Household Attitudes to Price Risk with Multiple Commodities: Evidence from Rural Ethiopia*

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FIRST COMPLETE DRAFT – COMMENTS GREATLY APPRECIATED

Abstract

We study household attitude with respect to price risk. Whereas price risk aversion has so far been studied only for single staple commodities, we expand the analytical framework so as to derive the full matrix of own- and cross-price risk aversion coefficients. This imposes strong restrictions on the matrix of price risk aversion coefficients, which has a complex relation to the household's Slutsky substitution matrix. Using a panel of rural Ethiopian households, we test whether the restrictions implied by the theory hold empirically, as well as whether distinct patterns of price risk aversion emerge. We ultimately find strong empirical support for the theory and widespread support for the hypothesis that households are on average risk-averse over own- and cross-price fluctuations.

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"[*T*]*he tendency of these measures to focus directly or indirectly on price, which, as stated, is the greatest source of uncertainty, has led economists to regard the management of prices as being of unique importance. And they have far more frequently related such management to the maximization of profits than to the minimization of risks. That is unfortunate, for the development of the modern business enterprise can be understood only as a comprehensive effort to reduce risk.*"

– John Kenneth Galbraith, *The Affluent Society* (1958).

1. Introduction

The effects of price risk on the behavior of competitive firms have been well-explored in the theoretical literature (Baron, 1970; Sandmo, 1971). Yet, when it comes to individuals and households, economists have largely ignored the effects of price risk, focusing instead on income risk. To be sure, the analysis of commodity price risk has been extended to agricultural households both theoretically (Newbery and Stiglitz, 1981; Finkelshtain and Chalfant, 1991) and empirically (Barrett, 1996), but these analyses have only focused on one staple good. In this paper, we develop and test the theory as it applies to the more general – and realistic – case of multiple commodities.

We use the general framework of agricultural household models (Singh et al., 1986) because it allows for households to be net buyers, net sellers, or autarkic with respect to goods, relaxing the stronger assumptions of the pure theories of the consumer or firm. Because a household's indirect utility function is defined over the *vector* of prices for the commodities it produces or consumes and the household's income, in theory it is possible to derive and estimate a matrix of price risk aversion coefficients, i.e., a matrix that reflects how price risk premia with respect to one good change with respect to changes in the variance of any other good. Such a matrix yields the usual (own-) price risk aversion coefficients for each of the commodities observed by the econometrician (the diagonal elements), but also the cross-price risk aversion coefficients (the off-diagonal elements). These off-diagonals have thus far been overlooked in the literature, as best as we can tell, although they have an intuitive interpretation and may be important to understanding behavior with respect to price risk.

Based on an extension of Barrett's (1996) work to the multiple commodity case, we derive the matrix of price risk aversion as well as its properties and establish its formal relationship with the Slutsky matrix in section 2. In section 3, we discuss the data and present some descriptive statistics. We then develop an empirical framework to estimate the price risk aversion coefficients in section 4. In section 5 we then estimate several marketable surplus equations, use their results to estimate own- and cross-price risk aversion coefficients, use these coefficients to construct the matrix of price risk aversion coefficients, and, finally, conduct hypothesis tests of the structure implied by the theory, progressively imposing more structure as a way of conducting robustness checks. We conclude by discussing the policy and research implications of our findings in section 6.

2. Theoretical Framework

This section develops a simple unitary agricultural household model (AHM) and derives the household's matrix of own- and cross-price risk aversion coefficients for the multiple commodity case. We then derive some key properties of this matrix, which yield the implications that we test in section 5.

2.1 Agricultural Household Model

The derivations in this section closely followed those in Barrett (1996), which followed Finkelshtain and Chalfant's (1991) extension to the AHM of the Sandmo-Baron framework for analyzing firm behavior under price uncertainty. Consider a representative agricultural household whose preferences are represented by a von Neumann-Morgenstern utility function $U(\cdot)$ defined over consumption of a vector $c_o = (c_{o1}, c_{o2}, ..., c_{oK})$ of all goods whose consumption and/or production is observed by the econometrician; a composite c_u of all goods whose consumption and/or production is unobserved by the econometrician;[5] and leisure ℓ. The function $U(\cdot)$ is quasiconcave but concave in each of its arguments, with the Inada condition $\frac{\partial U}{\partial x}|_{x=0} = \infty$ with respect to each argument *x*.

All *K* goods observed and the good unobserved by the econometrician can, in principle, be produced and/or consumed by the household.[6] The household has an endowment E^L of time and an endowment E^A of land. The production of each of the *K* observed commodities is denoted by

$$F_{oi}(L_{oi}, A_{oi}),\ i \in \{1,...,K\}, \quad (1)$$

[5] In order simplify the exposition, we refer to the vector of commodities whose consumption and/or production is unobserved by the econometrician as "the unobserved good" in what follows.

[6] For example, it is quite common in developing countries for rural household to grow a staple crop (e.g., barley, wheat, maize, etc.) and many other non-staple crops (e.g., cooking oil, coffee, soap, onions, etc.) For a specific crop, it is also common for some households to be net buyers of it, for some households to be autarkic with respect to it, and for some households to be net sellers of it. Finally, households may switch from one category – net buyer, autarkic, or net seller – to another from one period to the next.

where L_{oi} denotes the amount of labor used in producing observed commodity *i* and A_{oi} denotes the amount of cultivable land used in producing observed commodity *i*. The production of the unobserved good is denoted by

$$F_u(L_u, A_u), \qquad (2)$$

where L_u and A_u denote the amount of labor and cultivable land, respectively, used in producing the unobserved commodity. Both F_{oi} and F_u are strictly increasing but weakly concave in each argument.

Agricultural labor is a function of household labor on the farm L^f and of hired labor L^h, but note that those are imperfect substitutes given that monitoring of hired workers may be imperfect, with the usual moral hazard consequence (Feder, 1985; Frisvold, 1994). The household can also sell a quantity L^m of labor on the market at parametric wage rate *w*. Furthermore, the household's endowment of cultivable land E^A is a fixed factor of production, and the markets for land and credit are both missing.

The household's time constraint is such that $L^m + \ell + L_i^f + L_u^f \leq E^L$, where L_i^f is the amount of household labor devoted to production of observed commodity *i* and L_u^f is the amount of household labor devoted to production of the unobserved good. Finally, let *I* denote the household's unearned income, i.e., income from transfers or remittances.

In what follows, we consider a two-period model. All product prices are unknown when labor allocation decisions are made, but post-harvest prices are revealed before consumption decisions are made. The household's maximization problem is thus

$$\max_{\{L_i^h, L_i^f, L_u^h, L_u^f, \ell\}} E \max_{\{c_o, c_u\}} U(c_o, c_u, \ell) \tag{3}$$

subject to

$$p_o c_o + p_u c_u \leq Y^*, \tag{4}$$

$$Y^* \equiv w[L^m - \sum_{oi} L_{oi}^h - L_u^h] + \sum_i p_{oi} F_{oi}(L_{oi}, A_{oi}) + p_u F_u(L_u, A_u) + I \quad \forall i, \tag{5}$$

$$L_{oi} \equiv h(L_{oi}^h) + L_{oi}^f \quad \forall i, \tag{6}$$

$$L_u \equiv h(L_u^h) + L_u^f, \tag{7}$$

$$L^m + \ell + \sum_i L_{oi}^f + L_u^f \leq E^L, \tag{8}$$

$$h(L_{oi}^h) \in [0, L_{oi}^h], \text{ and} \tag{9}$$

$$h(L_u^h) \in [0, L_u^h]. \tag{10}$$

Given that the household's utility function is strictly increasing, preferences are locally non-satiated and, as a result, the constraints in equations (4) and (8) – the budget and labor resource constraints, respectively – are binding. The household allocates labor conditional on its expectations regarding its *ex post* optimal choices of c_o, c_u, and ℓ.

