significantly different from each other. As shown in panel B of the table, the gender differences are apparent in input usage: female plots are less intensively cropped as indicated by the negative gender gap in labor input per Ha. The difference is largest and statistically significant in polygynous households. Those households are also significantly less likely to use chemical fertilizer or manure on female-owned plots although that is not the case in any of the households headed by a monogamous couple. Panel C of the table establishes that the gender gaps in yields cannot be explained by the differences in type of labor inputs (although the gap remains large for monogamous couples with a co-resident adult son but it is poorly determined and not statistically significant). Land preparation is traditionally dominated by males: there is no evidence of gender differences in the fraction of labor that is allocated to plot preparation across male and female plots.

Taking the production results together, they are suggestive that the behavior of polygynous households may be different from monogamous households. However, it is also plausible that there are differences in the nature and extent of unobserved characteristics of plots owned by males and females in the different types of households. It is, therefore, difficult to draw firm conclusions about whether behavior of any of these types of farm households is collectively rational. Results from the consumption-side tests suggests that households allocate labor inputs taking into account unobserved differences in the plots and the opportunity costs of time of male and female farmers. The production-side evidence is far from being as informative as the consumption tests we conducted above in terms of highlighting complexity in decision-making within West African farm households.

5. Conclusions

Comparisons of the productivity of farm plots controlled by different people within the same Burkinabe households indicate that those households do not maximize profits since marginal products are not equalized across plots. This has been interpreted as evidence that these households do not allocate resources efficiently. However, theoretical models of decision-making by households provide predictions about consumption behavior and we find no evidence that the same farm households can reallocate resources so that at least one member is better off without another being worse off. That is, we do not reject the hypothesis that resource allocations are Pareto efficient. We establish this is not because the consumption-side tests lack power and conclude that tests based on production choices are not well-suited to provide information about efficiency of resource allocations as they are likely to be contaminated by unobserved heterogeneity at the plot level that is correlated with agricultural output and land ownership.

After establishing the implications of the unitary model of the household for consumption choices is not rejected for households headed by one person (a single woman), we document that model is rejected for all other household types. We find no evidence that these more complex households do not behave as if they are "collectively rational" in the sense that their allocations are Pareto efficient. Exploiting insights from the theoretical literature in combination with the richness of household structures in Burkinabe farm households, we establish that in households headed by monogamous couples with no adult sons, decision-making is consistent with there being two players in the allocation of resources. In more complex households - those headed by a monogamous couple with an adult son and those headed by polygynous couples - there are more decision-makers and, once that is taken into account, consumption choices are consistent with the predictions of the Pareto efficient model. These are powerful results since they involve tests based on the shape of the price-responsiveness matrix and are difficult to attribute to contamination from measurement error or unobserved heterogeneity.

The methods used in this paper provide an empirical example of how the combination of theory with survey data from farm households can advance understanding of decision-making in complex households across the globe and, potentially, lay the groundwork for assessing the impact of changes in resource availability, technology and environmental factors on well-being of individuals. To wit, these models are likely to provide valuable insights for mechanisms that will advance the empowerment of women. More broadly, the research presented here suggests that thinking about household behaviors in the context of a model of collective rationality is likely to be profitable for both science and policy.

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Technical Appendix.

Implementing hypothesis tests based on bootstrapped singular value decomposition (SVD)

Since the rank function has the property that for any matrices $\mathbf{M}_1$ and $\mathbf{M}_2$

$$rank(\mathbf{M}_1 + \mathbf{M}_2) \leqslant rank(\mathbf{M}_1) + rank(\mathbf{M}_2),$$

$\mathbf{\Psi}$ will be SR_J, or $\mathbf{\Omega}$ will be of rank J, if and only if:

$$\begin{aligned} rank(\mathbf{\Delta}) &\leqslant rank(\mathbf{\Omega}) + rank(-\mathbf{\Omega}') \\ &\leqslant 2 \times rank(\mathbf{\Omega}) \\ &\leqslant 2 \times J \end{aligned}$$

