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Title*

Farmers' Subjective Valuation of Subsistence Crops: The Case of Traditional Maize in Mexico

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Abstract: Shadow prices guide farmers' resource allocations, but for subsistence farmers growing traditional crops, shadow prices may bear little relationship with market prices. We econometrically estimate shadow prices of maize using data from a nationally representative survey of rural households in Mexico. Shadow prices are significantly higher than the market price for traditional but not improved maize varieties. They are particularly high in the indigenous areas of southern and southeastern Mexico, indicating large *de facto* incentives to maintain traditional maize there.

Keywords: Shadow prices, non-market values, supply response, traditional crops, onfarm conservation, Mexico

JEL classification: O12, O13, Q12, Q39

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1. Introduction

Small-scale farmers' supply response for traditional varieties may seem puzzling from an economic point of view if differences between shadow prices and market prices are not taken into account. The market price may fail to represent the true decision price if farmers attach non-market values to their crop (Brush and Meng, 1998; Smale et al., 2003; Altieri, 2004; Dyer Leal, 2006; Bellon et al., 2006). We test whether decision prices are equal to market prices for maize farmers in rural Mexico, and if not, what accounts for the divergence between the two. If high shadow prices play a role in farmers' continued cultivation of maize, then information about these prices may be a valuable input into the design of in-situ conservation programs.

Mexico is the center of maize domestication and diversity, where farmers have selected and cross bred traditional maize varieties since 7000 BC (Dowswell et al., 1996; Turrent and Serratos-Hernandez, 2004). It hosts the largest genetic diversity of maize in the world, with 59 different races that are valuable inputs to crop breeding research for the worlds' most widely used food grain (Berthaud and Gepts, 2004; Yunez Naude and Taylor, 2006). Maize farming in Mexico is primarily carried out by small-scale subsistence farmers, who cultivate landraces and contribute to both the creation and conservation of crop genetic diversity (Berthaud and Gepts, 2004; Brush and Chauvet, 2004).[1] Given the importance of on-farm conservation in complementing conservation in gene-banks, Mexico is an ideal place to study farmers' incentives to maintain maize landraces and improve the efficiency of on-farm conservation programs.

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[1] A landrace is a crop cultivar that evolved with and has been genetically improved by traditional agriculturalists, but was not influenced by modern breeding practices. All components of landraces are adopted to local climate conditions, cultural practices, diseases and pests (Hoisington et al., 1999; Jarvis et al., 2000).

2. Background

The term “shadow price” commonly refers to the value of goods or services not traded in markets (Becker, 1965). More accurately, the shadow price is the decision price. For a commercial farmer or agricultural household producing in a context of well-functioning and complete markets, this price is given exogenously by the market (Singh et al., 1986). In the absence of perfect and complete markets, the decision price may instead be an endogenous shadow price. When a household is constrained to produce and consume at its internal equilibrium, the shadow price is shaped by variables influencing both supply and demand (Singh et al., 1986; de Janvry et al., 1991; Taylor and Adelman, 2003). In an economy where many farmers are subsistence producers, the structure and determinants of shadow prices may be critical in shaping cultivation decisions and crop genetic diversity outcomes.[2]

Shadow prices may diverge from market prices because of high transaction costs of buying and selling, as postulated by de Janvry et al. (1991). Alternatively, the divergence may result from an imperfect substitutability between market-purchased and home-grown crops.

Agricultural households in less developed countries generally consume part or all of their output and supply part or all of their inputs (Chihiro, 1986). Early studies in the agricultural household literature assume perfect markets, but later ones allow for imperfect or missing markets, which are common in developing countries (Singh et al., 1986; Jacoby, 1993; Skoufias, 1994; de Janvry et al., 1991; Taylor and Adelman, 2003). While most use market prices to value agricultural output, de Janvry et al. (1991); Key et al. (2000) and Taylor and Adelman (2003) analyze farmer decisions under missing product markets and represent the

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[2] Throughout this text we use the term “subsistence farmer” to refer to small scale farmers who produce mainly for home consumption.

value of the constrained food crop with a shadow price. Missing markets in these models are farmer-specific and arise from transaction costs that trap some farmers within a price band.

Shadow prices may diverge from market prices even in the absence of high transaction costs. Imperfect substitutability in consumption implies an asymmetric (one-sided) missing market: the farmer can sell the crop at the market price but must produce it in order to consume it. This is similar in spirit to the "partly absent market" defined by Strauss (1986). The crop is a distinct consumption good, due to qualities it embodies that are not valued in the market. The value which the household attaches to these qualities is reflected in the shadow price. The home-produced crop may be transformable into a market good (via sales). When the crop is sold, the decision price becomes the market price. The market price thus represents the lower bound on the shadow price in an asymmetric missing market.

In an asymmetric-market model, a crop can be conceptualized as a bundle of multiple characteristics. These characteristics include production attributes, consumption attributes, the subjective importance farmers place on conserving their seed, which may have provided subsistence to the family for decades, and other non-market benefits (Brush and Meng, 1998; Smale et al., 2001, 2003; Edmeades et al., 2004; Badstue et al., 2006; Dyer Leal et al., 2006).[3] All of these characteristics are convoluted where the seed is also the consumption good.

Studies of technology adoption focus primarily on production considerations, including seed attributes (e.g., plant strength, resistance to pests and disease, ear length, flowering time, adaptability to certain environments), agro-ecological conditions, risk, and information constraints that may shape farmers' variety choices (e.g., see Feder (1980); Just and Zilberman (1983); Bellon and Taylor (1993)). Market-determined output prices are used to

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[3] Small maize farmers in Mexico value maize for traditional, ceremonial, ritual values, as well as different tastes and cooking qualities (Fussell, 1992; Salvador, 1997; Berthaud and Gepts, 2004; Brush and Chauvet, 2004; Dyer Leal, 2006).

value output in most technology adoption models. In contrast to the other social science disciplines, economists have paid less attention to understanding how consumption attributes and non-market values affect the values farmers attach to their crops.

Subsistence farmers in Mexico demand a diversity of consumption attributes of maize, including ease of shelling and processing, color, taste, softness of dough and suitability for certain dishes, and these have been found to be correlated with on-farm genetic diversity of maize landraces (Smale et al., 2003; Bellon, 1996; Bellon et al., 2006; Perales et al., 2003). Some attributes are unobservable and may create an imperfect market for crops with the specific bundle of traits that farm households demand. The difficulty of buying a crop with a given set of consumption traits may be compounded if, as is typically the case, different maize varieties are mixed in the market, where it is virtually impossible to observe some attributes that are important to farmers.[4] Agricultural price support policies in Mexico traditionally have not differentiated among maize varieties. Unless every farmer's maize is of identical quality, it is impossible for the farmer to recover from the market the same quality that is perceived to exist in his or her own crop. Thus, some farmers may prefer to produce and consume their own crop, even at a cost that is well above the market price, in order to ensure the supply of all of the consumption traits they demand.

Non-market value may include the ceremonial or ritual importance associated with cultivating and consuming the subsistence crop. For indigenous farmers in Mexico, it appears to derive partly from one's identity as a good maize farmer and member of the community (Fussell, 1992; Smale et al., 2003; Badstue et al., 2006; Perales et al., 2005). When the

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[4] There could exist different silos for each maize quality, however, this would be very costly; visits to market places reveal that in practice few farmers have access to such finely differentiated markets for maize quality.

market for seed quality is also imperfect, an additional motivation for cultivating traditional varieties may be to maintain the family's seed stock and pass it down across the generations.