By Epstein's (1975) duality result, we can use the household's variable indirect utility function $V(\cdot)$, which is homogeneous of degree zero in prices and income, i.e., the measurement unit chosen to measure prices and income do not matter. Thus, we can set the price of the unobserved commodity p_u as numéraire, so that $p_i = p_{oi} / p_u$ and $y = Y^* / p_u$. Finally, assume that the household is (income) risk-averse, in the sense that $\frac{\partial^2 V}{\partial y^2} = V_{yy} < 0$.[7]

Using the household's (variable) indirect utility function, we can rewrite the household's maximization problem as

$$\max_{\{L_i^h, L_i^f, L_u^h, L_u^f, \ell\}} EV(\ell, p, y) \tag{11}$$

subject to

$$Y = w[E^L - \ell - \sum_i L_{oi}^f - \sum_i L_{oi}^h - L_u^f - L_u^h] +$$

[7] In a slight abuse of notation, we use subscripts to denote the partial derivatives of the function *V*(·).

$$\sum_i p_i F_{oi}(L_{oi}, A_{oi}) + F_u(L_u, A_u) + I \ . \tag{12}$$

The first-order necessary conditions (FONCs) for this problem are then:

$$\text{with respect to } L_{oi}^h: \ E\left\{V_y\left(p_i \frac{\partial F_{oi}}{\partial L_{oi}^h} - w\right)\right\} \leq 0 \ \ (=0 \text{ if } L_{oi}^h > 0), \tag{13}$$

$$\text{with respect to } L_{oi}^f: \ E\left\{V_y\left(p_i \frac{\partial F_{oi}}{\partial L_{oi}^f} - w\right)\right\} \leq 0 \ \ (=0 \text{ if } L_{oi}^f > 0), \text{ and} \tag{14}$$

$$\text{with respect to } \ell: \ E\{V_\ell - V_y w\} \leq 0 \ \ (=0 \text{ if } \ell > 0). \tag{15}$$

Intuitively speaking, equations (13) and (14) mean that the household will set the expected marginal utility of its marginal product of hired farm labor and of its own labor applied to the farm equal to the parametric wage rate, and equation (15) means that the household will set its expected marginal utility of leisure equal to the marginal utility of the income derived from working on the market. Thus, this set of FONCs is in itself similar what is usually derived from the basic agricultural household model (see Bardhan and Udry, 1999 for an introductory treatment).

This framework was used by Barrett (1996) to explain the existence of the inverse farm size–productivity relationship as a result of staple food crop price risk. We now extend this framework to the case of multiple goods with stochastic prices. As such, the next subsection shows how to derive the household's matrix of own- and cross-price risk aversion coefficients.

2.2 Price Risk Aversion over Multiple Commodities

Let $V(\underline{p}, y)$ denote the household's indirect utility function, which has the usual properties. The vector $\underline{p} = (p_1,..., p_K)$ is the vector of commodity prices faced by the household over the observed commodities, and the scalar y denotes household income. Let p_i denote the price of commodity *i* and p_j denote the price of commodity *j*, without any loss of generality. We know from Barrett (1996) that

$$sign[Cov(V_y, p_i)] = sign(V_{yp_i}), \tag{16}$$

and that, by Roy's identity, we have that

$$V_y = \frac{V_{p_i}}{M_i} = \frac{V_{p_j}}{M_j}. \tag{17}$$

Additionally, note that

$$V_{yp_j} = \frac{V_{p_i p_j}}{M_i} - \frac{V_{p_i}}{M_i^2}\frac{\partial M_i}{\partial p_j} = \frac{1}{M_i}\left\{V_{p_i p_j} - \frac{\partial M_i}{\partial p_j}V_y\right\}. \tag{18}$$

From Barrett (1996), we also have that

$$M_i = \frac{V_{p_i}}{V_y} \Leftrightarrow V_{p_i} = M_i V_y, \tag{19}$$

which implies that

$$V_{p_i p_j} = M_i V_{yp_j} + V_y \frac{\partial M_i}{\partial p_j}, \tag{20}$$

which, in turn, implies that

$$V_{p_i y} = M_i V_{yy} + V_y \frac{\partial M_i}{\partial y} = V_{yp_i}, \tag{21}$$

where the last equation is simply the result of applying Young's theorem. Replacing V_{yp_i} by equation (21) in equation (20) yields

$$V_{p_i p_j} = M_i \left\{ M_j V_{yy} + V_y \frac{\partial M_j}{\partial y} \right\} + V_y \frac{\partial M_i}{\partial p_j}. \tag{22}$$

Then, we have that

$$V_{p_i p_j} = M_i M_j V_{yy} + M_i V_y \frac{\partial M_j}{\partial y} + V_y \frac{\partial Mi}{\partial p_j}. \tag{23}$$

Multiplying the first term by $V_y y / V_y y$ yields (24)

$$V_{p_i p_j} = -\frac{M_i M_j R V_y}{y} + M_i V_y \frac{\partial M_j}{\partial y} + V_y \frac{\partial Mi}{\partial p_j}, \tag{25}$$

where R is the household's Arrow-Pratt coefficient of relative risk aversion. Multiplying the second term by $M_j y / M_j y$ and the third term by $M_i p_j / M_i p_j$ yields

$$V_{p_i p_j} = -\frac{M_i M_j R V_y}{y} + M_i V_y \eta_j \frac{M_j}{y} + V_y \varepsilon_{ij} \frac{M_i}{p_j}, \tag{26}$$

Where η_j is the income-elasticity of the marketable surplus of commodity *j* and ε_{ij} is the elasticity of commodity *i* with respect to the price of commodity *j*. Equation (26) is thus equivalent to

$$V_{p_i p_j} = M_i V_y \left[-\frac{M_j R}{y} + \eta_j \frac{M_j}{y} + \varepsilon_{ij} \frac{1}{p_j} \right]. \tag{27}$$

But then, multiplying the first two terms in the bracketed expression by p_j / p_j yields

$$V_{p_i p_j} = \frac{M_i V_y}{p_j} \left[-R\beta_j + \eta_j \beta_j + \varepsilon_{ij} \right], \tag{28}$$

in which β_j is the budget share of commodity *j*. When simplified, equation (28) is such that

$$V_{p_i p_j} = \frac{M_i V_y}{p_j}\left[\beta_j(\eta_j - R) + \varepsilon_{ij}\right]. \tag{29}$$

But then, note that we have a strong testable implication, since applying Young's theorem again yields the following equation:

$$V_{p_i p_j} = \frac{M_i V_y}{p_j}\left[\beta_j(\eta_j - R) + \varepsilon_{ij}\right] = \frac{M_j V_y}{p_i}\left[\beta_i(\eta_i - R) + \varepsilon_{ji}\right] = V_{p_j p_i}. \tag{30}$$