Consider the hypothesis test regarding the antisymmetric matrix $\mathbf{\Delta}$ (of dimensions $S \times S$)

$$H_o : rank(\mathbf{\Delta}) = \underline{s} \quad \text{, where } \underline{s} \leqslant S$$

versus $\quad H_A : rank(\mathbf{\Delta}) > \underline{s}$

The SVD of $\mathbf{\Delta}$ yields the following factorization (all matrices are $S \times S$)

$$\mathbf{\Delta} = M_1 D M_2^{'}$$

where D (a diagonal matrix) collects the singular values d_s in decreasing order, and M_1 and M_2 are orthogonal matrices. Singular values are unique for a given matrix Δ, but the orthogonal matrices are not (the diagonal matrix of singular values is invariant to pre- and post-multiplication by orthogonal matrices). Partitioning the matrices in the factorization

$$\begin{aligned} M_1 D M_2^{'} &= \begin{bmatrix} M_{1,1} & M_{1,2} \end{bmatrix} \begin{bmatrix} D_1 & 0 \\ 0 & D_2 \end{bmatrix} \begin{bmatrix} M_{2,1}^{'} \\ M_{2,2}^{'} \end{bmatrix} \\ &= M_{1,1} D_1 M_{2,1}^{'} + M_{1,2} D_2 M_{2,2}^{'} \end{aligned}$$

where D_2 is a $(S - \underline{s}) \times (S - \underline{s})$ matrix.

Under the null hypothesis, $D_2 = 0$, (i.e., only $\underline{s}$ of the S singular values are different from zero)which suggests an equivalent description of the null hypothesis

$$H_o : D_2 = 0$$

Alternatively, since the singular values are in decreasing order in the diagonal of D, one can explore the contrast between the following paired hypotheses

$$H_o : rank(\Delta) \leqslant \underline{s} \Leftrightarrow H_o : d_{\underline{s}+1} = 0$$

versus $\quad H_A : rank(\Delta) > \underline{s}$

where $d_{\underline{s}+1}$ is henceforth referred as a *borderline singular value*.

Therefore, our alternative estimation is based on the singular value decomposition of the estimated matrix $\hat{\Delta}$. Let the estimation of such random matrix be denominated $\hat{\Delta}_0$, for which the singular values are $\hat{D}_0$ and $\hat{d}_{0,\underline{s}+1}$ (the rank- $\underline{s}$ borderline singular value). Therefore by generating K bootstrap replications of the estimation of Δ and the computation of the singular values one can obtain draws from the small sample distribution of the variables of interest — in this case, $\left\{\hat{\Delta}_k\right\}_{k=1}^{k=K}$ and $\left\{\hat{d}_{k,\underline{s}+1}\right\}_{k=1}^{k=K}$.

In order to perform inferences, however, one has to draw singular values from the small sample distribution under the null hypothesis. Following Bullock(1995) and Hinkley (1988), the objective is to find Δ^* such that

$$\Delta^* = \underset{rank(F)=\underline{s}}{\operatorname{argmin}} \bar{\Delta} - F$$

where $\bar{\Delta} = \frac{1}{K}\sum_{k=1}^{K}\hat{\Delta}_k$.

Considering the singular value decomposition, $\bar{M} = \overline{M_1}\bar{D}\overline{M_2}'$, the solution to this minimization problem can be approximated by computing

$$\Delta^* = \overline{M_1}D^*\overline{M_2}'$$

where D^* is exactly like $\bar{D}$, except that the $S-\underline{s}$ smallest singular values are substituted by zeros.

Finally, define the antisymmetric matrix drawn under the null hypothesis as

$$\Delta_k^H = \Delta^* + \left[\hat{\Delta}_k - \bar{\Delta}\right]$$

Hence, the bootstrap procedure can produce a sequence of singular value decompositions of Δ_k^H, $\left\{\hat{d}_{k,\underline{s}+1}^H\right\}_{k=1}^{k=K}$, against which one can perform the rank tests described above.

