

Full Length Research Paper

The on-farm diversity of maize cultivars and landraces in the Lacandon region of Chiapas, Mexico

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The loss of maize landraces is of major global concern. Landraces provide the genetic building blocks for the development of high yielding pest- and drought-tolerant maize varieties, and their loss reduces the capacity to adapt to changing environmental conditions. The extinction of maize landraces is an incidental effect of the planting decisions of farmers. Although maize landraces are important both as a staple food and the source of traditional specialty foods required in particular cultural events and ceremonies, they are frequently displaced by high-yielding cultivars. The study considers the factors influencing on-farm maize diversity in the Lacandon tropical forest in the Mexican state of Chiapas. Using a censored regression model fitted with cross-sectional household farmer data, the factors behind crop choices was investigated, paying particular attention to the relation between crop diversity, wealth, and income transfers. It was found that maize diversity bears a non-monotonic relation to wealth, but is positively associated with both agricultural subsidies and poverty support.

Key words: Crop choice, crop diversity, Lacandon forest, maize diversity, poverty, on-farm conservation, Mexico, censored regression.

INTRODUCTION

One of the most pressing biodiversity conservation problems world-wide is the loss of genetic diversity of landraces and crop wild relatives. High yielding varieties have displaced landraces on farms (Brush, 2000; Perales et al., 2003; Brush and Perales, 2007; Lipper and Cooper, 2009; Perrings, 2018) to the point where many landraces and their wild relatives are now at risk of extinction (Villa et al., 2007; Plucknett and Smith, 2014). In Mexico, for example, the genetic diversity of lima bean (*Phaseolus lunatus*) landraces was found to have declined by 72% (Nei index) between 1979 and 2007 due

to allelic displacement (Martínez-Castillo et al., 2012). Similar results have been found for maize (*Zea mays*) (Dyer et al., 2014), which is the focus of this paper.

Why does the loss of maize landraces matter? Maize is the dominant food crop in both Latin America and Sub-Saharan Africa, a major food crop in East Asia, and the leading feed grain world-wide (Sweeney et al., 2013; Fischer et al., 2014; Bellon et al., 2018). Maize production is expected to be compromised by climate change, with yields expected to decline most in tropical and sub-tropical regions (Monterroso et al., 2011; Nelson

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et al., 2010; Fischer et al., 2014). While the development of new varieties through either plant breeding or genetic engineering has some potential for adaptation to changes in climatic conditions, both depend on the existence of genetic material adapted to the new climatic conditions (Brush, 2000; Esquinas-Alcázar, 2005). Since the dominant characteristic of landraces is that they are genetically diverse and dynamic, continuously adapting to local conditions, they are the main genetic reservoir for the development of cultivars adapted to changed environmental conditions (Arteaga et al., 2016). The decision to plant landraces offers benefits both to farming households, and to the wider community of plant breeders and genetic engineers. This makes conservation of the genetic diversity of landraces *in situ* a public good. Like many public goods, it is underprovided when left to the market (Smale et al., 2004; Esquinas-Alcázar, 2005; Pascual and Perrings, 2007).

In this paper, we consider the factors influencing the decisions farmers make to plant maize landraces and cultivars in Chiapas, Mexico. Although there is a substantial literature on crop choices in agriculture, there is a sense that the socioeconomic determinants of landrace conservation are still not well-understood (Dyer et al., 2014). Aside from market conditions, two factors have been argued to be important: the management of risk, and culturally determined food preferences. The diversity of landraces, for example, has been argued to have direct value to Mexican rural communities both because it provides insurance against variable environmental conditions, pests, or pathogens, and because it supports a wide range of culturally preferred food types (Perales et al., 2003, 2005; Benz et al., 2007; Brush and Perales, 2007). Both risk management and the production of specialty crops have been shown to be sensitive to farm income and wealth. There is evidence that lowest-income farmers use crop diversity as a production risk-reducing strategy (Bellon, 1996; Leslie, 2008; Harvey et al., 2014), but that as farmers' income and wealth increase, they tend to adopt alternative risk management strategies. In Mexico, Van Dusen and Taylor (2005) found that greater household wealth is generally associated with the lower richness of milpa crops. Bellon and Hellin (2011) found that wealth had a positive effect on the area committed to hybrid maize, which generally implies fewer maize varieties. Typically, wealthier farmers manage production risk by choosing appropriate technology (e.g., through the use of irrigation, herbicides, pesticides, and fertilizers), by maintaining multiple landholdings, or by exploiting both on-farm and off-farm income-earning opportunities (Smale et al., 1998; Meng et al., 1998; Isakson, 2011). Indeed, farmers with larger landholdings have an incentive to exploit economies to scale by farming fewer maize varieties (Bellon and Hellin, 2011; Kruzich and Meng, 2006). At the same time, there is also some evidence that the cultivation of culturally important specialty crops