In other words, the V_{pp} matrix is symmetric. Finally, note that the V_{pp} matrix is such that

$$V_{pp} = \begin{bmatrix} V_{p_1 p_1} & V_{p_1 p_2} & \cdots & V_{p_1 p_K} \\ V_{p_2 p_1} & V_{p_2 p_2} & \cdots & V_{p_2 p_K} \\ \vdots & \vdots & \ddots & \vdots \\ V_{p_K p_1} & V_{p_K p_2} & \cdots & V_{p_K p_K} \end{bmatrix}, \tag{31}$$

and that from the V_{pp} matrix, we can derive matrix **A** of price risk aversion coefficients:

$$\mathbf{A} = -\frac{1}{V_y}\cdot V_{pp} = -\frac{1}{V_y}\cdot\begin{bmatrix} V_{p_1p_1} & V_{p_1p_2} & \cdots & V_{p_1p_K} \\ V_{p_2p_1} & V_{p_2p_2} & \cdots & V_{p_2p_K} \\ \vdots & \vdots & \ddots & \vdots \\ V_{p_Kp_1} & V_{p_Kp_2} & \cdots & V_{p_Kp_K} \end{bmatrix}$$

$$= \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1K} \\ A_{21} & A_{22} & \cdots & A_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ A_{K1} & A_{K2} & \cdots & A_{KK} \end{bmatrix} \tag{32}$$

This matrix of price risk aversion coefficients carries a reasonably straightforward interpretation. The diagonal elements are, as Barrett (1996) notes, analogous to Pratt's (1964) coefficient of absolute income risk aversion, but for prices; $A_{ii} > 0$ implies that welfare is decreasing in the volatility of the price of *i*. This is the classic concern of the literature on commodity price stabilization (Newbery and Stiglitz, 1981). The off-diagonals, meanwhile, reflect how variation in one good's price affects the household's marginal utility with respect to variation in the other good's price. Consequently, $A_{ij} > 0$ implies that greater volatility in price *j* reduces welfare associated with the net consumption of good *i*. The price risk aversion coefficient matrix thus speaks directly to the welfare effects of and household preferences with respect to price risk. Intuitively, these coefficients provide information on how the marginal utility of a price change in good *i* is impacted by a price change in good *j*.

This can be seen by defining a rescaled version α of the price risk aversion coefficient matrix A as $\alpha_{ij} \equiv A_{ij}\frac{p_j}{M_i} = -\frac{\partial \ln V_{p_i}}{\partial \ln p_j}$. The coefficients in α are precisely the elasticity of the marginal indirect utility from a price change in good *i* with respect to a price change in good *j*. Because the first-order utility effects of price changes map directly to marketable surplus by Roy's Identity, it is not surprising that one can then express elasticities of substitution—which provide unit-free measures of first-order *demand* effects of price changes—in terms of the price risk aversion elasticities α_{ij}, which provide unit-free measures of the *second-order* utility impacts of price changes. More precisely, the Morishima elasticity of substitution $m_{ij} \equiv \frac{\partial \ln(M_i / M_j)}{\partial (p_j / p_i)}$ (Morishima, 1967; Blackorby and Russell, 1981) between goods i and $j \neq i$ can be written as $m_{ij} = \alpha_{ii} - \alpha_{ji}$.

The theory clearly implies a strong and testable symmetry restriction on the estimated price risk aversion coefficients. With adequate data, one can test the following null hypothesis:

$$H_0 : V_{p_i p_j} = V_{p_j p_i} \text{ for all } i \neq j, \qquad (33)$$

which consists of $\frac{K(K-1)}{2}$ testable restrictions. We pursue this test in the empirical application below.

2.3 Relationship between *A* and the Slutsky Matrix

The derivations above and their result culminating in the price risk aversion coefficient matrix **A** raise the natural question: What is the relationship between matrix **A** and the Slutsky matrix? That is, what can knowledge of a household's Walrasian demand functions – whether positive in the case of net buyers or negative in the case of net sellers – tell us about its attitude with respect to price risk?

Let $x_i(p, y)$ be the household's Walrasian demand function for good *i* as a function of the prices the household faces and its income, and assume for now that the household is a net buyer of all commodities. We know from first principles that the Slutsky matrix *S* is such that (Mas-Colell, Whinston, and Green, 1995)

$$S_{ij}(p, y) = \frac{\partial x_i}{\partial p_j} + \frac{\partial x_i}{\partial y} x_j = B_{ij} + C_{ij}. \qquad (34)$$

Where $B_{ij} \equiv \frac{\partial x_i}{\partial p_j}$ and $C_{ij} \equiv \frac{\partial x_i}{\partial y} x_j$. Based on the derivations of the previous section, we can show that

$$A_{ij} = x_i \left[\frac{1}{x_j} C_{jj} - \frac{R}{y} + B_{ij} \right]. \qquad (35)$$

That is, a household's marginal utility with respect to a change in the price of good i changes as a result of a change in the price of good j – what we called cross-price risk aversion – and that effect is a function of the commodity's own-income effect as well as the cross-price effect between goods i and j. In this sense, since the cross-price risk aversion between goods i and j is linked both to S_{jj} and to S_{ij}. There does not exist a one-to-one correspondence, even in sign, between the elements of matrices *A* and *S*. thus, the sign of any cross-price risk aversion coefficient does not depend on whether two goods are complements or substitutes.

2.4 Certainty Equivalent for Price Stabilization Policy

Suppose that a policymaker wanted to eliminate all price uncertainty. In order to do so, one would first need to compute the total certainty equivalent (CE), i.e., the certainty equivalent for the entire price risk aversion matrix. Then,

$$CE = V\left(E\left(p\right), y\right) - E\left(V\left(p, y\right)\right), \tag{36}$$

so that

$$CE = V\left(E\left(p\right), y\right) - E\left(V\left(p, y\right)\right) = E\left[V\left(E\left(p\right), y\right) - V\left(p, y\right)\right]. \tag{37}$$

A Taylor series approximation around $V\left(E\left(p\right), y\right)$ yields

$$CE \approx E\left[-V_p\left(E(p),y\right)\left(p-E(p)\right) - \frac{1}{2}\left(p-E(p)\right)'V_{pp}\left(E(p),y\right)\left(p-E(p)\right)\right], \quad (38)$$

in other words,

$$\begin{aligned}
CE &\approx -\frac{1}{2}E\left[\left(p-E(p)\right)'V_{pp}\left(E(p),y\right)\left(p-E(p)\right)\right] \\
&= -\frac{1}{2}E\left[\begin{bmatrix} p_1-\mu_1 & p_2-\mu_2 & \cdots & p_k-\mu_k \end{bmatrix}\begin{bmatrix} V_{p_1p_1} & V_{p_1p_2} & \cdots & V_{p_1p_K} \\ V_{p_2p_1} & V_{p_2p_2} & \cdots & V_{p_2p_K} \\ \vdots & \vdots & \ddots & \vdots \\ V_{p_Kp_1} & V_{p_Kp_2} & \cdots & V_{p_Kp_K} \end{bmatrix}\begin{bmatrix} p_1-\mu_1 \\ p_2-\mu_2 \\ \vdots \\ p_k-\mu_k \end{bmatrix}\right] \\
&= -\frac{1}{2}E\left[\left(p_1-\mu_1\right)\sum_{i=1}^{k}\left[\left(p_i-\mu_i\right)V_{p_ip_1}\right] \quad \left(p_2-\mu_2\right)\sum_{i=1}^{k}\left(p_i-\mu_i\right)V_{p_ip_2} \quad \cdots \quad \left(p_k-\mu_k\right)\sum_{i=1}^{k}\left(p_i-\mu_i\right)V_{p_ip_k}\right] \\
&= -\frac{1}{2}\left[\sum_{i=1}^{k}\sigma_{p_1p_i}V_{p_ip_1} \quad \sum_{i=1}^{k}\sigma_{p_2p_i}V_{p_ip_2} \quad \cdots \quad \sum_{i=1}^{k}\sigma_{p_kp_i}V_{p_ip_k}\right]
\end{aligned}$$