The p-value for the test of the null hypothesis that $rank(\Delta) \leqslant \underline{s}$ is, therefore

$$p\_value_{boot} = \frac{1}{K}\sum_{k=1}^{K} 1\left\{\hat{d}_{k,\underline{s}+1}^H > \hat{d}_{\underline{s}+1}^0\right\}$$

Table 1. Characteristics of farm households

Households in which at least one male or female household head owns at least one productive plot with a formal title or through inheritance

	All farm households [1]	Couples w/ no other adults [2]	Couples w/ other adults, no adult son [3]	Couples w/ adult son(s) [4]	Polygynous [5]
A. Land ownership					
Amount owned (Ha)	4.97	4.14	4.59	5.42	5.57
	(0.18)	(0.35)	(0.44)	(0.45)	(0.26)
# plots	3.37	2.81	3.19	3.33	3.95
	(0.03)	(0.04)	(0.07)	(0.06)	(0.06)
# individual owners	1.14	1.09	1.13	1.12	1.21
	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)
% male head owns	98.9	99.4	98.5	98.3	99.1
Amount owned (Ha)	4.84	4.00	4.46	5.30	5.42
(conditional on owning)	(0.18)	(0.34)	(0.44)	(0.44)	(0.26)
# plots	3.18	2.71	2.99	3.18	3.69
(conditional on any plots)	(0.03)	(0.04)	(0.06)	(0.06)	(0.06)
% female head owns	8.4	7.5	8.3	8.2	9.4
Amount owned (Ha)	1.54	1.72	1.11	1.81	1.47
(conditional on >0 plots)	(0.25)	(0.67)	(0.24)	(0.81)	(0.18)
# plots	1.81	1.33	1.67	1.55	2.35
(conditional on >0 plots)	(0.06)	(0.07)	(0.14)	(0.10)	(0.12)
B. Housheold size and composition					
# of members	8.9	4.8	8.0	8.8	12.9
	(0.08)	(0.05)	(0.12)	(0.13)	(0.16)
# male adults	2.0	1.0	1.7	2.9	2.4
	(0.02)		(0.04)	(0.04)	(0.05)
# female adults	2.4	1.0	2.5	2.2	3.6
	(0.03)		(0.04)	(0.04)	(0.05)
# children	4.5	2.8	3.8	3.7	6.8
	(0.05)	(0.05)	(0.08)	(0.08)	(0.10)
C. Characteristics of heads					
Male head age	48.2	40.1	41.1	57.4	52.5
	(0.22)	(0.38)	(0.46)	(0.38)	(0.37)
% literate male head	24.7	27.1	27.0	22.4	23.0
% Muslim male head	60.3	58.7	55.9	53.8	68.9
Sample	*4,664*	*1,228*	*884*	*1,058*	*1,494*

Note: Standard-errors in parentheses.

Table 2. Land ownership and yields by gender of owner of land

Plot-level statistics

Only households in which either male or female head owns land

	Owned by female head [1]	Owned by male head [2]	Difference female-male [3]	Difference if both own land [4]	Difference if both own land and farm same crop [5]
A. ln(yield per hectare, CFAF/Ha) in owned plots					
1. No controls	10.17	9.96	0.21		
	(0.06)	(0.02)	(0.07)		
2. Include HH FE			0.11		
			(0.08)		
3. add plot area and crop FE			-0.25		
			(0.07)		
4. add plot characteristics			-0.25	-0.32	-0.29
			(0.07)	(0.09)	(0.12)
Number of plots	*1,069*	*15,253*	*16,322*	*2,242*	*380*
Number of households			*4,945*	*527*	*128*
B. ln(yield per hectare, CFAF/Ha) in plots inherited or owned with title					
1. No controls	10.12	9.96	0.16		
	(0.09)	(0.02)	(0.09)		
2. Include HH FE			0.07		
			(0.10)		
3. add plot area and crop FE			-0.27		
			(0.09)		
4. add plot characteristics			-0.27	-0.36	-0.28
			(0.09)	(0.11)	(0.13)
Number of plots	*694*	*14,339*	*15,033*	*1,454*	*328*
Number of households			*4,664*	*341*	*107*
C. Plot size, crop choice and plot characteristics					
1. Plot size (Ha)	0.79	1.56	-0.77	-0.74	-1.06
	(0.11)	(0.06)	(0.11)	(0.12)	(0.60)
2. Crop choice					
% Monoculture	77.5	79.0	-1.4	8.5	
% Sorghum or millet	21.2	49.2	-28.0	-48.7	
% Peanuts	47.1	11.1	35.9	46.4	
3. Plot characteristics					
% Flat topography	64.4	57.7	6.7	1.0	-4.7
% Sandy soil	52.5	49.0	3.5	3.7	0.0
% Near homestead	36.8	35.8	0.9	3.2	-1.9
4. % plots fallowed	2.8	3.3	-0.6	-0.8	
5. % Inherited or has title	64.9	94.0	-29.1	-30.9	-11.9
Number of plots	*1,069*	*15,253*	*16,322*	*2,242*	*380*

Note: Standard-errors in parentheses clustered at household level.