Findings from surveys in Mexico indicate significant differences in perceived consumption characteristics of home-produced and purchased maize (Smale et al., 2001; Preibisch et al., 2002; Dyer Leal and Yunez Naude, 2003; Dyer Leal, 2006). It is not uncommon to find that small scale maize farmers incur cash losses when their output is valued at the price of maize available in local markets (Heath, 1987; Dyer Leal and Yunez Naude, 2003; Brush and Chauvet, 2004). Rather than reflecting the "irrationality" of maize farmers, this finding likely results from the use of the wrong price to value maize production. When one takes into account the non-market benefits that farmers accrue from cultivating and consuming their own maize, cash losses may lose significance (Dyer Leal et al., 2002).

Past studies also find that most maize farmers in Mexico consume most or all of their harvest, consistent with both a transaction-cost and asymmetric-market model. Empirically, it is extremely difficult to test whether a divergence between shadow and market prices is the result of transaction costs or an asymmetric market, because broadly speaking, an asymmetric market could be conceptualized as a variant of a transaction cost model. In theory, a farmer might be able to find a variety in the market that is virtually identical to the one she could grow at home, or even select specific varieties out of the mix available in the market. This would entail transaction costs associated with information, search and sorting, however. Cultural considerations associated with cultivating maize, e.g., to preserve one's identity within the community, by definition endow home-produced maize with attributes for which there is no substitute in the market.

These arguments are not unique to maize and Mexico. Indigenous farmers in the Peruvian Andes prefer cultivating traditional potato varieties that are associated with various non-market benefits (Brush, 1992). Similarly, maize in Guatemala, wheat in Turkey and rice in the Philippines have been associated with consumption characteristics that make it difficult to purchase close substitutes in the market (Meng et al., 1998; Bellon et al., 1998; Isakson, 2007).

Centers of crop domestication and diversity are particularly important for the conservation of traditional crop varieties. Traditional varieties are the main source of crop genetic diversity because of millennia-old evolution and farmer selection to match seeds with heterogenous soil and climate conditions, as well as to meet various consumption needs (Liu et al., 2003; Berthaud and Gepts, 2004). The resulting genetic diversity is one of the most important material inputs for crop breeding research that improves yields and resistance of world food crops (Koo et al., 2003). Crop breeders agree that on-farm conservation allowing continued crop evolution in natural environments is an essential complement to gene banks (Brush, 1989; Bellon and Smale, 1999). On-farm conservation programs depend on farmers' incentives to continue cultivating these crops (Bellon and Smale, 1999). Dyer Leal and Yunez Naude (2003) and Brush and Meng (1998) acknowledge the need to use shadow prices instead of market prices to understand subsistence farmers' incentives to cultivate traditional crops with high non-market values; however, previous research does not explicitly do this.

3. Theoretical Model

The theoretical foundation for our empirical estimation of shadow prices can be illustrated by a simple model of an agricultural household in the presence of a market constraint for the subsistence maize crop. This market constraint is asymmetric, such that the farmer can sell the crop but cannot buy maize of identical quality in the market. It reflects non-market values attached to home-produced maize that make purchased maize an imperfect substitute in consumption.[5] Consequently, the home-produced and purchased maize enter the utility function as separate consumption goods.[6]

Suppose that a farmer produces output (Q) of the subsistence maize crop using labor (L), a fixed amount of land (A) and a technology described by the production function $Q = g(L, A)$.[7] Farmers allocate family and hired labor to the crop and output to home consumption (X_s^h) and the market (X_s^s), in the latter case receiving a fixed price, p_s, per unit sold. They also allocate income to consumption of the market-purchased crop (X_m), and family time to work and leisure (X_l). The household's assumed objective is to maximize utility derived from consumption of home-produced maize, the purchased crop and leisure, $U = U(X_s^h, X_m, X_l; Z)$. The agricultural household model of Singh et al. (1986) is a special case in which subsistence maize is a perfect substitute for market-purchased maize and transaction costs are nil.

Under the assumption of a perfect labor market as in Singh et al. (1986), the household can hire out its own labor and hire in as much labor as it wishes at an exogenous market wage w.

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[5] "Subsistence" and "home produced" are used interchangeably in this paper.

[6] Through informal interviews with maize farmers in 2 states (Puebla and Oaxaca) and 15 different communities in Mexico during July 2005, we have found that most farmers prefer their traditional maize for consumption; do not like modern varieties (either because they do not have the perfect growing conditions or do not like tortillas made with modern maize); think that maize production is "not just to generate income" and has some non-market values. These observations suggest two broad categories of maize; home-produced maize that is mostly traditional maize and purchased maize that is mostly modern maize.

[7] Finan et al. (2005) find that land rental markets in rural Mexico are very inactive with only 5% of farmers participating in rental market using 1999 data from 25,000 households. This ratio is 7.6% of all plots for data used in the empirical analysis of this article.

Formally, the farmer's problem is given by:

$$\max U(X_s^h, X_m, X_l; Z)$$

...subject to full-income and production constraints

$$p_m X_m + w X_l \leq p_s X_s^s - wL + wT + \bar{Y} \tag{1}$$

$$X_s^h + X_s^s \leq Q_s \tag{2}$$

...and non-negativity constraints

$$X_s^s, X_s^h, L \geq 0. \tag{3}$$

$\bar{Y}$ denotes exogenous income, and Z is a vector of household characteristics shaping marginal utilities of consumption, $U_i,\ i = s, m$. $U(.)$ is a continuously differentiable and strictly quasi-concave utility function, and $g(.)$ is a quasi-convex production function.

The full-income constraint 1 states that total expenditure on the market good and leisure cannot exceed the value of marketed surplus net of labor costs plus the value of the family's time endowment (T) and exogenous income. Constraints 2 and 3 are of special interest. Together they define the market constraint for the subsistence crop. Constraint 2 states that the consumption of the subsistence crop cannot exceed the total amount produced minus sales when an identical good cannot be obtained in the market. The non-negativity constraints state that the consumption of home-produced maize, marketed surplus and labor used for maize production cannot be negative (but they may be zero).[8,9]

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[8] We assume that the marginal utilities of the first unit of leisure and the market goods are very large (i.e. $MU_n|_{X_n=0} = \infty$, $n = l, m$), hence we are not concerned about a corner solution for X_l and X_m.

[9] This might be the case if, for example, the household did not produce the crop or its marginal utility from purchased maize were very low.

The Lagrangean associated with this model is:

$$\max_{X_s^s, X_s^h, X_l, X_m, L, \lambda, \mu_1, \mu_2, \mu_3, \mu_4} \mathscr{L} = U(X_s^h, X_m, X_l; Z) \tag{4}$$

$$+\lambda[p_s X_s^s + w\bar{T} - wL + \bar{Y} - p_m X_m - wX_l] + \mu_1[g(L, A) - X_s^s - X_s^h] + \mu_2 X_s^s + \mu_3 X_s^h + \mu_4 L$$

We discuss the first order conditions (FOC) and the Karush-Kuhn-Tucker (KKT) conditions for variables that can have corner solutions in detail in the Appendix.[10] The optimal solution implies that an agricultural household with perfect markets will equalize the ratio of marginal utilities of each good to the ratio of market prices (i.e. $\frac{MU_i}{MU_j} = \frac{p_i}{p_j}$). However, in the present model, where the market for the subsistence good is asymmetric, this condition takes the following form:

$$\frac{MU_s^h}{MU_m} = \frac{\mu_1 - \mu_3}{\lambda p_m}. \tag{5}$$

For farmers who produce some subsistence crop and consume some of it, μ_3 equals to zero; hence $\frac{\mu_1}{\lambda}$ takes the place of p_s in the conventional optimality conditions. Given this optimization rule, we define the "shadow price" of X_s^h as follows:

$$\rho \equiv \frac{\mu_1}{\lambda}, \tag{6}$$

which equals p_s if the household sells this crop. μ_1 is the marginal utility of having one more unit of Q_s, and λ is the marginal utility of income.[11] The shadow price is conceptually similar

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[10] For the KKT conditions to be sufficient for a maximum, we assume that the utility function is *pseudoconcave* in addition to the quasi-concavity and quasi-convexity assumptions above. *Pseudoconcavity* also implies quasi-concavity because *U(.)* is *pseudoconcave* if and only if its gradient vanishes only at the global optimum and it is quasi-concave (Simon, 2006).