may be increasing in income and wealth. Specifically, wealthier farmers choose to plant different maize varieties, not because of any benefits they might offer for the management of production risks, but because of their culinary, cultural or religious properties (Rana et al., 2000; Jarvis et al., 2000; Smale et al., 2004).

Aside from the effect of farm income and wealth, crop choices may be influenced by government interventions that ostensibly address other issues in agriculture, such as poverty alleviation, price stabilization, or technology transfer. Public policies that change either input prices or farm incomes have been shown to impact crop choice (Bellon, 1996; Di Falco and Perrings, 2005; Pascual and Perrings, 2007; Baumgärtner and Quaas, 2010). Examples include both subsidies on agricultural inputs (e.g., seeds, fertilizers, or pesticides) and direct area payments to farmers. It has been argued that input subsidies promote the adoption of high-yielding maize varieties, while anti-poverty programs may have a positive impact on maize landraces (Bellon and Hellin, 2011).

In Mexico, the poverty alleviation program PROGRESA (Programa de Educación, Salud y Alimentación) provides lump-sum transfers to families designated as poor (SEDESOL, 2018). It is worth noting, though, that anti-poverty support programs include payments to older farmers regardless of their wealth or income. The Mexican agricultural support program, PROAGRO, provides a monetary payment per hectare of cultivated land available to those with property rights to land. The amount decreases as the registered area increases (SAGARPA, 2018; OECD, 2019). Farmers with large landholdings who lack property rights are ineligible. We wish to understand what effect these programs have on farmers' crop choices, and whether the effect on landraces is different from the effect on cultivars.

In what follows, we test the hypotheses (a) that the least and most wealthy farmers, for different reasons, cultivate a greater diversity of landraces than farmers of average wealth; and (b) that agricultural and poverty support policies have different effects on the diversity of landraces and cultivars. We use a censored regression model estimated with cross-sectional household farmer data on farming practices, socioeconomic characteristics, and assets. Our data derive from the Lacandon tropical forest in the Mexican state of Chiapas (Figure 1) which is one of the diversity centers of maize in Mexico (Perales and Golicher, 2014). We take diversity to be measured by an index (Simpson's) of the number of landraces and cultivars planted and the quantity of each produced.

MATERIALS AND METHODS

Nine villages in the municipalities of Marqués de Comillas and Maravilla Tenejapa at the Lacandon tropical forest were selected for this research. Their selection was based on their population size

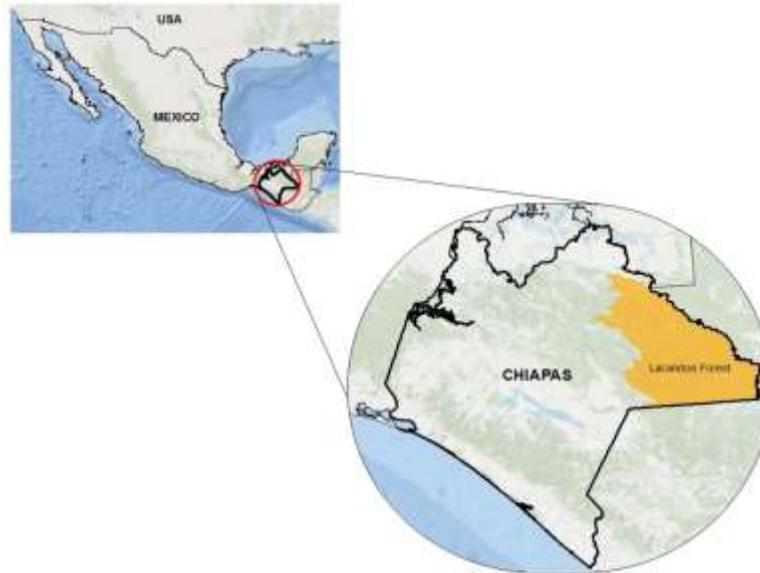


Figure 1. Map of Chiapas, Lacandon forest*. *This map was done with the assistance of Jimena Deschamps and the shapes were obtained from the National Information System on Biodiversity of CONABIO (2019).