Table 3. Budget share demand function, land owned by males and females, and price-effects

Household-level statistics

Households in which either male or female head owns inherited or titled land

	Cereal	Meat + veges	Other food	HH & personal gds	Housing	Transport	Recreation
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
A. Budget shares							
Budget share	25.4	15.7	14.6	19.9	4.9	8.2	11.3
	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
B. Impacts of individual land ownership over consumption							
(1) if female owns land	-1.16	-0.67	-1.20	1.16	0.11	0.72	1.04
[p value]	[0.28]	[0.40]	[0.06]	[0.25]	[0.89]	[0.53]	[0.16]
Amt owned by female (quartic root)	2.49	0.85	0.56	-1.55	-0.22	-0.59	-1.54
[p value]	[0.02]	[0.28]	[0.39]	[0.12]	[0.78]	[0.63]	[0.04]
(1) if male owns land	1.06	0.00	1.42	0.95	-0.27	-2.47	-0.69
[p value]	[0.33]	[0.99]	[0.13]	[0.35]	[0.72]	[0.01]	[0.53]
Amt owned by male (quartic root)	0.04	1.10	-1.37	-0.18	-0.69	2.09	-1.00
[p value]	[0.91]	[0.00]	[0.00]	[0.69]	[0.02]	[0.00]	[0.00]
C. Joint tests of significance							
Female own land & amount owned	11.83	1.32	8.50	3.08	0.19	0.52	5.49
[p value]	[0.00]	[0.52]	[0.01]	[0.22]	[0.91]	[0.77]	[0.06]
Male own land & amount owned	1.21	19.90	18.13	0.95	8.02	34.45	14.55
[p value]	[0.55]	[0.00]	[0.00]	[0.62]	[0.02]	[0.00]	[0.00]
All land ownership covariates	12.03	20.22	24.38	7.64	8.48	34.80	19.20
[p value]	[0.02]	[0.00]	[0.00]	[0.11]	[0.08]	[0.00]	[0.00]
D. System-wide tests of unitary model							
1. Significance of land owned effects (p value)							
Female ownership	[0.02]						
Male ownership	[0.00]						
Joint (male & female)	[0.00]						
2. Symmerty of 21 cross-price effects in pseudo-Slutsky matrix							
% p-values <=0.05	52.4						
% p-values <=0.10	66.7						
joint test (p value)	[0.00]						

Note: Sample is 4,664 households. (Standard errors) below budget shares and [p values for significance] below regression coefficient estimates and joint test statistics.

Table 4. Testing implications of unitary model

Significance of distribution factors and Slutsky symmetry in budget share demand system with 7 sub-aggregates

	I. HHs with single head	II. HHs headed by one male and at least one female				
			HHs headed by monogamous couple			
	Single female, no other adult	All	Couple, no other adults	Couple + other adults, no son	Couple + ≥1 adult son	Polygynous HHs
	[1]	[2]	[3]	[4]	[5]	[6]
A. Tests of significance of land ownership distribution factors (p values)						
Female ownership	[0.09]	[0.02]	[0.24]	[0.01]	[0.01]	[0.00]
Male ownership		[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Joint (male & female)		[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
B. Tests for symmetry of Pseudo-Slutsky matrix						
Pairwise tests (21)						
% pvalues<=0.05	0.0	52.4	23.8	23.8	42.9	28.6
% pvalues<=0.10	0.0	66.7	38.1	23.8	47.6	33.3
Joint tests (p values)	[0.22]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Number of households	*555*	*4,664*	*1,228*	*884*	*1,058*	*1,494*

Notes: Land ownership measures are gender-specific amount of land owned with title plus individual-specific amount of land inherited. Controls include indicator (1) for land ownership and area owned (quartic root) conditional on ownership, separately for males and females. All test statistics based on robust estimates of variance-covariance matrices taking into account clustering at the village level.