[11] The FOC for leisure yields the same shadow price: $\frac{MU_s^h}{MU_l} = \frac{\mu_1 - \mu_3}{\lambda w}$.

to de Janvry et al. (1991); however, the conditions under which it arises are different.[12] Some farmers may not participate in markets if the non-market benefits of the subsistence crop are significant for them. For farmers who sell part (all) of their subsistence crop, the shadow price is equal to (less than or equal to) the market price. If, however, the farmer consumes all of Q at home (i.e. $X_s^s = 0$), this implies that the shadow price is greater than or equal to the selling price, i.e.:[13]

$$\rho = \frac{\mu_1}{\lambda} \geq \frac{\mu_1 - \mu_2}{\lambda} = p_s. \tag{7}$$

μ_2, the multiplier associated with the non-negativity constraint for X_s^s, represents the utility the farmer would enjoy by being able to buy an identical product in the market. Therefore, farmers constrained by the non-negativity constraint for X_s^s value the subsistence crop more than does the market.[14]

Conceptually, this model differs from the TC band model in two ways. First, the upper limit of the TC band depends on the how costly it is for a household to purchase a homogeneous good on the market, whereas in the asymmetric model it depends on the cost of finding a close substitute for the subsistence crop in the market. Second, in the asymmetric model, the lower limit of the TC band is higher for farmers who attach a higher value on their domestic crops (implying less substitutability between the domestic and market crop). Figure 1 demonstrates how allowing for imperfect substitution affects the traditional TC band model using the graphical presentation in Taylor and Adelman (2003).

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[12] ρ, is the monetary value the household would attach to having an additional unit of Q, i.e., the additional income required to increase the household's utility by the same amount as one more unit of subsistence crop production – holding the technology and inputs constant (Heckman, 1974).

[13] For this group of farmers $\mu_2 \geq 0$ and $\mu_3 = 0$. See Appendix for details.

[14] Rewriting the right hand side of the Equation 7 as $\frac{\mu_2}{\lambda} = \frac{\mu_1}{\lambda} - p_s$ provides more intuition by monetizing all terms. The monetized value of relaxing the non-negativity constraint on sales by one unit is equal to the subjective value of one more unit of production using the same inputs minus the market value of that crop. Hence the conclusion that the shadow price is greater than or equal to the market price for farmers who do not sell any subsistence crop given market prices.

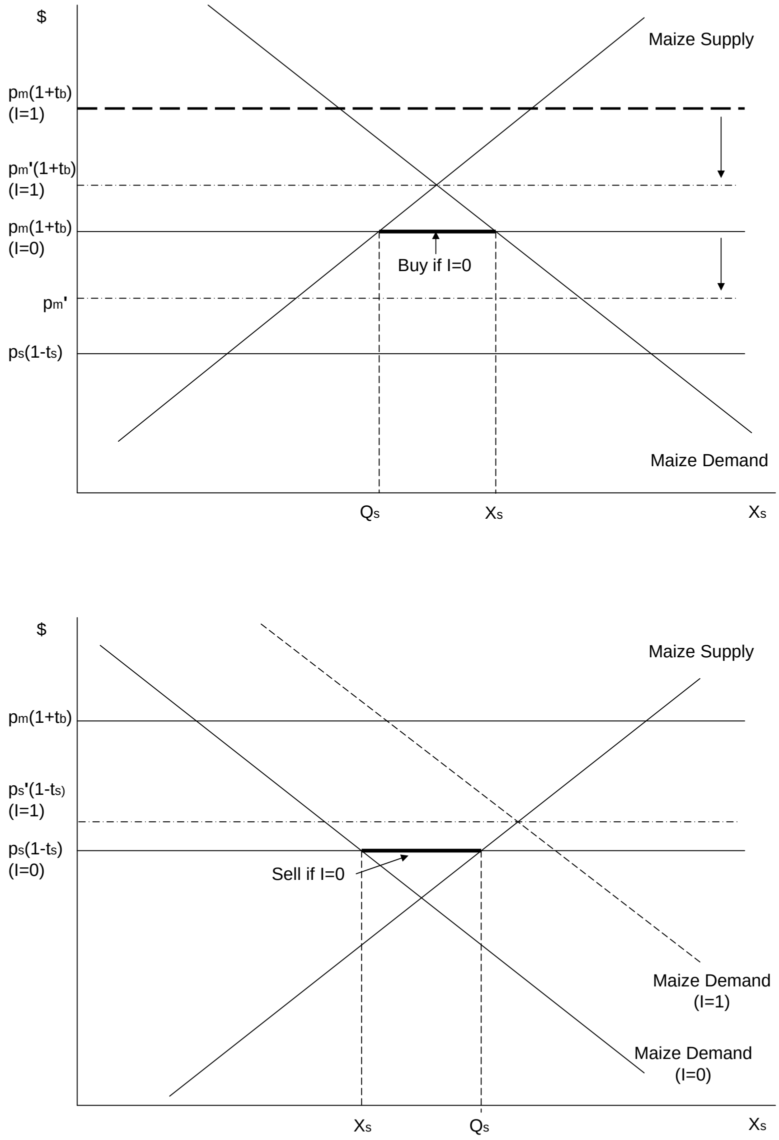

Figure 1. Transaction cost band and imperfect substitutability in consumption due to non-market values of domestic crop. The top panel shows the wider TC band for $I = 1$ as opposed to the TC band for $I = 0$. The bottom panel shows the higher selling price required to enter the market by farmers with $I = 1$.

Consider two agricultural households, one that attaches high non-market values to the home-produced crop ($I = 1$) and another that does not ($I = 0$). Suppose that both are identical in all other respects, including facing the same observable transaction cost associated with buying (t_b) and selling (t_s) a unit of average-quality maize in the market at price p. In this example, a a farmer with $I = 0$ will produce Q_s and buy maize equal to the difference between demand and supply of domestic maize (i.e. $X_s - Q_s$). However, a farmer with $I = 1$ will not buy at the given price, because for her the transaction costs associated with finding a close substitute for the domestic good are higher. This is represented by the wider transaction cost band for this farmer. (See the bold dashed upper limit of the TC band for $I = 1$). Some farmers with $I = 1$ do not buy maize in the market even though they face the same transaction costs as others who are in the market. Farmers who have higher unobserved transaction costs will begin buying in the market only after the market price and/or observable TC is lower than $p'_m(1 + t_b)$, corresponding to a lower market price p'_m. As a result, supply response to market signals may be more inelastic than depicted in a conventional transaction cost model

The bottom panel of figure 1 depicts the demand for maize by the two farmers. The higher valuation of the subsistence crop for $I = 1$ is represented by the greater willingness to pay for home-grown maize and less willingness to sell at the market price.