If instead one wishes to stabilize only one price, the above derivations become such that

$$CE = V\left(E(p_i), p_{\sim i}, y\right) - E\left(V(p_i, p_{\sim i}, y)\right), \quad (39)$$

so that

$$CE = E\left(V\left(E(p_i), p_{\sim i}, y\right)\right) - E\left(V(p_i, p_{\sim i}, y)\right) = E\left[V\left(E(p_i), p_{\sim i}, y\right) - V(p_i, p_{\sim i}, y)\right]. \quad (40)$$

Again, a Taylor series expansion yields

$$CE \approx E\begin{bmatrix} V(E(p),y)+V_{p_{\sim i}}(E(p),y)(p_{\sim i}-E(p_{\sim i}))+\frac{1}{2}(p_{\sim i}-E(p_{\sim i}))'V_{p_{\sim i}p_{\sim i}}(E(p),y)(p_{\sim i}-E(p_{\sim i})) \\ -V(E(p),y)-V_{p_{\sim i}}(E(p),y)(p_{\sim i}-E(p_{\sim i}))-V_{p_i}(E(p),y)(p_i-E(p_i)) \\ -(p_{\sim i}-E(p_{\sim i}))'\frac{1}{2}V_{p_{\sim i}p_{\sim i}}(E(p),y)(p_{\sim i}-E(p_{\sim i})) \\ -(p_i-E(p_i))'\frac{1}{2}V_{p_ip_i}(E(p),y)(p_i-E(p_i)) \\ -(p_i-E(p_i))'\frac{1}{2}V_{p_ip_{\sim i}}(E(p),y)(p_{\sim i}-E(p_{\sim i})) \\ -(p_{\sim i}-E(p_{\sim i}))'\frac{1}{2}V_{p_{\sim i}p_i}(E(p),y)(p_i-E(p_i)) \end{bmatrix}$$

$$CE \approx -\frac{1}{2}\sigma_i^2 V_{p_ip_i} + E\begin{bmatrix} -(p_i-E(p_i))'\frac{1}{2}V_{p_ip_{\sim i}}(E(p),y)(p_{\sim i}-E(p_{\sim i})) \\ -(p_{\sim i}-E(p_{\sim i}))'\frac{1}{2}V_{p_{\sim i}p_i}(E(p),y)(p_i-E(p_i)) \end{bmatrix}$$

$$CE \approx -\frac{1}{2}\sigma_i^2 V_{p_ip_i} - \sum_{j\neq i}\sigma_{ij}V_{p_ip_j} . \tag{41}$$

This last equation thus provides the transfer payment a policymaker would need to make to the household in order to compensate them for the uncertainty over p_i, and the previous derivations provide the transfer payment a policymaker would need to make to the household in order to compensate them for the uncertainty over *all* prices.

3. Data and Descriptive Statistics

In the remainder of the paper we demonstrate the estimation of the price risk aversion coefficient matrix and test the symmetry restriction implied by the theory. We use data from the Ethiopian Rural Household Survey (ERHS). These data are made available by the Department of Economics at Addis Ababa University (AAU), the Centre for the Study of African Economies (CSAE) at Oxford University, and the International Food Policy Research Institute (IFPRI). Funding for data collection was provided by the Economic and Social Research Council (ESRC), the Swedish International Development Agency (SIDA) and the US Agency for International Development (USAID). The preparation of the public release version of the ERHS data was supported, in part, by the World Bank. It goes without saying that AAU, CSAE, IFPRI, ESRC, SIDA, USAID, and the World Bank are not responsible for any errors in these data or for their use or interpretation.

The publicly available ERHS data include results from five rounds: 1989, 1994a, 1994b, 1995, and 1997, although the latter round is still being processed. The survey instrument and sampling strategy changed significantly between 1989 and 1994a, with the addition of nine peasant associations (PAs) to the original six surveyed in 1989.[8] Because of these significant differences, we exclude the 1989 round from our sample. See Dercon and Krishnan (1998) and Dercon (2002, 2004) for details on the survey instrument and sampling strategy.

We chose this dataset because it records household consumption and production decisions over multiple years and seasons, and because there is low attrition and a standardized survey instrument across the rounds we retain for analysis. The sample

[8] Ethiopia is subdivided into eleven zones subdivided into *woredas*, which are roughly equivalent to US counties. Within each *woredas* are PAs. Random sampling occurred at the village level within these PAs. Other differences between 1989 and subsequent surveys included (i) a longer list of consumption items starting in the 1994a round; (ii) a lack of price data in the 1989 round which were collected in future rounds; and (iii) a war that ended between the 1989 and 1994a rounds (Dercon 1998).

includes a total of 1477 households with an attrition rate of around 2 percent of households across the three rounds selected for analysis (Dercon and Krishnan, 1998).

Table 1 presents descriptive statistics for the commodities we consider in this paper. Given that many of the households in our data were autarkic with respect to several commodities due to the presence of transactions costs that prevents them from participating in the market either as net buyers or as net sellers (de Janvry et al., 1991), for every time period in which a household is neither a net buyer or a net seller of a given commodity, this household has a marketable surplus of zero for that particular commodity. In fact, there are only seven commodities for which the proportion of observations with a marketable surplus that differs from zero is greater than five percent (i.e., cooking oil, coffee, maize, soap, wheat, barley, and onions). We thus focus on these seven commodities in what follows.

Table 1 also introduces descriptive statistics for these seven. A positive (negative) mean marketable surplus indicates that the average household is a net seller (buyer) of a commodity. On the one hand, the average household is a net buyer of cooking oil, coffee,[9] soap, and onions. On the other hand, the average household is a net seller of maize, wheat, and barley. This is consistent with the latter three commodities being staple

[9] It may be surprising that the number of net buyers of coffee far exceeds the number of net sellers of coffee in our data set. As it turns out, the average buyer buys about 16 kg of coffee per year, and the average seller sells 87 kg of coffee per year (both statistics are significant at the 1 percent significance level). These numbers are consistent with the net buyers buying coffee purely for household consumption, and the net sellers selling much larger quantities at market. Although the 16 kg figure for net buyers may seem high, note that a can of Illy coffee contains 0.25 kg of (roasted) whole coffee beans. This means that the average net buyer household would have to consume about 64 such cans per year (i.e., a little more than one per week), which is far from unlikely considering the average household size as well as the frequency at which coffee is consumed in Ethiopia.

crops produced by the households in our data set and the former four commodities being non-staples. As a result, for all non-staples except coffee, no household is a net seller of cooking oil, soap, or onions.

Table 2 lists the mean price for each of the seven commodities under study in birr,[10] along with the mean budget share for each commodity. Note that maize and barley represent the highest budget shares, at 43.5 and 32.8 percent of the average household's budget, and that wheat and cooking oil – which both have negative budget shares because the average household is a net buyer of these commodities – represent the lowest budget shares.

The income measure used in this paper is the sum of proceeds from off-farm labor, off-farm business activity and land rentals, gifts, crop sales, and other sources of incomes.[11] That said, average income from the aforementioned sources is different from zero in about 56 percent of cases, which explains why the average annual income of $54 may seem low.

4. Empirical Framework

We estimate the following marketable surplus functions for the seven commodities *i* for the seven commodities discussed in the previous section:

$$M_i = \beta_{i0} + \beta_{i1} \ln W_i + \beta_{i2} \ln P_i + \beta_{i3} \ln P_{-i} + \lambda + \tau + \varepsilon_i \,, \qquad (42)$$

[10] As of writing, US$1 ≈ Birr 9.43.