(villages with more than 100 inhabitants) and the cooperation provided by their local authorities in the implementation of the surveys. The survey was carried out as a part of the Biological Corridor Project in Chiapas of the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO by its Spanish acronym).

The municipalities of Marqués de Comillas and Maravilla Tenejapa are located on the eastern extreme of the State of Chiapas and within the Lacandon tropical forest (Figure 1). The federal and state government have both increased efforts to promote economic and social development in the last decades, especially after the armed rising that occurred in 1994. Cattle ranching and road infrastructure have been promoted as a means to develop the Lacandon region. As a result, cattle ranching has become one of the main economic activities (De Vos, 2002; Bray and Klepeis, 2005; Alemán et al., 2007; Eakin et al., 2014).

Once the villages were selected, a census of all active farmers older than 18 years old (the age of adulthood in Mexico) was provided by the local authorities. Two hundred and forty farmers were then randomly selected from the joint census to complete a household survey, 218 of whom completed the survey. The surveys were carried out between March and June of 2016.

In order to understand how wealth and government subsidies influence farmers' maize diversity, we also consider farmer households' market access, environmental constraints, and socio-economic variables that are central to explain the variety choice of households (Meng et al., 1998). Maize varieties in the Lacandon region are mostly landraces and cultivars—creolized (hybrid) varieties that are a mix between a local landrace and a modern variety. Most inhabitants in the study region are formally defined to be in poverty. The variables selected are grouped into four sections: (Section I) social characteristics of the household head; (Section II) biophysical characteristics of land; (Section III) household assets; (Section IV) farm production characteristics; and (Section V) household participation in government programs. These variables are shown in Table 1. These variables were also selected to be consistent with other studies that have examined the factors influencing farmers' crop choices (Van Dusen and Taylor, 2005; Bellon and Hellin, 2011; Isakson, 2011).

The first section contains the variables: household head age and education. These variables are included because it is presumed that older farmers tend to cultivate more maize diversity because they have traditional preferences and educated farmers cultivate less maize diversity because they are prone to interact with markets (Meng et al., 1998; Smale et al., 2006; Isakson, 2011). The number of household members older than 13-years is also included in Section I. This variable is a proxy for the family labor supply (as well as food demand) and it is hypothesized to be positively correlated with crop diversity as is reported by Smale et al. (2006). Information on ethnicity and gender was obtained for this section, but since more than 92% of household heads are mestizo and men these variables were eliminated.¹

The second section includes a subjective soil quality index that measures how farmers rank their maize parcels in terms of soil quality and the number of maize parcels cultivated. The latter is a proxy for the environmental heterogeneity of agricultural land, as suggested by Taylor and Bellon (1993). Land heterogeneity is associated with maize diversity because farmers require distinct maize varieties to deal with different agro-ecological conditions (Taylor and Bellon, 1993; Meng et al., 1998). The soil quality index is included to test whether the high opportunity cost of cultivating in high-quality soils discourages farmers from planting insurance or specialty crops, as shown by Taylor and Bellon (1993) and Arslan and Taylor (2009) in other regions of Mexico.

The household assets section, section III, consists of: agricultural landholdings, rangelands, the number of cattle, and the size of the family house owned by the households. We group these variables using their monetary valuation in US dollars of 2017 to measure household wealth. This information was obtained from different interviews in the study region.

Section IV contains farm production variables that influence the cultivation of different maize diversity, such as distance to a regional market, maize production area, number of cash crops, labor intensity, and the use of chemical fertilizers and pesticides.

¹ 7% of the respondents stated that they native Mexican Indians and only 5% were females.