For farmers within the TC band defined as above, production decisions are affected by the shadow price, which in turn depends on household characteristics that would not affect production under perfect market scenario.

Estimation Strategy for the Shadow Price. For a farmer who produces the subsistence crop (i.e. $\mu_4 = 0$), the FOC for L yields:

$$\mu_1 MPL_s = \lambda w \tag{8}$$

The left hand side of equation 8 represents the marginal benefit the farmer receives (in utility terms) from allocating an additional unit of labor to the production of the subsistence crop.

The right hand side represents the marginal cost of that last unit of labor in utility terms.[15] Although μ_1 and λ are not observable, we can define an estimable expression for ρ as follows:

$$\rho \equiv \frac{\mu_1}{\lambda} = \frac{w}{MPL_s}. \tag{9}$$

When the shadow price exceeds the market price, farmers appear to allocate excessive amounts of inputs to the subsistence crop. A high shadow price can explain the rationality of farmers' behavior by capturing the non-market values associated with the subsistence crop.

Given Equation 9 and using an empirical method similar to that used in the shadow wage models of Jacoby (1993) and Skoufias (1994), we can econometrically estimate household-specific shadow prices, test whether they are significantly different from market prices and analyze the determinants of this difference. The method entails estimating production functions for maize in subsistence and commercial households; using equation 9 to obtain shadow price estimates; then testing for differences between these and market prices.

4. Estimation and Decomposition of Shadow Prices

The empirical analysis uses agricultural household data from the Mexican National Rural Household Survey (ENHRUM), carried out in January-February 2003. The sample of 1782 households was designed by the National Institute of Statistics, Geography and Informatics (INEGI) to be nationally representative of rural Mexico.[16] The survey gathered the data

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[15] This is because λ is the marginal utility of income and it is multiplied by the wage the farmer pays for labor.

[16] For a geographical distribution of the communities in the ENHRUM sample see `http://precesam.colmex.mx/ENHRUM/Encuenta\%20Hogares_archivos/Mapa\%20regiones1.htm`.

required for this analysis, including information on household demographics; plot level information on inputs and output of all crops; marketing and consumption of agricultural and livestock products; and maize seed varieties and their origins. It also gathered information about migration and work histories, off-farm income sources, credit market participation and household assets.[17]

The survey covers all agricultural activities in two crop cycles (Spring-Summer and Autumn-Winter) in 2002. 573 households cultivated maize on 897 plot-cycles. Input data at the plot level make it possible to control for plot characteristics when estimating production functions. This is difficult for plots with multiple crops, however. Thus, we restrict the analysis to plots cultivated only with maize, which constituted 63% of all maize plots and 67% of maize growing households in the sample.[18] Among plots monocropped in maize, 86% were planted with traditional varieties (TVs) as opposed to modern varieties (MVs; table 1).[19] In the South-Southeast Region, which includes the poorest and most heavily indigenous states in Mexico, 92% of the plots were cultivated with TVs. In the Northwest Region, which includes states with higher GDP per capita, large scale farming and industrial production (Chiquiar, 2005), only 15% of plots were cultivated with TVs.

Summary statistics in table 1 reveal that households in the South-Southeast and Central Regions have lower wealth; own less land, mostly not irrigated; and are more likely to

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[17] For more details on the ENHRUM data see: `http://precesam.colmex.mx`.

[18] We tested whether some key variables that affect households' production and preferences differ significantly between the sub-sample and the whole sample. We conclude that the subsample we use in the empirical analysis is not statistically significantly different from the whole sample. Details are available upon request.

[19] Classification of maize into distinct varieties is problematic due to the open pollinated nature of maize (Bellon et al., 2006). We use farmer definitions to classify maize into traditional and improved varieties. Traditional maize (TV) refers to maize identified as *"criollo"* by farmers. Modern maize (MV) refers to maize identified as *"híbrido."*

Table 1. Means of Plot and Household Characteristics by Region

	TV plots (%)	Wealth Index (q-tile)	Total land owned (ha.)	Irrigated land (%)	Indigenous %	Total farm inc. ($MX)	Maize sold (%)
South-Southeast	92	1.63	6.71	9.57	74	2,105	9
Central	93	2.03	1.74	21.06	29	7,572	7
Western Cent.	78	3.46	8.37	17.21	2	12,705	31
Northwest	15	4.85	21.43	61.54	0	124,596	83
Northeast	80	2.95	61.73	7.09	3	8,260	13
Total	86	2.28	10.93	15.85	4	9,067	14

belong to an indigenous community.[20] They also have less farm income and sell only small percentages of their total maize production.

In the full sample, 74% of households did not sell any maize in the market, and this proportion increases to 80% for households that grow only TVs. Controlling for variables likely to influence transaction costs, we expect the shadow prices of TVs to be higher than market prices for these households, reflecting the non-market benefits farmers receive from them.

4.1. Econometric Model: Estimating production functions and shadow prices of maize.

The production technologies of MVs and TVs are different. MVs require irrigation and regular application of fertilizers and pesticides, whereas TVs are usually grown on rain-fed land with little or no fertilizer. Farmers perceive that TVs are more resistant to pests and diseases during storage, which makes them preferable for subsistence households that save their own seed (Bellon et al., 2006). Some of these differences can be observed in table 2. There is a three-fold difference between the yields of the two types of maize. TVs are produced on smaller plots, with more labor, less fertilizer and less investment. 69% of

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[20] The wealth index was created using Principal Component Analysis based on the characteristics of households' primary residence, access to utilities, and ownership of a television and refrigerator. Quintiles of the wealth index give an idea of the distribution of wealth in the sample.

Table 2. Summary Statistics for Plots Cultivated with TV and MV

Variable name	**Definition**	**TV**	**MV**
yieldpha	Yield (kg./ha.)	875.71	2821.24
noryieldpha	Yield in a normal year	1471.31	3914.08
land	Plot area (ha.)	1.94	3.41
seedpha	Seed amount/ha.	19.36	21.77
totlabpha	Total labor (days/ha.)	58.93	39.08
machpha	Total machinery hours/ha.	6.42	25.03
animpha	Total animal hours/ha.	15.62	7.53
inpcostpha	Total input cost/ha. (fert.&pestic.)	474.83	642.25
investpha	Fixed investment spending ($MX/ha.)	73.84	365.94
irrigD	Irrigation dummy	0.11	0.37
soilq	Soil quality (1: Bad, 2: Regular, 3: Good)	2.33	2.20
slope	Slope (1: Plain, 2: Sloped, 3: Very steep)	1.55	1.41
droughtD	Drought dummy	0.33	0.39
m1400	Plot is > 1400 masl.	0.76	0.63
ownseedD	Used own seed (%)	0.69	0.13
walktime	Walking time from the parcel to the community center (mins.)	39.04	38.41
N	Number of observations	476	75

traditional maize plots are cultivated with saved seed, as opposed to 13% of modern maize plots.