[11] Recall that we omit own-crop revenue from income in each marketable surplus equation estimated below so as to avoid biasing our estimates below due to the endogeneity of income to marketable surplus.

where i denotes the commodity rather than the observation; W_i denotes household income net of income from commodity *i*; P_i is a household-specific measure of the price of commodity *i*; P_{-i} is a household-specific measure of the prices of all (observed) commodities other than i (including *j*); λ is a region-*woreda*-peasant association-household fixed effect; τ is a time period fixed effect which allows controlling for the price of the unobservable composite good; and ε_i is an error term with mean zero. Note that since the household is a price-taker for all commodities, then all prices are fully exogenous to the dependent variable in equation 42, and household income is exogenous by virtue of net of the household's income from commodity *i*.[12]

Given the panel nature of our data, we estimate equation over a total of 1,412 units of observation spread out over three rounds and three seasons. No household was observed over all three years and three seasons, as the number of observations per household ranged from one to five with an average of 3.8 observations per household.[13]

Computation of own- and cross-price elasticities, of the income-elasticity, and of the budget share of marketable surplus follows from equation 42. For example, given the functional form of equation 42, to derive the estimated cross-price risk aversion

[12] Because the theoretical model does not yield a structural form for marketable surplus, we chose to estimate marketable surplus as a Walrasian demand function (for net buyers) and its inverse (for net sellers). Moreover, given the number of equations estimated in this paper – seven marketable surplus equations each estimated for three assumptions regarding relative risk aversion – we chose not to include interaction terms.

[13] By controlling for household unobservables, the use of fixed effects controls for the possible selection problem posed by households for which we only have one observation through time, which are dropped from the fixed effects regressions we estimate.

coefficient $\hat{A}_{ij}$, one would first need to compute $\hat{\beta}_j = \frac{M_j p_j}{W}$, $\hat{\eta}_j = \frac{\hat{\beta}_{j1}}{M_j}$, and $\hat{\varepsilon}_{ij} = \frac{\hat{\beta}_{i3}}{M_i}$, where $\hat{\beta}_{i3}$ is the estimated coefficient for the price of commodity *j* in marketable surplus equation for commodity *i*. Then, one could combine these estimates to obtain the point estimate

$$\hat{A}_{ij} = \frac{M_i}{p_j}[\hat{\beta}_j(\hat{\eta}_j - R) + \hat{\varepsilon}_{ij}], \tag{43}$$

where $\hat{\beta}_j = \frac{M_j p_j}{W}$, $\hat{\eta}_j = \frac{\hat{\beta}_{j3}}{M_j}$, and $\hat{\varepsilon}_{ij} = \frac{\hat{\beta}_{i5}}{M_i}$. Given that marketable surplus is often zero, we use the mean of M_j and M_i so as to compute elasticities at means. Although it might be preferable to use mean elasticities, it is simply not possible to do so in these data.[14] The standard errors can then be computed using either the delta method or through bootstrapping, given that $\hat{A}_{ij}$ is a nonlinear combination of estimates. The coefficient of relative risk aversion *R* can either be directly estimated – if the data allows it – or assumed to be equal to a certain value. Given that our data do not allow direct estimation of *R*, we estimate the A_{ij} coefficients for $R = 1$, $R = 2$, and $R = 3$, which provides an additional robustness check.

[14] Likewise, given that we use the household's income from non-agricultural sources as a proxy for total income *W*, so as to avoid endogeneity problems, many households have an income of zero. Table 2 shows that income was different from zero in 2969 observations out of 5667. In this case, we compute the estimated budget share by dividing by *W* + 0.001 (MaCurdy and Pencavel, 1986). We also add 0.001 to each observation for the variables for which logarithms are taken so as to not drop observations in a nonrandom fashion and introduce selection bias.

As shown in table 1, many households have a marketable surplus of zero for several commodities, so we estimate several version of the matrix of price risk aversion coefficients. We first estimate the **A** matrix for the top three commodities consumed and produced by the households in our data (i.e., cooking oil, coffee, and maize), and then estimate it for the top four, and so on for the five, six, and seven top commodities (i.e., cooking oil, coffee, maize, soap, wheat, barley, and onions). We stop at estimating the matrix of price risk aversion coefficients for the top seven commodities because the percentage of nonzero marketable surplus observations does not exceed five percent for the remaining commodities. Finally, note that we divide each coefficient of price risk aversion by its standard error so as to standardize them and make them comparable with one another, given that it would be otherwise impossible to compare different crops.[15]

5. Estimation Results and Hypothesis Tests

This section first presents estimation results for the marketable surplus equations. Given that these results are ancillary in the sense that they represent an intermediate step in computing own- and cross-price risk aversion coefficients, we only discuss them briefly and devote the bulk of the analysis to the estimated matrices of price risk aversion as well as the tests of the hypothesis that these matrices are symmetric.

Tables 3 to 7 present estimation results for the marketable surplus equations when considering anywhere from three to seven commodities. We present this wide array of results so as to offer a robustness check on our results. The first thing to note is that

[15] For more on the impossibility to compare different crops without standardizing price risk aversion coefficients, see Bellemare (2005).

although own- and cross-price elasticities are used along with income elasticities of marketable surpluses in computing coefficients of own- and cross-price risk aversion, what matters for the estimated marketable surplus equations are the estimated coefficients themselves. In other words, one should normally expect the estimated coefficient on p_i to be positive in the marketable surplus equation for M_i, even though the elasticity will flip signs depending on whether the mean of M_i is positive or negative since we are relying on elasticities *at means* rather than mean elasticities when computing coefficients of price risk aversion. Consequently, one should focus on β_{i2} in equation 42 in order to determine whether p_i has the expected effect on M_i.

Intuitively, one would expect β_{i2} to be positive, i.e., as the price of commodity *i* increases, the household buys less and less or sells more and more of the same commodity. But given that we are studying agricultural households, and not pure producers or pure consumers, however, it is entirely possible that β_{i2} be negative. Recall that within an agricultural household, there exists a profit effect on top of the usual income and substitution effects (Singh et al., 1986). It is thus entirely possible that, as p_i increases, the household increases its production of commodity *i* (which would increase M_i), but that it also decides to increase its consumption of it via an increased profit due to the increase in M_i. If the latter effect dominates, then β_{i2} will be negative. Obviously, one would expect β_{i2} to be more likely to be negative for goods that are actually produced by the households in the data, i.e., for goods for which there is a profit effect.

Such counterintuitive results have been reported in the market participation studies of Goetz (1992), Bellemare and Barrett (2006), and Stephens and Barrett (2006).

Turning to the estimation results, own price has a positive and significant effect on the marketable surplus of cooking oil in every specification in tables 3 to 7. The price of coffee, although it has a positive effect on the marketable surplus of coffee in every specification, is only statistically significant in table 7, which considers seven commodities. Likewise, the prices of maize and soap almost always have a positive effect on their respective marketable surpluses, but these effects are never significant.[16]

The prices of barley and wheat always have a negative effect on their respective marketable surpluses, and the effect is always significant for wheat. As one would expect, along with maize, barley and wheat are staple crops in these data, and so the profit effect dominates for staples, i.e., the commodities that are produced by the households in these data, which is consistent with our intuition.

As discussed above, we use the results of table 3 to 7 to compute standardized coefficients of own- and cross-price risk aversion, and we use these coefficients to construct matrix **A** of price risk aversion. Looking at tables 8 to 12, the first thing to note is that the households in our data are price risk-averse over most commodities except maize and soap, whose own-price risk aversion coefficients are never significant. In addition, the average household is most price risk-averse over cooking oil and coffee, and

[16] Note that the low overall R^2 measures likely come from the measurement error introduced by our use of prices at the village level.

least price risk-averse over maize and soap. Similarly, the average household is risk-averse over co-fluctuations in the prices of cooking oil and the other goods and over co-fluctuations in the prices of coffee and the other goods, as witnessed by the off-diagonal elements in the matrices reported in tables 8 to 12.