Table 1. Survey results.

Variable	Definition of the variable	Result
Section I: Household head's characteristics and household members		
Family head's age	Average age in years	45.5(12.5)
Household head's years of education	Average education in years	5(3.3)
Household members older than 13-years	Average number of household members	5.3(1.7)
Section II: Biophysical characteristics of land		
Number of maize parcels	Average number of maize parcels	1.4(0.515)
Medium soil quality (where maize is cultivated) (dummy variable)	% farmers that claim that they have medium soil quality	38(.48)
High soil quality (where maize is cultivated) (dummy variable)	% farmers that claim that they have high soil quality	22(0.41)
Section III: Household's assets		
Household agricultural landholdings	Average agricultural area in hectares	4.2(2.5)
Household livestock holdings	Average cattle heads	13(11)
Household rangelands	Average rangelands area in hectares	15(14)
Size of household's house	Average house size in square meters	102.4(51)
Value of all assets	Average value in thousands of US Dollars	7.16(4.22)
Section IV: Household's agricultural practices		
Distance to a major market	Average distance in kilometers	2.8(1.71)
Maize production area	Average area in hectares	1.36(0.46)
Number of cash crops	Average of cash crops	1.27(1.071)
Labor intensity	% of hours	16.72(16.19)
Section V: household participation in government programs		
Household's participation in agricultural support programs (dummy variable)	% of beneficiaries	60(0.49)
Household's participation in poverty alleviation programs (dummy variable)	% of beneficiaries	55(0.48)

Total sample size 218 (households). Standard deviation in parentheses.

Since most farmers use pesticides in standard amounts, we dropped this variable. We expected that farmers planting cash crops would be less likely to invest in multiple maize crops. We therefore expected to find a negative correlation between cash crops and maize diversity. In the case of the maize production area, there is evidence that farmers plant a larger number of maize varieties in larger maize production areas (Van Dusen and Taylor, 2005).

In order to test the influence of market development on maize diversity, we included both the distance from the farmers' parcels to the nearest regional markets and the labor intensity of crops.

The former variable aims to measure the effects of transaction costs on maize diversity (Van Dusen and Taylor, 2005; Bellon and Hellin, 2011). Different studies have reported a positive correlation between transaction costs and maize diversity in Mexico (Van Dusen and Taylor, 2005; Arslan and Taylor, 2009). This relationship is explained by the fact that farmers cannot cover their demand for maize diversity in the markets or the markets offer poor substitutes for the goods demanded (de Janvry et al., 1991; Bellon 1996). Following Van Dusen and Taylor (2005) we included the labor intensity variable to test the effect of labor markets on maize diversity. In particular, it measures the hired-labor proportion

of total labor used to cultivate maize diversity. Because planting different maize varieties is more labor-intensive than planting a single variety, we expected to find a negative relation between labor intensity and diversity (Zimmerer, 1991; Brush et al., 1992; Smale et al., 2004).

In the last section, we include variables that measure the number of households that receive either area payments or poverty alleviation support. Distinguishing between landraces, cultivars, and all crop types together, we estimated a censored regression model (Tobit regression model). On- farm landrace, cultivar, and all maize diversity was measured using a Simpson’s Diversity Index, constructed from information that farmers provided on maize varieties planted and the quantity produced. A censored regression model was utilized to fit the fact that the outcomes of the Simpson’s

$$D_i = \beta_0 + \beta_1 AGE + \beta_2 (AGE)^2 + \beta_3 EDU + \beta_4 HM + \beta_5 MP + \beta_6 MSI + \beta_7 HMI + \beta_8 WLTH + \beta_9 (WLTH)^2 + \mu_i \tag{1}$$

Where: D_i = Diversity of maize category i . (i = Landrace, Cultivar, All crop types together), AGE = Age of household head, $(AGE)^2$ = Squared age of household head, EDU = Formal education in years, HM = Members of household, MP = Number of maize parcels, MSI = Medium maize quality index (Medium quality=1, otherwise=0), HMI = High maize quality index (High=1, otherwise=0), $WLTH$ = farm household's wealth, $(WLTH)^2$ = squared farm household's wealth, DST = Distance to a major market, $PARA$ = Maize production area, NCP = Number of cash crops, $LINT$ = Labor intensity, AGS = Household’s participation in agricultural support programs, PVS = Household’s participation in poverty alleviation programs (Table 1).