Therefore, we specify plot-specific production functions for TVs and MVs separately as:

$$Q_i = g_i(\mathbf{V}|\mathbf{P}, \mathbf{Z}_q) + v_i, \quad i = TV, MV \tag{10}$$

where $\mathbf{V}$ is a vector of variable inputs and $\mathbf{P}$ is a vector of plot characteristics such as soil quality, slope and elevation. $\mathbf{Z}_q$ is a vector of household characteristics that affect production through their effects on preferences due to the non-recursive nature of farmers' problem, and v is a random error. Ideally we would like to estimate the production functions using panel data to control for unobservable household variables (e.g., ability) that affect production. Given the cross sectional nature of our data, we use regional fixed effects and cluster the regression standard errors at the Rural Development District (DDR) level to correct for potential error correlation due to unobserved characteristics that are common to all households within a DDR.[21]

We estimate the production functions using a log-Cobb-Douglas specification as in Jacoby (1993) and Skoufias (1994), which provides a good approximation for general input elasticities when the focus is not on the production structure (Murthy, 2002). The estimated coefficients are input elasticities, $\hat{\beta} = \frac{\partial Q}{\partial L}\frac{L}{Q}$; hence the estimated MPL of labor is $M\hat{P}L = \hat{\beta}\frac{Q}{L}$ (Jacoby, 1993; Skoufias, 1994). We use the $M\hat{P}L$ to calculate the estimated shadow prices for both varieties based on equation 9.

Estimates of production functions for TVs and MVs can suffer from selection bias if there are unobservable variables that affect both farmers' crop choice and productivity (Vella, 1998). Using the Heckman procedure, we fail to reject the null hypothesis associated with sample-selectivity bias; the p-values of the Wald test to test the independence of the selection and outcome equations were 0.48 and 0.86, for TVs and MVs respectively.[22] This result is robust to different specifications with different sets of identifying instruments.

One might suspect that farmers who produce maize exclusively for home consumption and those who produce it commercially differ in terms of production practices. We define commercially oriented farmers as those who sold more than 30% of their maize in the survey year. (They constituted 27% of all maize farmers.) Differences between commercial and

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[21] Rural Development Districts are districts defined by SAGARPA (Secretary of Agriculture, Ranching, Rural Development, Fisheries, and Food Supply) that have similar production potentials. See `http://www.cem.itesm.mx/derecho/nlegislacion/federal/35/index.html` Capitulo 6, 7 and 8.

[22] We use six exogenous variables as identifying instruments: the percentage of plots in the same village that are cultivated with TVs/MVs excluding the farmer's own plots, the percentage of the village maize production that is marketed excluding the farmer's sales, the percentage of households in the village that had off-farm income from employment in other parts of Mexico and in the US in 1980, whether the farmer speaks an indigenous language very well and whether he/she has saved any maize seed for longer than 2 years at the time of the survey. Given that the Heckman regressions are not the focus of the present paper, they are available from the authors upon request.

non-commercial farmers with regard to their use of labor, animal traction and plot slope are statistically significant (table 3).

Table 3. Differences Between Commercial and Non-commercial Farmers

Sold more than 30%?	**Labor days/ha**	**Seed kg/ha**	**Machinery hrs/ha**	**Animal hrs/ha**	**Soil quality**	**Slope**
No	62.33	19.89	4.39	16.36	2.31	1.57
Yes	24.80	18.68	4.84	5.18	2.31	1.33
Difference	37.53*	1.21	-0.45	11.18*	0	0.24*

* Indicates that the difference between the means of two groups is statistically significant at %10 level using a t-test.

We employ a two-stage least squares (2SLS) model with instrumental variables (IV) to control for the endogeneity of farmers' status as commercial or subsistence farmers when estimating the production functions. Two-stage least squares estimation employs a linear probability model with instruments in the first stage. Because the first stage involves a binary variable, the use of a probit model might seem more intuitive; however, the probit depends on the normality assumption. Angrist (2000) shows that a linear probability model is consistent regardless of whether the first stage is linear or not, concluding that "it is safer to use a linear first stage." We report the results of the 2SLS method in table 4.[23]

The following instruments are used for farmer commercial status: the percentage of village maize production sold, the time required to travel from the household dwelling to the community center on foot, and dummy variables identifying whether the household had an immediate family member working for a wage off-farm or as a migrant in Mexico or in the US in 1980, 22 years prior to the survey. The percentage of village maize production sold in the market may affect farmers' commercial orientation through network effects or village market structure. However, this variable should not affect productivity except through its influence

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[23] The results of IV-probit model are very similar to the 2SLS results and are available upon request.

TABLE 4. Production Functions Estimated with 2SLS to Control for the Endogenous Commercial Farmer Dummy (Dep. var: ln(yieldpha))

Variables	TV	MV
ln(land)	-0.307***	-0.17
ln(totlabpha)	0.178*	0.232*
ln(seedpha)	0.194**	0.676**
ln(inpcostpha)	0.121***	0.075
ln(machpha)	0.15	0.655**
ln(animpha)	0.029	0.062
droughtD	-0.084	-0.755*
soilq†	0.300***	0.218
slope†	0.051	-0.617**
irrigD	0.425	0.525***
m1400	-0.036	-1.026***
age	-0.008	-0.030*
educ	-0.043	-0.05
South-Southeast	-0.737	-0.401
Central	-0.559	-1.287**
Western Central	-0.443	-0.422
sold30	0.727	0.304
Constant	5.452***	5.684***
Observations	425	66

Significance levels: * : 10% ** : 5% *** : 1%

† We rescaled soil quality and slope as (-1,0,1) to prevent unnecessary imposition of a cardinal meaning to categorical variables.

on the farmer commercial-status dummy. Community centers are usually where markets are located; hence, the time required to go there may be correlated with the commercial farmer dummy, but it should not affect productivity directly. Even if there is no market at the community center, this variable can instrument for access to information about marketing opportunities that may be correlated with commercial farming. Wage work and migration experience may influence attitudes towards participating in markets or the capacity to do so (e.g., information networks outside the village). However, these variables are measured far enough back in time that they should not affect current production.

Table 5. Tests for the Validity of Instrumental Variables (p-values reported)

Tests	**TV**	**MV**
Underid. test: H_0=Eqn. is underidentified		
Anderson canonical correlation	0.01	0
Overid. tests: H_0=Overid. restrictions are valid		
Hansen J Statistic	0.41	0.25
Anderson-Rubin F-test	0.27	0.69

An Anderson Canonical Correlations test easily rejects the hypothesis that the equation is underidentified (5).[24] Overidentification tests fail to reject the hypothesis that the instruments are uncorrelated with the error term and correctly excluded from the production function equation.[25] Therefore, we conclude that the instruments are reasonably valid.

The results of the production function estimation are reported in table 4.[26] All of the estimated input elasticities are positive as expected. There are some notable differences between the production functions for TVs and MVs. There are significant decreasing returns to scale to land for TVs but not MVs. Drought, slope and elevation are correlated significantly and negatively with per hectare productivity of MVs, but the correlation is not significant for TVs, suggesting that, other things constant, TVs are more resilient to sub-optimal growing conditions, consistent with findings of past research (Bellon and Taylor, 1993; Smale et al., 1994).

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[24] The Anderson canonical correlations test is a likelihood-ratio test of whether the equation is identified, i.e., that the excluded instruments are "relevant," meaning correlated with the endogenous regressors. These tests are done using Stata's **ivreg2** command (Baum et al., 2002).

[25] Hansen J statistic tests the joint null hypothesis is that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. Under the null, the test statistic is distributed as chi-squared in the number of overidentifying restrictions. Anderson-Rubin statistic is a Wald test that is distributed as chi-squared with L2 degrees of freedom, where L2 is the number of excluded instruments.

[26] Because the number of plots per household vary, the reciprocal of the square root of the number of plots for each household is used as a weight to ensure equal representation.