Turning to our main testable hypothesis, i.e., the symmetry of the matrix of price risk aversion coefficients, for matrix $\mathbf{A}_3$ (the matrix of price risk aversion coefficients for the top three commodities in the data, i.e., cooking oil, coffee, and maize), the null hypothesis of symmetry cannot be rejected, with a *p*-value of 0.90. Thus, even though the test of symmetry has low power, given that most of the probability mass rests on non-rejection of the null hypothesis, the *p*-value gives us confidence in the outcome of the test. Likewise, symmetry cannot be rejected for matrices $\mathbf{A}_4$ to $\mathbf{A}_7$, with *p*-values of 0.98, 0.89, 0.98, and 0.96, respectively. Thus, as we expand matrix **A** to cover more and more commodities, the core result of this paper remains: symmetry of the matrix of price risk aversion coefficients cannot be rejected, and even though the test does have low power, the increasing number of commodity and the high *p*-values offer strong empirical support for the theoretical framework. Note that these results are not due to the fact that the coefficients included in matrices $\mathbf{A}_3$ to $\mathbf{A}_7$ are not statistically significant: for every matrix, the null hypothesis that all coefficients are equal to zero is rejected with a *p*-value of 0.00, and more than half of the coefficients in each matrix are significantly different from zero, except in matrix $\mathbf{A}_7$. Finally, table 13 shows that the symmetry results are consistent whether we assume that relative risk aversion is such that $R=1$, $R=2$, or $R=3$, which provides an additional robustness check.[17]

Our results thus seem to indicate that (i) the households in our data are significantly risk-averse over the price of specific commodities; (ii) the households in our data are significantly risk-averse over co-movements in the prices of specific pairs of commodities; and (iii) the households in our data behave exactly as theory predicts, in the sense that their risk preferences over co-movements in the prices of specific pairs of commodities are symmetric.

A *caveat* is in order, however. Recall that the proportion of non-zero observations for marketable surplus was at most 25 percent for the commodities considered, and that only six commodities exhibit 10 percent or more of non-zero observations. This high proportion of zero-marketable surplus observations may introduce a significant amount of noise in the data. Evidently, this would entail large standard errors around our estimates for the coefficients of own- and cross-price risk aversion, which would make non-rejection of the symmetry of the A matrix more likely. We take comfort, however, in the high *p*-values obtained when testing for symmetry as well as in the fact that given the high transactions costs faced by households in developing countries (Key et al., 2000; Renkow et al., 2004; Bellemare and Barrett, 2006), one would be hard-pressed to find a data set without such a large number of zero-valued observations for the marketable surplus of many commodities.

[17] Note that because these coefficients are treated as constants in the price risk aversion coefficients, they do not introduce any noise in these coefficients, and so changing risk aversion should have an effect on our point estimates, but not on our standard errors.

6. Conclusion

Based on the observation that the indirect utility function of a unitary household allows computing coefficients of risk aversion over more than just income or wealth, this paper has modestly extended microeconomic theory so as to allow studying price risk aversion over multiple commodities. Specifically, we have derived a pseudo-Slutsky matrix that measures the curvature of the indirect utility function in the hyperspace defined by the vector of all commodity prices faced by the household. Then, based on the method developed by Newbery and Stiglitz (1981) and extended in turn by Finkelshtain and Chalfant (1991) and by Barrett (1996), we have estimated the aforementioned matrix of price risk aversion coefficients using well-known survey data on a panel of rural Ethiopian households. In order to ensure robustness, the matrix of price risk aversion coefficients was estimated for subsets of the three, four, five, six, and seven commodities, as well as for three different assumptions over the relative risk aversion of households.

We then tested the paper's main testable implication (i.e., symmetry of the matrix of price risk aversion coefficients) on these same subsets of commodities. In no case could we reject symmetry of the matrix of price risk aversion coefficients, and the *p*-values of the tests were always high enough so as to give us faith in the results and obviate concerns regarding the low power of our test.

Above and beyond the technical results presented in this paper, our results also have important policy implications. First off, the average household in these data is not only adversely affected by the price fluctuation of most commodities in the data, but also by co-movements in the price of the commodities we chose to include in our analysis. Based on this finding, we have shown that it is possible to compute certainty equivalents for each commodity or for all commodities, depending on whether policymakers want to compensate households for the price fluctuations of a few select staple crops or of a number of commodities taken as a whole.[18] As such, not only does our method allow computing average transfer payments, it also allows computing such transfer payments conditional on certain household covariates, such as income and the prices faced by each household.

That said, a *caveat* is in order. Many of the households in our data were autarkic with respect to all the commodities considered in our analysis, and even for the households whose marketable surplus was non-zero for one commodity, their marketable surplus of other commodities was often equal to zero. This means that we had to rely on elasticities at means rather than on mean elasticities when computing coefficients of price risk aversion, and so the variation exploited in computing the typical coefficient of price risk aversion came from marketable surplus, price, and budget share, rather than from the same variables augmented with price elasticity, and income elasticity. As such, the standard errors around our estimated coefficients of price risk aversion are smaller than they would be under ideal circumstances, i.e., they are smaller than they would be if we had data for which *all* households have a nonzero marketable surplus of *all* commodities. This could in turn lead to our not rejecting symmetry of the matrix of price risk aversion coefficients. It would thus be of interest to both theoretical and applied microeconomists

[18] Giving such a transfer payment to American taxpayers to compensate them for fluctuations in the price of gasoline in 2008 resulted in the Bush administration economic stimulus checks.

to estimate matrices of price risk aversion coefficients using data from industrialized countries, testing for symmetry for both single- and multiple-person households, much like Browning and Chiappori (1998) did in their seminal study of efficient intrahousehold decisions. For now, such an investigation is left for future research.

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Table 1: Descriptive Statistics for the Dependent Variables

Crop	Mean	(Std. Dev.)	Observations	Nonzero Observations	Net Buyers	Net Sellers
Cooking Oil (Kg)	-7.21	(27.48)	5334	1333	1333	0
Coffee (Kg)	-1.18	(49.85)	5334	1353	1194	159
Maize (Kg)	39.66	(886.71)	5334	1329	895	434
Soap (Kg)	-2.80	(18.51)	5334	625	625	0
Wheat (Kg)	24.94	(290.56)	5334	833	664	169
Barley (Kg)	56.23	(481.79)	5334	1044	518	526
Onions (Kg)	-3.55	(25.95)	5334	411	411	0

Table 2: Descriptive Statistics for the Independent Variables

Crop	Mean	(Std. Dev.)	Observations
Prices			
Cooking Oil (Birr/Kg)	0.33	(0.45)	5334
Coffee (Birr/Kg)	2.52	(0.42)	5334
Maize (Birr/Kg)	0.11	(0.27)	5334
Soap (Birr/Kg)	2.24	(0.24)	5334
Wheat (Birr/Kg)	0.53	(0.19)	5334
Barley (Birr/Kg)	0.31	(0.25)	5334
Onions (Birr/Kg)	0.49	(0.55)	5334
Budget Shares			
Budget Share of Cooking Oil	-0.004	(0.10)	2977
Budget Share of Coffee	0.203	(3.61)	2977
Budget Share of Maize	0.435	(20.21)	2977
Budget Share of Soap	-0.003	(0.06)	2977
Budget Share of Wheat	-0.173	(15.58)	2977
Budget Share of Barley	0.328	(7.77)	2977
Budget Share of Onions	-0.003	(0.07)	2977
Income (Birr)	509.06	(4694.90)	5334

Note: Income (i.e., the sum of off-farm income and all crop revenues) was different from zero for 2977 observations only.