A Durbin-Wu-Hausmann test was used to test the potential endogeneity of the variables used. The test showed the possible endogeneity of the maize production area variable. In order to correct for resulting bias, we ran a regression using an instrumental variable (IV), in which the Durbin method was used to select the instrument. We then re-estimated the models for landraces, cultivars, and all varieties using an instrumental variable. The results are presented in Table 3.

RESULTS

We found that farmers produce maize largely for self-consumption and animal feed. Most planted between one and three varieties: 29% of farmers cultivated only one variety, 50% cultivated two varieties, and 21% cultivated three or more varieties. On average, farmers held 13 head of cattle on 15 ha-approximately one head per hectare. However, the distribution of cattle ownership was highly skewed: 19% of farmers had no livestock, and 20% had fewer than 9 head. The average value of farmers' assets was 7,000 US Dollars. Agricultural and poverty alleviation transfers were received by more than half of farmers, as shown in Table 1.

The regression models in Tables 2 and 3 are very alike in terms of signs and magnitudes (there is no significant difference between the results obtained without the instrument and with the instrument). We found our measure of wealth to bear a negative and statistically significant relationship to maize diversity for all landraces, cultivars, and all crop types together, while wealth squared was positive and statistically significant for land races and all crop types together. Amongst

Diversity Index are left-bounded (Simpson’s index has a lower limit of zero if only one variety is planted).

In particular, we employed the farmers' wealth and the square of it to test the influence of wealth over farmers’ maize diversity and, as in the Mincer earnings equation; we included the square of the age of the family head to test for monotonicity of the relation between farmers’ age and maize diversity. We estimated three models of the diversity of, respectively, landraces, cultivars, and all crop types together, using the STATA software (StataCorp, 2015). Descriptive statistics of the data set are offered in Table 1. Here we note that 93 percent of farmers cultivate cultivars and 63 percent of farmers cultivate landraces. The estimated models were all of the following form (results are presented in Table 2):

household characteristics, the age of the family head was positively associated with maize diversity for all crop types together, and was significant. However, this effect decreased with age-implying an inverted- U shaped relationship. The turning point in the quadratic equation was at 57 years of age in the third model.

Van Dusen and Taylor (2005) also found a positive but decreasing relationship with a turning point at 60 years of age. Interestingly, in the models for landraces and cultivars separately, the age of the family head was not significant nor was the level of education of the household head or size of the family labor pool. Amongst the biophysical characteristics of farms, soil quality was negatively and significantly associated with the diversity of cultivars, landraces, and all crop types together. Farms characterized by poorer soils tend to see more crops and crop types planted. The number of cash crops and labor intensity were also found to be negatively and significantly associated with across crop types.

Finally, we found that participation in government programs for agriculture and rural poverty alleviation had markedly different implications for the diversity of different crop types. Participation in both programs had a positive and significant effect on crop diversity for all crop types together, but a different association with diversity of landraces and cultivars separately. Participation in PROAGRO, for example, was negatively, but not significantly, associated with landrace diversity, but positively and significantly associated with cultivar diversity. Participation in PROGRESA was positively but not significantly associated with diversity of either landraces or cultivars.

DISCUSSION

The Lancadon region is characterized by conditions frequently associated with the loss of crop genetic diversity. These include increasing market integration, increasing population density, and public policies favoring agricultural intensification. Previous studies of on-farm changes in maize diversity have found diversity to be

Table 2. Censored regression model without instruments.