Table 6. Summary Statistics for Estimated Shadow Prices and Observed Market Prices

Variable	**TV**	**MV**
Shadow price for full sample	48.34	13.77
Shadow price for sellers	20.50	5.19
Shadow price for non-sellers	58.18	25.53
Observed market price/kg.	1.98	1.57

The estimated labor elasticities are the basis for calculating the marginal product of labor (MPL) and shadow prices of home-produced maize for each farmer using Equation 9.[27] Table 6 summarizes shadow prices for sellers and non-sellers of both maize variety categories.

Estimated shadow prices are significantly higher for TVs than MVs, and they are higher for non-sellers of both varieties. The average village-level market price is lower than the shadow prices for all groups. The difference between market prices and estimated shadow prices is large, consistent with inelastic marginal value product curves in traditional farming systems. This is illustrated in figure 2. Very high shadow prices indicate that more labor is applied than would appear optimal if the marginal value product of labor were estimated using the market price of maize. This excess application of labor need not be large to produce high shadow prices if the marginal product of labor is inelastic. In the figure, observing a labor input of L' instead of L^* implies a shadow price that far exceeds the market price. The high levels of labor use observed in these households is consistent with a higher subjective valuation of landraces, especially by non-sellers. Smale (2005) argues that labor to land ratios explain where landraces are still grown and will continue to be grown. A high labor to land ratio, ceteris paribus, corresponds to a high shadow price in the current model.

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[27] Equation 9 essentially assumes that the labor market is perfect for the households in the sample, because it uses market wages to value their time. We have tested this assumption by estimating production functions with family labor and hired labor separated. We calculated the shadow wages for family labor and ran the test of separability as in Jacoby (1993) for farmers who sold some of their product in the market. We fail to reject the separability hypothesis and conclude that shadow wages are not significantly different from market wages, hence use the market wage to value households' time.

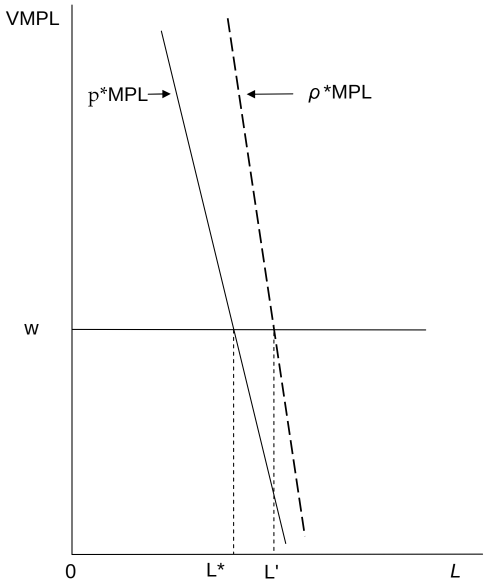

FIGURE 2. Inelastic $VMPL$ for subsistence maize production. An increase in labor from L^* to L' would decrease the MPL by a lot resulting in a high shadow price. The decreasing distance between the two lines indicates the decrease in the shadow price as more output is produced with more labor.

To test whether the estimated shadow prices are significantly different from market prices, we use the method in Jacoby (1993) and Skoufias (1994). The regression

$$\hat{\rho} = \alpha + \beta p + u, \tag{11}$$

was estimated for sellers and non-sellers of both TVs and MVs to test the null hypothesis of $\alpha = 0, \quad \beta = 1$. Under the null, the market price reflects the value of the marginal product of labor. Rejection of H_0 implies that market prices do not reflect farmers' subjective valuation of the crop; thus, estimated shadow prices are a more accurate basis for understanding farmer behavior. We estimate Equation 11 using weighted least squares and the same weights as in the production function estimation. We also use village level clusters to control for possible error correlation among farmers in the same village.

Table 7. Are Estimated Shadow Prices Equal to Observed Market Prices?

	MV		TV	
	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\alpha}$	$\hat{\beta}$
Seller	-1.94	5.22	21.08	0.70
F-test	(0.17)		(0.00)	
t-tests	(0.83)	(0.44)	(0.38)	(0.97)
Non-seller	-15.03	40.10	52.95	2.62
F-test	(0.17)		(0.00)	
t-tests	(0.77)	(0.41)	(0.06)	(0.89)

(p-values in parentheses)

Table 7 summarizes the results of F-tests and t-tests corresponding to the null hypothesis. For MVs, we fail to reject the null hypothesis of equality of shadow and market prices with both tests regardless of whether or not the farmer sold maize.

For sellers of TVs, the F-test rejects the joint hypothesis; however, the individual t-tests fail to reject the equality of shadow and market prices. We can conclude that although the average estimated shadow price for sellers of TVs is higher than the local market price, this difference is not statistically significant; hence, we can use market prices to represent the value of domestic maize to a farmer who is selling it in the market.

For non-sellers of TVs, in contrast, both F and t-tests easily reject the null hypothesis that estimated shadow prices are equal to market prices: $\hat{\alpha}$ is significantly different from zero at the 6% level.

4.2. **What predicts high shadow prices?** Based on the theoretical model developed in Section 3, endogenous shadow prices depend on household characteristics (through preferences and endowments), plot characteristics and indicators of market access. Table 8 summarizes the sample means of estimated shadow prices and some socio-economic and market access variables for the non-sellers of TVs by region. The South-Southeast region has the highest estimated shadow prices and the highest percentage of indigenous farmers.

Table 8. Sample Means of Socio-economic and Market Access Variables by Region

Region	$\hat{\rho}$	**indig.**	**wqtile**	**offarmD**	**ownseed**	**TC/kg**
South-Southeast	84.95	0.72	1.5	0.38	0.69	0
Central	34.25	0.26	2.06	0.5	0.75	0.02
Western Cent.	56.72	0.02	2.95	0.47	0.36	0
Northwest	0.18	0	4.75	0.75	0.25	0.00
Northeast	20.05	0	2.88	0.63	0.40	0.01
Total	58.18	0.38	2.07	0.46	0.63	0.01

This region also exhibits the lowest levels of wealth and off-farm income in the sample. Most farmers in the Northwest and Northeast regions have some kind of off-farm income, and they have the smallest shadow prices for TVs. Wealth and off-farm income both appear to be negatively correlated with farmers' subjective valuation of TVs, based on unconditional means. More farmers in the Southern and Central regions use their own seed, and this seems to be correlated with high shadow prices. The last column summarizes the transportation costs per kilogram paid by farmers to buy/sell maize. These costs are very small and cannot justify the high estimated shadow prices.

The differences between estimated shadow and observed market prices can be analyzed econometrically using the following equation:

$$\hat{\rho} - p = f(\mathbf{P}, \mathbf{Z}) + u. \tag{12}$$

P, as in equation 10, is a vector of plot characteristics that affect production; **Z** is a vector of preference shifters, of which $\mathbf{Z}_q$ is a subset. The fact that $\hat{\rho}$ is not observed directly but estimated with error introduces an additional source of variance to the standard errors in this regression (Dumont et al., 2005). We use bootstrapping to correct for this potential bias following Cameron and Trivedi (2005).

Determinants of farmers' crop choices and preferences for traditional crops from other studies are included in the vector **Z** (Bellon and Smale, 1999; Van Dusen, 2000; Meng, 1997; Brush and Meng, 1998; Smale, 2006). They include: wealth, gender, age, education, land size, animals owned, the share of maize area, migration, off-farm income, credit access, time spent to go to community center, government transfers, soil quality, slope, altitude, irrigation and regional controls. All of these variables have different correlations with on farm diversity in different settings as summarized in Smale (2006). Indigenous identity is often cited as being correlated with the cultivation of traditional crops; however, it is generally absent from econometric analyses (Brush and Perales, 2007; Perales et al., 2005; Preibisch et al., 2002). We include a dummy variable to test for an effect of indigenous status on shadow-price divergence. It equals one if the farmer speaks an indigenous language and zero otherwise.