Table 5. Testing implications of Pareto efficiency

Tests for equality of ratios of distribution factor effects and rank of Pseudo-Slutsky matrix in budget share demand system with 7 sub-aggregates

	HHs headed by man + >1 wives	HHs headed by monogamous couple			Polygynous
		Couple, no other adults	Couple + other adults, no son	Couple + >1 adult son	HHs
	[1]	[2]	[3]	[4]	[5]
A. Equality of ratios of distribution factor effects					
1. Equality of all ratios X^2	13.69	7.59	14.20	17.49	15.93
[p value]	[0.75]	[0.98]	[0.72]	[0.49]	[0.60]
2. Pair-wise tests of equality					
2.1 Distribution factors: All					
% pvalues<=0.05	2.4	0.0	4.8	7.1	11.9
% pvalues<=0.10	14.3	0.0	9.5	14.3	16.7
2.2 Distribution factors: Amount of land owned					
% pvalues<=0.05	4.8	0.0	9.5	14.3	19.0
% pvalues<=0.10	28.6	0.0	19.0	28.6	19.0
2.3 Distribution factors: (1) if own land					
% pvalues<=0.05	0.0	0.0	0.0	0.0	4.8
% pvalues<=0.10	0.0	0.0	0.0	0.0	14.3
B. Tests based on rank of Pseudo-Slutsky matrix					
1. Rank 2					
Browning-Chiappori SR1 X^2	29.32	6.31	7.30	19.24	27.17
[p value]	[0.00]	[0.79]	[0.70]	[0.04]	[0.00]
2. Rank 4					
Dauphin-Fortin-Lacroix X^2	0.52	-	-	0.49	2.14
[p value]	[0.92]			[0.92]	[0.54]
Bootstraped-SVD					
[p value]	[0.74]	-	-	[0.99]	[0.15]
Number of households	*4,664*	*1,228*	*884*	*1,058*	*1,494*

Notes: Land ownership measures are gender-specific amount of land owned with title plus individual-specific amount of land inherited. Controls include indicator (1) for land ownership and area owned (quartic root) conditional on ownership, separately for males and females. All test statistics based on robust estimates of variance-covariance matrices taking into account clustering at the village level.

Table 6. Differences in farm outputs and inputs by gender of land owner (female-male)

By household type, plot-level statistics

		Monogamous couples			
	All HHs	Couple, no other adults	Couple + other adults, no son	Couple + >=1 adult son	Polygynous HHs
	[1]	[2]	[4]	[3]	[5]
A. ln(yield/Ha)					
1. Plots owned with title or by inheritance	-0.27	-0.14	-0.23	-0.39	-0.30
	(0.09)	(0.21)	(0.20)	(0.19)	(0.13)
2. All owned plots	-0.25	-0.19	-0.24	-0.36	-0.25
	(0.07)	(0.17)	(0.15)	(0.15)	(0.10)
B. Inputs on plots owned with title or by inheritance					
1. ln(labor days/Ha)	-0.30	-0.17	-0.26	-0.15	-0.41
	(0.05)	(0.09)	(0.11)	(0.09)	(0.07)
2. (1) if use chemical fertilizer	-0.09	0.01	-0.03	-0.03	-0.17
	(0.03)	(0.04)	(0.06)	(0.06)	(0.05)
3. (1) if use manure	-0.13	-0.08	-0.05	-0.02	-0.20
	(0.03)	(0.06)	(0.06)	(0.06)	(0.05)
C. Allocation of labor					
1. ln(yield/labor day)	0.03	0.03	0.03	-0.24	0.11
	(0.10)	(0.20)	(0.24)	(0.20)	(0.15)
2. % of total labor allocated to	0.47	1.79	-1.79	2.05	0.22
plot preparation	(0.96)	(1.75)	(1.63)	(1.73)	(1.63)
D. Sample sizes					
1. Plots owned with title or by inheritance					
plots	*15,030*	*3,343*	*2,669*	*3,352*	*5,666*
households	*4,664*	*1,228*	*884*	*1,058*	*1,494*
2. All owned plots					
plots	*16,322*	*3,636*	*2,860*	*3,597*	*6,229*
households	*4,945*	*1,318*	*933*	*1,110*	*1,584*

Notes: Standard-errors in parentheses clustered at household level. Samples restricted to households with male and female heads who own plots that generated income and used own or hired labor. Controls include household fixed effects, main crop fixed effects and plot characteristics (indicator variables for plot area, topography, location, soil type and monoculture).