Maize diversity (Simpson's diversity index)		Cultivars Regression	Landraces Regression	All varieties Regression
		Coefficients (N=203)	Coefficients (N=138)	Coefficients (N=218)
Section I: Family head characteristics	Family head's age	0.015(0.023)	0.030(0.023)	0.031*** (0.008)
	Family head's age squared	-0.0001(0.0002)	-0.0002(0.0002)	-0.0002*** (0.000)
	Family head's years of education	-0.005(0.013)	-0.015(0.013)	-0.002(0.004)
	Household members older than 13-years	-0.032(0.024)	0.009(0.023)	-0.008(0.008)
Section II: Biophysical characteristics of land	Number of maize parcels	0.136(0.083)	-0.107(0.081)	0.017(0.029)
	Medium soil quality (dummy variable)	-0.257*** (0.089)	-0.243*** (0.087)	-0.069** (0.028)
	High soil quality (dummy variable)	-0.415*** (0.112)	-0.508*** (0.109)	-0.315*** (0.042)
Section III: Household assets	Wealth index (Value of all assets)	-0.061* (0.0315)	-0.062** (0.030)	-0.029** (0.010)
	Wealth index squared (Value of all assets squared)	0.002(0.001)	0.002* (0.0015)	0.001* (0.000)
Section IV: Household agricultural practices	Distance to a major market (Kilometers)	0.030* (0.018)	-0.002(0.021)	0.004(0.0025)
	Maize production area	0.001(0.090)	0.027(0.087)	0.040(0.029)
	Number of cash crops	0.012(0.035)	-0.056(0.034)	-0.032** (0.012)
	Labor intensity	-0.028*** (0.008)	-0.003(0.008)	-0.008*** (0.002)
Section V: household participation in government programs	Household's participation in agricultural support programs (dummy variable)	0.335* (0.198)	-0.018(0.172)	0.064** (0.027)
	Household's participation in poverty alleviation programs (dummy variable)	0.153(0.110)	0.066(0.165)	0.054* (0.026)
Constant		0.939(0.604)	10.32** (0.587)	-0.297(0.201)

Significance levels are denoted by *, ** and *** at the 10, 5 and 1% levels, respectively.

falling in the Chiapas region (Dyer et al., 2014). To gain an understanding of the factors that lie behind such trends, we distinguished between the diversity of landraces and cultivars (creolized varieties), estimating separate models for each crop type, as well as a model for all varieties together. We hypothesized that on-farm landrace diversity offers two quite different benefits to farmers. One is to reduce on-farm production risks. A combination of varieties with different requirements in terms of soils, nutrients, water availability, and temperature is expected to perform better over a range of environmental conditions than a single variety. The other is to meet culturally specific demand for traditional maize varieties used in the production of locally important dishes, or in locally significant celebrations or events.

While we did not formally model farmers' aversion to environmental or market risk, we did suppose that the utility of maize diversity is sensitive to the range of earned and unearned income sources, and hence to wealth. Implicitly, farmers are risk-averse, and the mix of on- and off-farm activities offers a portfolio of income-earning opportunities, each of which responds to environmental fluctuations in different ways. Low-income

farmers choose more maize diversity in order to hedge against production risks. While wealthier farmers have other productive activities to spread risk more efficiently, they have the resources to commit at least some land to the production of specialized crops of cultural significance. The net result is that we expected on-farm diversity to be highest amongst the least and most wealthy farmers. What we found is that the diversity of landraces and all varieties together were congruent with this hypothesis, but that the diversity of cultivars was not. While the diversity of all varieties was first decreasing and then increasing in the wealth of farmers, the up-turn was significant at the ten per cent level only for landraces and all crop types together.

This finding is consistent with the hypothesis that the least and most wealthy farmers tend to cultivate more varieties, and especially more landraces, than farmers of average wealth. The turning point of the quadratic term is 14,600 US Dollars in the third model. From this point on, an increase in farmers' wealth was associated with an increase in the number of maize varieties cultivated. We note that average wealth in the sample was 7,000 US Dollars, so the positive wealth effect is driven by farmers at the upper end of the wealth distribution.

Table 3. Censored regression results with instruments.