Table 9 presents the results of the price-divergence regression, with standard errors clustered by household and village to control for possible error correlation across plots of the same household or of different households within the same village. We use two different specifications: Column (1) uses only socio-economic variables that shape farmers' preferences, and Column (2) includes variables related to farmers' market access in addition to socio-economic variables.

The coefficient on the indigenous dummy is significant and positive. This indicates that non-market values of TVs captured in shadow prices are higher for indigenous farmers, underlining their role as stewards of genetic diversity. The gender dummy is also significant: male farmers appear to value TVs more highly than female farmers.

Bellon and Taylor (1993) find that cultivation of TVs is negatively correlated with high soil quality in the region they studied in southeastern Mexico. We find that soil quality is

Table 9. Decomposing the Difference Between Shadow and Market Prices of Traditional Maize, i.e. $\hat{\rho} - p$. (Standard errors are bootstrapped.)

$(\hat{\rho} - p)$	**(1)**	**(2)**
irrigD		-39.77^{***}
soilq		-33.52^{**}
walktime		0.34^{*}
othersoffD		35.91
otherscredit		-18.99
slope		-4.42
m1400		-22.06
indigenous	25.76^{*}	26.57^{*}
gender	35.47^{**}	35.73^{**}
wealth ind.	-2.99	-2.83
age	-0.26	-0.17
educ	-1.48	-1.1
area owned	-0.05	-0.09
maize area, %	23.76	17.53
Bracero	-16.11	-17.62
South-Southeast	41.98	50.33
Central	-1.46	15.73
Western Cent.	44.81	51.89^{*}
Northwest	18.72	71.81
Constant	-10.8	-13.66
Root MSE	99.33	97.32
AIC	3793	3787

Significance levels : $*$: 10% $**$: 5% $***$: 1%

negatively and significantly correlated with farmers' subjective valuation of TVs, consistent with that finding. Irrigation is also negatively and significantly correlated with shadow prices. Perales et al. (2003) find that altitude is positively correlated with the cultivation of maize landraces in Mexico in his small sample of villages in Central Mexico. This variable was not found to be a significant determinant of shadow prices using the national data.

The insignificance of wealth, household size and farmer human capital mirror the conflicting influences of these variables on seed-variety choice elsewhere in the literature (Smale, 2006; Bellon and Taylor, 1993). Shadow prices are not significantly associated with farm size. It has been argued that international migration is a deterrent to on-farm conservation of maize landraces in Mexico (Nadal, 2000; Turrent and Serratos-Hernandez, 2004).

Inasmuch as migration and planting decisions are likely to be correlated, we included a dummy variable identifying households with at least one member who ever participated in the Bracero Program.[28] If migration shifts households' preferences towards market goods, we might expect that households with migration histories will have a lower valuation for TVs. Although the Bracero variable has a negative coefficient, it is not significant.

Three variables represent market access: the percentage of farmers in the village that have-off farm income (othersoffD), the percentage of farmers in the village that have some kind of credit (otherscredit) and the time it takes for the farmer to go to the community center (walktime).[29] The relationship between on-farm diversity and market access is theoretically ambiguous (Van Dusen and Taylor, 2005). Although some previous studies find a negative effect (Bellon and Taylor, 1993; Meng, 1997; Van Dusen, 2000; Smale et al., 1994), we do not find evidence that farmers' valuation of TVs decreases with market access.

4.3. **Additional Estimation Concerns and Caveats.** It is not possible to fully control for heterogeneity among households when estimating production functions using cross-section data. We experimented with the method proposed by Barrett et al. (2004), to control for household unobservables using cross-section data. However, in the ENHRUM data, there were insufficient households cultivating both varieties at the same time to do this. The best that could be done in this regard was to include regional fixed-effects and cluster. Although these methods address the unobservables at the regional level and the error correlation within DDRs, they do not directly address household unobservables. Fortunately, the ENHRUM data provide a rich set of controls, including plot quality variables, to capture heterogeneity

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[28] The Bracero Program was actually a series of binational agreements under which Mexican workers were contracted legally to work in the US, primarily in agriculture. The program lasted from 1942 until 1964, during which time approximately 4 million "braceros" came to the US.

[29] The first two variables exclude the farmer himself/herself to remove potential endogeneity of these variables.

among households. A fixed-effects model would not allow one explicitly to estimate the ways in which time-invariant variables, like plot traits, ethnic status and geographic location, influence shadow prices. The influences of these variables on shadow prices is a focus of the present research. Neither fixed-effects nor cross-sectional methods control for time-varying unobservables. The endogeneity and selectivity issues controlled for in our econometrics are germane regardless of whether or not panel data are available.

One might argue that because production is uncertain and farmers are risk averse, more labor may be applied to maize as a mechanism to hedge against down-side risk, inflating shadow price estimates. Risk and uncertainty are not part of our model, and it is not clear how one would identify their effects on shadow prices using these data. Nevertheless, if risk did account for the discrepancy between shadow and market prices, we would not expect to observe higher shadow prices for TVs than MVs unless the latter were less risky. This is not consistent with received wisdom (Feder, 1980; Day-Rubenstein and Heisey, 2007) nor with farmer's perceptions of the risk attributes of traditional and improved varieties (Smale et al., 1994, 2001; Edmeades et al., 2004; Bellon et al., 2006). To the extent that farmers' risk aversion is decreasing in wealth, our model may control for risk attitudes indirectly through the wealth index.

The methodology used here is applied to traditional varieties as a group. It does not test for differences in shadow prices among TVs. While ideally one might wish to estimate shadow prices for each variety, this is not possible given the available data, and identification challenges multiply when new varieties are added to the analysis. Understanding the non-market incentives for cultivating diverse varieties, we believe, is a priority for future research.

The method proposed here can serve as a basis for doing this, and it is flexible enough to be applied to other crops.

5. Summary and Conclusions

When farmers attach significant non-market values to their crops, resource allocation decisions are better modeled by allowing decision prices to deviate from market prices. Using market prices to value output may lead to puzzling results when, as frequently found, farmers allocate more resources to production than would appear to be justified by conventional profit-maximization criteria. Shadow prices that deviate from market prices may confound estimates of supply response. Farmers may exhibit an inelastic supply response to market price shocks even if the supply elasticity with respect to endogenous shadow prices is high.

Empirically, we find significant divergence between shadow and market prices of traditional maize varieties in Mexico. Controlling for variables conventionally used to represent market transaction costs, this finding is consistent with an asymmetric market in which traits of home-grown maize valued by farmers and their households are not reflected in market prices. In contrast, estimated shadow prices are not significantly higher than market prices for improved maize varieties. High shadow prices create incentives to grow subsistence crops with non-market values.