Appendix Table 1. Consumption side tests with broader definition of land ownership

Gender-specific distribution factors are whether land is owned and amount of land owned

	HHs headed by man + ≥1 wives	HHs headed by monogamous couple: Couple, no other adults	Couple + other adults, no son	Couple + ≥1 adult son	Polygynous HHs
	[1]	[2]	[3]	[4]	[5]
A. Testing unitary model					
1. Tests of significance of land ownership distribution factors (p values)					
Female ownership	0.007	0.114	0.063	0.005	0.000
Male ownership	0.000	0.000	0.000	0.000	0.000
Joint (male & female)	0.000	0.000	0.000	0.000	0.000
2. Tests for symmetry of Pseudo-Slutsky matrix					
Pairwise tests of equality					
% pvalues<=0.05	52.4	28.6	23.8	42.9	33.3
% pvalues<=0.10	71.4	38.1	28.6	47.6	33.3
Joint tests (p value)	0.000	0.000	0.000	0.000	0.000
B. Equality of ratios of distribution factor effects					
1. Equality of all ratios X^2	14.05	7.59	17.35	18.30	19.66
[p value]	[0.7261]	[0.9842]	[0.4992]	[0.4360]	[0.3524]
2. Pair-wise tests of equality					
2.1 Distribution factors: All					
% pvalues<=0.05	9.5	0.0	0.0	9.5	11.9
% pvalues<=0.10	14.3	0.0	11.9	19.0	26.2
2.2 Distribution factors: Amount of land owned					
% pvalues<=0.05	19.0	0.0	0.0	19.0	19.0
% pvalues<=0.10	28.6	0.0	14.3	33.3	33.3
2.3 Distribution factors: (1) if own land					
% pvalues<=0.05	0.0	0.0	0.0	0.0	4.8
% pvalues<=0.10	0.0	0.0	9.5	4.8	19.0
C. Tests based on rank of Pseudo-Slutsky matrix					
1. Rank 2					
Browning-Chiappori SR1 X^2	30.19	7.49	10.19	18.50	21.94
[p value]	[0.0008]	[0.6785]	[0.4243]	[0.0472]	[0.0154]
2. Rank 4					
Dauphin-Fortin-Lacroix X^2	0.73	-	-	0.52	1.58
[p value]	[0.8657]			[0.9139]	[0.6632]
Bootstraped-SVD					
[p value]	[0.938]	-	-	[0.976]	[0.376]
Sample sizes	*4,971*	*1,324*	*941*	*1,118*	*1,586*

Appendix Table 2a. Consumption-side tests with 9 sub-aggregate demand system

	HHs headed by man + ≥1 wives	HHs headed by monogamous couple			Polygynous
		Couple, no other adults	Couple + other adults, no son	Couple + ≥1 adult son	HHs
	[1]	[2]	[3]	[4]	[5]
<u>A. Testing unitary model</u>					
1. Tests of significance of land ownership distribution factors (p values)					
Female ownership	0.001	0.001	0.000	0.000	0.000
Male ownership	0.000	0.000	0.000	0.000	0.000
Joint (male & female)	0.000	0.000	0.000	0.000	0.000
2. Tests for symmetry of Pseudo-Slutsky matrix					
Pairwise tests of equality (36)					
% pvalues<=0.05	50.0	25.0	25.0	36.1	30.6
% pvalues<=0.10	63.9	41.7	36.1	44.4	47.2
Joint test [p value]	0.000	0.000	0.000	0.000	0.000
<u>B. Equality of ratios of distribution factor effects</u>					
1. Equality of all ratios X^2	25.00	17.02	21.10	35.10	22.58
[p value]	[0.5189]	[0.9085]	[0.7369]	[0.1095]	[0.6569]
2. Pair-wise tests of equality					
2.1 Distribution factors: All					
% pvalues<=0.05	0.0	1.4	5.6	16.7	9.7
% pvalues<=0.10	15.3	2.8	9.7	22.2	13.9
2.2 Distribution factors: Amount of land owned					
% pvalues<=0.05	0.0	2.8	8.3	33.3	11.1
% pvalues<=0.10	25.0	5.6	11.1	41.7	13.9
2.3 Distribution factors: (1) if own land					
% pvalues<=0.05	0.0	0.0	2.8	0.0	8.3
% pvalues<=0.10	5.6	0.0	8.3	2.8	13.9
<u>C. Tests based on rank of Pseudo-Slutsky matrix</u>					
1. Rank 2					
Browning-Chiappori SR1 X^2	45.12	25.72	13.10	26.55	68.27
[p value]	[0.0017]	[0.2172]	[0.9052]	[0.1862]	[0.000]
2. Rank 4					
Dauphin-Fortin-Lacroix X^2	1.53	-	-	4.27	2.40
[p value]	[0.9988]			[0.9346]	[0.9922]
Bootstraped-SVD					
[p value]	[0.044]	-	-	[.086]	[0.030]
Sample sizes	4689	1234	892	1066	1496