Table 3: Marketable Surplus Equations for Three Commodities

	Cooking Oil	**Coffee**	**Maize**
Cooking Oil Price	**7.690*** **	5.555*	-84.032
	(1.891)	(3.293)	(57.432)
Coffee Price	2.477	**2.774**	40.115
	(2.120)	(3.692)	(64.294)
Maize Price	-1.345	-26.204***	**-14.520**
	(2.436)	(4.240)	(73.978)
Income	1.153***	0.456***	5.202**
	(0.075)	(0.130)	(2.266)
Round 3	-7.846***	8.462***	92.317**
	(1.498)	(2.599)	(45.384)
Round 4	-8.459***	-3.937*	16.069
	(1.371)	(2.386)	(41.535)
Intercept	-9.289	-6.390	-58.314
	(5.730)	(9.985)	(173.738)
N	5334	5334	5334
p-value	0.00	0.00	0.00
Overall R^2	0.06	0.01	0.00
p-value (Fixed Effects)	1.00	0.00	0.00

Note: Standard errors in parentheses. The symbols ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively. Coefficients in bold face denote own price.

Table 4: Marketable Surplus Equations for Four Commodities

	Cooking Oil	Coffee	Maize	Soap
Cooking Oil Price	**8.423*** **	3.332	-58.418	-0.093
	(1.934)	(3.368)	(58.731)	(1.299)
Coffee Price	2.077	**3.978**	25.700	2.659
	(2.131)	(3.709)	(64.644)	(1.431)
Maize Price	-0.483	-28.716***	**15.448**	-0.962
	(2.482)	(4.315)	(75.356)	(1.668)
Soap Price	-7.006*	20.811***	-245.317**	**1.622**
	(3.915)	(6.797)	(118.714)	(2.630)
Income	1.170***	0.414***	5.720**	0.456
	(0.076)	(0.130)	(2.279)	(0.051)
Round 3	-4.977**	-0.104	193.172***	-3.280
	(2.194)	(3.817)	(66.633)	(1.474)
Round 4	-8.054***	-5.121**	29.932	-2.846
	(1.389)	(2.415)	(42.056)	(0.933)
Intercept	6.304	-52.744*	488.907	-10.669
	(10.428)	(18.130)	(316.676)	(7.006)
N	5334	5334	5334	5334
p-value	0.00	0.00	0.00	0.00
Overall R^2	0.06	0.01	0.00	0.02
p-value (Fixed Effects)	1.00	0.00	0.00	0.85

Note: Standard errors in parentheses. The symbols ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively. Coefficients in bold face denote own price.

Table 5: Marketable Surplus Equations for Five Commodities

	Cooking Oil	Coffee	Maize	Soap	Wheat
Cooking Oil Price	**8.386*** **	3.184	-59.213	-0.148	16.304
	(1.936)	(3.371)	(58.786)	(1.300)	(20.241)
Coffee Price	2.198	**4.457**	28.346	2.842**	-49.937**
	(2.147)	(3.737)	(65.141)	(1.442)	(22.444)
Maize Price	-0.750	-29.764***	**9.626**	-1.364	75.968***
	(2.549)	(4.429)	(77.377)	(1.712)	(26.664)
Soap Price	-7.657*	18.230**	-259.550**	**0.637**	-3.448
	(4.163)	(7.229)	(126.228)	(2.796)	(43.514)
Wheat Price	1.443	5.700	31.540	2.179	**-198.375*** **
	(3.127)	(5.439)	(94.995)	(2.101)	(32.712)
Income	1.169***	0.411***	5.694**	0.455***	1.605**
	(0.076)	(0.130)	(2.280)	(0.051)	(0.792)
Round 3	-4.656**	1.162	200.174***	-2.796*	93.119***
	(2.302)	(4.004)	(69.898)	(1.546)	(24.064)
Round 4	-7.855***	-4.335*	34.264	-2.546***	3.772
	(1.454)	(2.529)	(44.038)	(0.977)	(15.200)
Intercept	6.566	-51.694***	494.624	-10.272	228.995**
	(10.445)	(18.157)	(317.180)	(7.016)	(109.216)
N	5334	5334	5334	5334	5334
p-value	0.00	0.00	0.00	0.00	0.00
Overall R^2	0.06	0.01	0.00	0.02	0.01
p-value (Fixed Effects)	1.00	0.00	0.00	0.85	0.06

Note: Standard errors in parentheses. The symbols ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively. Coefficients in bold face denote own price.

Table 6: Marketable Surplus Equations for Six Commodities

	Cooking Oil	**Coffee**	**Maize**	**Soap**	**Wheat**	**Barley**
Cooking Oil Price	**7.756***	0.528	-128.401**	0.004	-10.287	93.574***
	(2.074)	(3.613)	(62.888)	(1.393)	(21.655)	(34.842)
Coffee Price	1.530	**1.650**	-44.849	3.004*	-78.134***	133.682***
	(2.288)	(3.982)	(69.291)	(1.537)	(23.879)	(38.462)
Maize Price	-0.598	-29.108***	**26.624**	-1.401	82.313***	-70.126
	(2.555)	(4.439)	(77.492)	(1.717)	(26.692)	(42.940)
Soap Price	-7.867*	17.337**	-283.687**	**0.688**	-12.387	-41.437
	(4.170)	(7.240)	(126.336)	(2.802)	(43.533)	(70.118)
Wheat Price	0.129	0.200	-113.036	2.496	**-253.717***	-23.682
	(3.491)	(6.071)	(105.909)	(2.345)	(36.450)	(58.666)
Barley Price	2.269	9.497*	249.738***	-0.548	95.777***	**-58.403**
	(2.681)	(4.663)	(81.243)	(1.801)	(27.985)	(45.070)
Income	1.164***	0.390***	5.270**	0.456***	1.4088*	0.893
	(0.076)	(0.131)	(2.282)	(0.051)	(0.793)	(1.280)
Round 3	-4.161*	3.228	254.615***	-2.915*	113.984***	117.594***
	(2.375)	(4.129)	(72.034)	(1.595)	(24.792)	(39.901)
Round 4	-7.927***	-4.640*	26.795	-2.528***	0.752	70.690***
	(1.457)	(2.532)	(44.058)	(0.979)	(15.205)	(24.474)
Intercept	8.837	-42.135**	745.434**	-10.821	324.869***	-243.500
	(10.785)	(18.747)	(327.176)	(7.245)	(112.607)	(181.254)
N	5334	5334	5334	5334	5334	5334
p-value	0.00	0.00	0.00	0.00	0.00	0.00
Overall R^2	0.06	0.01	0.00	0.02	0.01	0.01
p-value (Fixed Effects)	1.00	0.00	0.00	0.86	0.07	0.00

Note: Standard errors in parentheses. The symbols ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively. Coefficients in bold face denote own price.