These results have obvious implications for modeling supply response but also for designing programs to promote on-farm crop genetic resource (CGR) conservation. CGR policies can be made more cost effective by targeting populations with high shadow prices, for which de facto conservation is more likely (Bellon and Smale, 1999; Louette et al., 1997; Peterson, 2000; Altieri, 2004). The insignificance of wealth, credit and off-farm income variables in explaining shadow prices suggests that there may not necessarily be a tradeoff between development and conservation in populations that presently place a high value on growing traditional crops. More resources may be needed to promote in-situ conservation of TVs in regions where indigenous identity is not strong, irrigation projects are being developed or programs to improve soil quality exist. The potential negative effects of such projects on the cultivation of TVs in areas of diversity might be counteracted via the use of ancillary programs to increase farmers' incentives to maintain TVs, for example, conservation payments or programs to create niche markets for exotic maize varieties. Shadow price estimates can serve as a guide to determine required subsidies in these cases. Although policies may increase the incentives to grow TVs in areas where de facto incentives are low, they are likely to be costly. A more effective way of allocating conservation budgets might be to prioritize ex-situ conservation in regions where farm households do not presently attach a high non-market value to the traits of TVs.

Appendix: KKT Conditions

The Lagrangean for the theoretical model is:

$$\max_{X_s^h, X_s^s, X_m, X_l, L, \lambda, \mu_1, \mu_2, \mu_3, \mu_4} \mathscr{L} = U(X_s^h, X_m, X_l; Z) \tag{13}$$

$$+\lambda[p_s X_s^s + w\bar{T} - wL + \bar{Y} - p_m X_m - wX_l] + \mu_1[g(L, A) - X_s^s - X_s^h] + \mu_2 X_s^s + \mu_3 X_s^h + \mu_4 L$$

The first order conditions (FOC) are:

$$X_s^s : \lambda p_s = \mu_1 - \mu_2 \tag{14}$$

$$X_h^s : MU_s = \mu_1 - \mu_3 \tag{15}$$

$$X^m : MU_m = \lambda p_m \tag{16}$$

$$X_l : MU_l = \lambda w \tag{17}$$

$$L : \mu_1 MPL = \lambda w - \mu_4 \tag{18}$$

Leisure and the consumption of the market good cannot be zero by assumption, hence we can use the FOC to get their optimal conditions. Farmer equates the monetized value of his marginal utility of leisure and the market good respectively to wage rate and the market price at the optimum. We need to use the KKT conditions for optimal choices of X_s^s, X_s^h and L because of the possibility of corner solutions for these variables. For the KKT conditions to be sufficient for a maximum, we assume that the utility function is *pseudoconcave* in addition to the quasi-concavity and quasi-convexity assumptions above. *Pseudoconcavity* also implies quasi-concavity because *U(.)* is *pseudoconcave* if and only if its gradient vanishes only at the global optimum and it is quasi-concave (Simon, 2006). The KKT conditions are:

$$\frac{\partial \mathscr{L}}{\partial X_s^s} : \lambda p_s - \mu_1 + \mu_2 = 0 \tag{19}$$

$$\frac{\partial \mathscr{L}}{\partial \mu_2} : X_s^s \geq 0 \tag{20}$$

$$\mu_2 X_s^s = 0 \tag{21}$$

$$\frac{\partial \mathscr{L}}{\partial X_s^h} : MU_s^h - \mu_1 + \mu_3 = 0 \tag{22}$$

$$\frac{\partial \mathscr{L}}{\partial \mu_3} : X_s^h \geq 0 \tag{23}$$

$$\mu_3 X_s^h = 0 \tag{24}$$

$$\frac{\partial \mathscr{L}}{\partial L} : \mu_1 MPL - \lambda w + \mu_4 = 0 \tag{25}$$

$$\frac{\partial \mathscr{L}}{\partial \mu_4} : L \geq 0 \tag{26}$$

$$\mu_4 L = 0 \tag{27}$$

Let us interpret the different cases implied by the KKT conditions related to the production and consumption of the subsistence crop:

Case 1: $X_s^s > 0, X_s^h > 0, Q(L, A) - X_s^s - X_s^h > 0, L > 0, \mu_4 = 0.$

If the sum of home consumption and sales of Q is less than the total production, market price has to be equal to zero by 19. Therefore there will never be waste since market prices are strictly positive. For the following cases we assume that there is no waste and hence $\mu_1 > 0$.

Case 2: $X_s^s > 0, X_s^h > 0, L = 0, \mu_4 \geq 0$.

This case is impossible, since the farmer has to have $L > 0$ to be able to sell any Q. For $L = 0$, we can similarly rule out the cases where $X_s^s > 0, X_s^h = 0$ and $X_s^s = 0, X_s^h > 0$.

Case 3: $X_s^s = X_s^h = 0, L = 0, \mu_4 \geq 0$.

This case represents farmers who do not grow subsistence crop. We can rewrite the Equation 25 to get:

$$\frac{\mu_1}{\lambda} MPL = w - \frac{\mu_4}{\lambda}. \tag{28}$$

This condition indicates that the "shadow value of marginal product" of an extra unit of labor allocated to the cultivation of Q is less than the market wage. For farmers in this group the non-market benefits of the subsistence crop are not important. Therefore it is not worthwhile to allocate any labor to subsistence crop production.

Case 4: $X_s^s > 0, X_s^h > 0, L > 0, \mu_{2,3,4} = 0$.

This case characterizes the farmer who sells part of Q in the market. For this group of farmers market price equals shadow price, i.e. $\rho = p_s = \frac{\mu_1}{\lambda}$ and we can safely use market price to represent farmers' valuation of the subsistence crop. Therefore, the optimality conditions for allocation of labor is the conventional condition, where farmer equates the value of marginal product of labor to the wage rate, i.e.:

$$p_s MPL = w. \tag{29}$$

Case 5: $X_s^s > 0, X_s^h = 0, L > 0, \mu_3 \geq 0, \mu_4 = 0$.

Farmer is selling all his product at the market price, which is greater than or equal to the shadow price, i.e.

$$\rho = \frac{\mu_1 - \mu_3}{\lambda} \leq \frac{\mu_1}{\lambda} = p_s \tag{30}$$

This case is similar to Case 3 and we can use market prices. The case where both X_s^h and X_s^s are equal to zero when $L > 0$ is not likely to occur (given the "no-waste" assumption in Case 1), hence will not be considered here.

Case 6: $X_s^s = 0, X_s^h > 0, L > 0, \mu_2 \geq 0, \mu_{3,4} = 0$.

This case characterizes subsistence farmers, who consume all of their subsistence crop at home. The market price is less than or equal to farmers' shadow price as given by 19:

$$p_s = \frac{\mu_1 - \mu_2}{\lambda} \leq \frac{\mu_1}{\lambda} = \rho \tag{31}$$

Farmer is not selling Q since he values it more than the market. Rewriting the left hand side of this inequality as $\frac{\mu_2}{\lambda} = \frac{\mu_1}{\lambda} - p_s$ provides more intuition by monetizing all terms. The monetized value of relaxing the non-negativity constraint on sales by one unit is equal to the subjective value of one more unit of production using the same inputs minus the market value of that crop. Hence the conclusion that the shadow price is greater than or equal to the market price for farmers who do not sell any subsistence crop given market prices.

The optimality condition for labor sets the "shadow value of marginal product" of labor equal to market wage:

$$\frac{\mu_1}{\lambda} MPL = w \tag{32}$$

For this group of farmers we need to estimate shadow prices to understand how they value their subsistence crop, and how they make resource allocation decisions.

Appendix B: Maps

Figure 3. Regional distribution of the communities in the Mexican National Rural Household Survey (ENHRUM 2003)

Fuente: Elaborado en el Laboratorio de Análisis Espacial, Coordinación de Servicios de Cómputo, El Colegio de México con base en datos de la ENHRUM, 2003.

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