<u>Notes</u>: Inherited and/or titled land are used in computing individual holdings. System with 9 goods.

Appendix Table 2b. Consumption-side tests with 8 sub-aggregate demand system

	HHs headed by man + ≥1 wives	HHs headed by monogamous couple			Polygynous
		Couple, no other adults	Couple + other adults, no son	Couple + ≥1 adult son	HHs
	[1]	[2]	[3]	[4]	[5]
A. Testing unitary model					
1. Tests of significance of land ownership distribution factors (p values)					
Female ownership	0.000	0.015	0.000	0.007	0.000
Male ownership	0.000	0.000	0.000	0.000	0.001
Joint (male & female)	0.000	0.000	0.000	0.000	0.000
2. Tests for symmetry of Pseudo-Slutsky matrix					
Pairwise tests of equality (28)					
% pvalues<=0.05	53.6	32.1	21.4	25.0	32.1
% pvalues<=0.10	64.3	35.7	25.0	32.1	39.3
Joint test [p value]	0.000	0.000	0.000	0.000	0.000
B. Equality of ratios of distribution factor effects					
1. Equality of all ratios X^2	23.73	10.42	19.88	20.16	20.88
[p value]	[0.3616]	[0.9821]	[0.5905]	[0.5730]	[0.5281]
2. Pair-wise tests of equality					
2.1 Distribution factors: All					
% pvalues<=0.05	0.0	0.0	7.1	10.7	8.9
% pvalues<=0.10	16.1	0.0	10.7	14.3	16.1
2.2 Distribution factors: Amount of land owned					
% pvalues<=0.05	0.0	0.0	10.7	21.4	10.7
% pvalues<=0.10	25.0	0.0	14.3	25.0	17.9
2.3 Distribution factors: (1) if own land					
% pvalues<=0.05	0.0	0.0	3.6	0.0	7.1
% pvalues<=0.10	7.1	0.0	7.1	3.6	14.3
C. Tests based on rank of Pseudo-Slutsky matrix					
1. Rank 2					
Browning-Chiappori SR1 X^2	34.50	18.52	10.04	16.87	19.36
[p value]	[0.0029]	[0.2361]	[0.8170]	[0.3265]	[0.1979]
2. Rank 4					
Dauphin-Fortin-Lacroix X^2	2.12	-	-	2.63	2.49
[p value]	[0.9084]			[0.8540]	[0.8700]
Bootstraped-SVD					
[p value]	[0.646]	-	-	[0.562]	[0.106]
Sample sizes	4689	1234	892	1066	1496

Notes: Inherited and/or titled land are used in computing individual holdings. System with 9 goods.