Table 7: Marketable Surplus Equations for Seven Commodities

	Cooking Oil	Coffee	Maize	Soap	Wheat	Barley	Onions
Cooking Oil Price	**7.780*****	0.932	-129.796	0.032	-9.111	93.871***	-1.416
	(2.074)	(3.600)	(62.888)	(1.393)	(21.629)	(34.850)	(1.838)
Coffee Price	2.067	**9.092****	-76.779	3.624	-51.887**	140.322***	6.709***
	(2.407)	(4.179)	(72.858)	(1.617)	(25.085)	(40.460)	(2.132)
Maize Price	-0.851	-32.539***	**41.735**	-1.693	69.990***	-73.241*	-2.834
	(2.579)	(4.463)	(78.213)	(1.733)	(26.906)	(43.346)	(2.285)
Soap Price	-7.717*	19.223***	-292.852	**0.862**	-5.057	-39.593	8.049**
	(4.176)	(7.219)	(126.486)	(2.805)	(43.530)	(70.211)	(3.700)
Wheat Price	-0.594	-9.630	-69.913	1.661	**-289.042*****	-32.612	-7.856**
	(3.633)	(6.291)	(110.186)	(2.440)	(37.878)	(61.050)	(3.219)
Barley Price	2.131	7.524	257.850	-0.707	89.053***	**-60.108**	5.619**
	(2.688)	(4.657)	(81.435)	(1.805)	(28.019)	(45.190)	(2.381)
Onions Price	1.349	18.374***	-80.422	1.557	65.865***	16.653	**5.165*****
	(1.872)	(3.247)	(56.791)	(1.258)	(19.522)	(31.466)	(1.659)
Income	1.165***	0.428***	5.291	0.456	1.424*	0.898	0.207***
	(0.076)	(0.130)	(2.282)	(0.051)	(0.792)	(1.280)	(0.068)
Round 3	-4.500*	-1.394	274.771	-3.306	97.462***	113.417***	-7.122***
	(2.421)	(4.193)	(73.418)	(1.626)	(25.239)	(40.678)	(2.145)
Round 4	-7.673***	-1.073	11.752	-2.235	13.167	73.833***	-0.924
	(1.499)	(2.600)	(45.315)	(1.007)	(15.625)	(25.187)	(1.328)
Intercept	6.852	-69.156***	863.847	-13.111	228.010**	-267.983	-35.935***
	(11.131)	(19.274)	(337.651)	(7.477)	(116.065)	(187.081)	(9.862)
N	5334	5334	5334	5334	5334	5334	5334
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Overall R^2	0.06	0.00	0.00	0.02	0.01	0.01	0.05
p-value (Fixed Effects)	1.00	0.00	0.00	0.87	0.05	0.00	0.00

Note: Standard errors in parentheses. The symbols ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively. Coefficients in bold face denote own price.

Table 8: Price Risk Aversion Matrix with Three Commodities and *R* = 2

$$A_3 = \begin{bmatrix} \mathbf{0.069}^{***} & 0.052^{***} & 0.045^{***} \\ 0.067^{***} & \mathbf{0.047}^{***} & 0.025^{*} \\ 0.046^{***} & 0.022 & \mathbf{0.018} \end{bmatrix}$$

Joint Significance	$F(9,5333) = 7.99$
	p-value = 0.00
Symmetry	$F(3,5331) = 0.20$
	p-value = 0.90

Note: Rows and columns denote cooking oil, coffee, and maize, respectively.

Table 9: Price Risk Aversion Matrix with Four Commodities and *R* = 2

$$A_4 = \begin{bmatrix} \mathbf{0.069}^{***} & 0.052^{***} & 0.045^{***} & 0.045 \\ 0.067^{***} & \mathbf{0.047}^{***} & 0.025^{*} & 0.044^{***} \\ 0.046^{***} & 0.022 & \mathbf{0.018} & 0.018^{***} \\ 0.044^{***} & 0.030^{**} & 0.010 & \mathbf{0.021} \end{bmatrix}$$

Joint Significance	$F(16,5333) = 5.69$
	p-value = 0.00
Symmetry	$F(6,5328) = 0.19$
	p-value = 0.98

Note: Rows and columns denote cooking oil, coffee, maize, and soap, respectively.

Table 10: Price Risk Aversion Matrix with Five Commodities and *R* = 2

$$A_5 = \begin{bmatrix} \mathbf{0.069}^{***} & 0.052^{***} & 0.045^{***} & 0.045^{***} & 0.022 \\ 0.067^{***} & \mathbf{0.047}^{***} & 0.025^{*} & 0.044^{***} & 0.032^{**} \\ 0.046^{***} & 0.022 & \mathbf{0.018} & 0.18 & -0.021 \\ 0.044^{***} & 0.030^{**} & 0.010 & \mathbf{0.021} & -0.003 \\ 0.029^{**} & 0.025^{*} & 0.012 & 0.018 & \mathbf{0.044}^{***} \end{bmatrix}$$

Joint Significance	$F(25,5333) = 4.38$
	p-value = 0.00
Symmetry	$F(10,5324) = 0.51$
	p-value = 0.89

Note: Rows and columns denote cooking oil, coffee, maize, soap, and wheat, respectively.

Table 11: Price Risk Aversion Matrix with Six Commodities and *R* = 2

$$A_6 = \begin{bmatrix} \mathbf{0.069}^{***} & 0.052^{***} & 0.045^{**} & 0.045^{***} & 0.022 & 0.026^{*} \\ 0.067^{***} & \mathbf{0.047}^{***} & 0.025^{*} & 0.044^{***} & 0.032^{**} & 0.024^{*} \\ 0.046^{***} & 0.022 & \mathbf{0.018} & 0.018 & -0.021 & -0.015 \\ 0.044^{***} & 0.030^{**} & 0.10 & \mathbf{0.021} & -0.003 & 0.017 \\ 0.029^{**} & 0.025^{*} & 0.13 & 0.018 & \mathbf{0.044}^{***} & 0.012 \\ 0.017 & 0.024^{*} & -0.011 & 0.017 & 0.020 & \mathbf{0.032}^{***} \end{bmatrix}$$

Joint Significance	$F(36,5333) = 3.60$ p-value = 0.00
Symmetry	$F(15,5319) = 0.38$ p-value = 0.98

Note: Rows and columns denote cooking oil, coffee, maize, soap, wheat, and barley, respectively.

Table 12: Price Risk Aversion Matrix with Seven Commodities and *R* = 2

$$A_7 = \begin{bmatrix} \mathbf{0.069}^{***} & 0.052^{***} & 0.045^{***} & 0.045^{***} & 0.022 & 0.026^{*} & 0.033^{***} \\ 0.067^{***} & \mathbf{0.047}^{***} & 0.025^{*} & 0.044^{***} & 0.032^{**} & 0.024^{*} & 0.038^{**} \\ 0.046^{***} & 0.022 & \mathbf{0.018} & 0.018 & -0.021 & -0.015 & 0.019 \\ 0.044^{**} & 0.030^{**} & 0.010 & \mathbf{0.021} & -0.003 & 0.017 & 0.018 \\ 0.029^{**} & 0.025^{*} & 0.012 & 0.018 & \mathbf{0.044}^{***} & 0.012 & 0.017 \\ 0.017 & 0.024^{*} & -0.011 & 0.017 & 0.020 & \mathbf{0.032}^{**} & -0.014 \\ 0.019 & 0.019 & 0.015 & 0.015 & 0.018 & 0.010 & \mathbf{0.026}^{*} \end{bmatrix}$$

Joint Significance	$F(49,5333) = 3.09$ p-value = 0.00
Symmetry	$F(21,5313) = 0.53$ p-value = 0.96

Note: Rows and columns denote cooking oil, coffee, maize, soap, wheat, barley, and onions, respectively.

Table 13: Analysis of Sensitivity of the Symmetry Tests to Relative Risk Aversion

	***R* = 1**		***R* = 3**	
Number of Commodities	**F-statistic**	***p*-value**	**F-statistic**	***p*-value**
Three	0.20	0.90	0.20	0.90
Four	0.19	0.98	0.19	0.98
Five	0.51	0.89	0.51	0.89
Six	0.38	0.98	0.38	0.98
Seven	0.53	0.96	0.53	0.96

Note: The reported *F*-statistics and *p*-values are for tests of symmetry of the *A* matrix.