Appendix Table 2c. Consumption-side tests with 6 sub-aggregate demand system

	HHs headed by man + ≥1 wives	HHs headed by monogamous couple			Polygynous
		Couple, no other adults	Couple + other adults, no son	Couple + ≥1 adult son	HHs
	[1]	[2]	[3]	[4]	[5]
A. Testing unitary model					
1. Tests of significance of land ownership distribution factors (p values)					
Female ownership	0.014	0.238	0.020	0.019	0.000
Male ownership	0.000	0.001	0.000	0.000	0.020
Joint (male & female)	0.000	0.003	0.000	0.000	0.000
2. Tests for symmetry of Pseudo-Slutsky matrix					
Pairwise tests of equality (15)					
% pvalues<=0.05	60.0	53.3	26.7	53.3	40.0
% pvalues<=0.10	60.0	60.0	33.3	53.3	53.3
Joint test [p value]	0.000	0.000	0.000	0.000	0.000
B. Equality of ratios of distribution factor effects					
1. Equality of all ratios X^2	11.24	5.00	10.18	13.89	2.14
[p value]	[0.6671]	[0.9058]	[0.7486]	[0.4576]	[0.9520]
2. Pair-wise tests of equality					
2.1 Distribution factors: All					
% pvalues<=0.05	0.0	0.0	3.3	6.7	0.0
% pvalues<=0.10	6.7	0.0	10.0	20.0	6.7
2.2 Distribution factors: Amount of land owned					
% pvalues<=0.05	0.0	0.0	6.7	13.3	0.0
% pvalues<=0.10	13.3	0.0	20.0	33.3	13.3
2.3 Distribution factors: (1) if own land					
% pvalues<=0.05	0.0	0.0	0.0	0.0	0.0
% pvalues<=0.10	0.0	0.0	0.0	6.7	0.0
C. Tests based on rank of Pseudo-Slutsky matrix					
1. Rank 2					
Browning-Chiappori SR1 X^2	16.15	6.95	2.18	11.57	23.80
[p value]	[0.0130]	[0.3258]	[0.9028]	[0.0724]	[0.001]
2. Rank 4					
Dauphin-Fortin-Lacroix X^2	0.86	-	-	0.25	0.59
[p value]	[0.3529]			[0.6184]	[0.4418]
Bootstraped-SVD					
[p value]	[0.320]	-	-	[0.630]	[0.456]
Sample sizes	4689	1234	892	1066	1496

Notes: Inherited and/or titled land are used in computing individual holdings. System with 9 goods.

Appendix Table 2d. Consumption-side tests with 5 sub-aggregate demand system

	HHs headed by man + >1 wives	HHs headed by monogamous couple			Polygynous
		Couple, no other adults	Couple + other adults, no son	Couple + >1 adult son	HHs
	[1]	[2]	[3]	[4]	[5]
A. Testing unitary model					
1. Tests of significance of land ownership distribution factors (p values)					
Female ownership	0.007	0.204	0.045	0.054	0.000
Male ownership	0.000	0.003	0.005	0.000	0.008
Joint (male & female)	0.000	0.004	0.008	0.000	0.000
2. Tests for symmetry of Pseudo-Slutsky matrix					
Pairwise tests of equality (10)					
% pvalues<=0.05	70.0	40.0	40.0	60.0	60.0
% pvalues<=0.10	70.0	60.0	50.0	70.0	70.0
Joint test [p value]	0.000	0.000	0.000	0.000	0.000
B. Equality of ratios of distribution factor effects					
1. Equality of all ratios X^2	10.86	4.57	6.86	10.18	6.08
[p value]	[0.3689]	[0.9180]	[0.7385]	[0.4252]	[0.8088]
2. Pair-wise tests of equality					
2.1 Distribution factors: All					
% pvalues<=0.05	0.0	0.0	0.0	10.0	0.0
% pvalues<=0.10	15.0	0.0	10.0	25.0	10.0
2.2 Distribution factors: Amount of land owned					
% pvalues<=0.05	0.0	0.0	0.0	20.0	0.0
% pvalues<=0.10	30.0	0.0	20.0	40.0	20.0
2.3 Distribution factors: (1) if own land					
% pvalues<=0.05	0.0	0.0	0.0	0.0	0.0
% pvalues<=0.10	0.0	0.0	0.0	10.0	0.0
C. Tests based on rank of Pseudo-Slutsky matrix					
1. Rank 2					
Browning-Chiappori SR1 X^2	16.88	1.36	1.34	9.92	15.81
[p value]	[0.0007]	[0.7158]	[0.7189]	[0.0192]	[0.0012]
2. Rank 4					
Dauphin-Fortin-Lacroix X^2	ND	-	-	ND	ND
[p value]					
Bootstraped-SVD					
[p value]	ND	-	-	ND	ND
Sample sizes	4689	1234	892	1066	1496

Notes: Inherited and/or titled land are used in computing individual holdings. System with 5 goods.