Maize diversity (Simpson's diversity index)		Cultivars Regression Coefficients (N=203)	Landraces Regression Coefficients (N=138)	All varieties Regression Coefficients (N=218)
Section I: Family head characteristics	Family head's age	0.026(0.0036)	0.030(0.023)	0.031***(0.008)
	Family head's age squared	-0.0002(0.0003)	-0.0002(0.0002)	-0.0002***(0.000)
	Family head's years of education	-0.010(0.021)	-0.015(0.013)	-0.002(0.004)
	Household members older than 13-years	-0.046(0.037)	0.009(0.023)	-0.008(0.008)
Section II: Biophysical characteristics of land	Number of maize parcels	0.199(0.131)	-0.111(0.084)	0.017(0.029)
	Medium soil quality (dummy variable)	-0.335**(0.136)	-0.243***(0.087)	-0.069**(0.028)
	High soil quality (dummy variable)	-0.661(0.187)	-0.513***(0.114)	-0.315***(0.042)
Section III: Household assets	Wealth index (Value of all assets)	-0.097*(0.050)	-0.061*(0.032)	-0.029**(0.010)
	Wealth index squared (Value of all assets squared)	0.003(0.002)	0.002*(0.0015)	0.001*(0.000)
Section IV: Household agricultural practices	Distance to a major market (Kilometers)	0.036(0.031)	-0.002(0.021)	0.004(0.0025)
	Maize production area	0.181(0.256)	0.005(0.164)	0.040(0.029)
	Number of cash crops	0.015(0.054)	-0.056(0.034)	-0.032**(0.012)
	Labor intensity	-0.044***(0.013)	-0.003(0.008)	-0.008***(0.002)
Section V: Household participation in government programs	Household's participation in agricultural support programs (dummy variable)	0.320*(0.207)	-0.029(0.175)	0.064**(0.027)
	Household's participation in poverty alleviation programs (dummy variable)	0.155(0.197)	0.058(0.167)	0.054*(0.026)
Constant		0.702(0.993)	10.36**(0.631)	-0.297(0.201)

Significance levels are denoted by *, ** and *** at the 10, 5 and 1% levels, respectively. (A) The Wald chi-square (15) is 22.47 (P value= 0.096) and Wald test of exogeneity is Chi-square of (1) = 0.06 (P value =0.81) with a null hypothesis of no endogeneity. (B) The Wald chi-square (15) is 33.51 (P value= 0.004) and Wald test of exogeneity is Chi-square of (1) = 0.12 (P value =0.72) with a null hypothesis of no endogeneity. (C) The Wald chi-square (17) is 188.45 (P-value= 0.000) and Wald test of exogeneity is Chi-square of (1) = 0.24 (P-value =0.62) with a null hypothesis of no endogeneity.

One result that speaks to the role of diversity in managing production risk is the relation between (perceived) soil quality and crop diversity. For all crop types we found a strongly negative relation between soil quality and crop diversity. Farmers faced with soils of poor quality plant a greater variety of crops than farmers enjoying soils of good quality. Since we would expect some association between soil quality and wealth, this is consistent with the finding that crop diversity is, at least initially, decreasing in wealth.

A second result that also bears on risk is that the diversity of cultivars and all crop types taken together bears a strong negative relation to the labor intensity of crops. Farmers facing a labor supply constraint tend to focus on fewer crop types. We note that labor supply may be constrained both by the total number of working age members of the household, and by the number working off-farm. The diversification of income sources through participation in the wider labor market is also a household risk management strategy, but is likely inconsistent with the diversification of crops. Given the relation between crop diversity and wealth, we were particularly interested in the impact of public policies that affect farm wealth.

Since both PROGRESA and PROAGRO make lump-sum transfers to farming households we had expected to find a statistically significant relation between participation in these programs and crop diversity. Bellon and Hellin (2011) found that the poverty alleviation program, PROGRESA, had a positive effect on maize diversity. At the same time, they found that agricultural support programs tended to discourage diversity. That is, they showed that PROAGRO had incentivized the expansion of hybrid maize production which they saw as reducing diversity. This is congruent with our findings, but requires some explanation.

While we found a positive and significant relation between participation in both programs and the diversity of all crop types together, we found no significant relation between participation in either program and the diversity of landraces. We did, however, find a positive and significant relation between participation in PROAGRO and the diversity of cultivars, which are characterized by their high-yield potential as hybrid varieties. That is, PROAGRO is associated to high-yield varieties. We close by considering the scope for using agricultural programs to support landrace diversity a more targeted way. First,

public programs have the potential to preserve landrace diversity by increasing the direct incentive to cultivate landraces. Unlike area payments that encourage farmers to increase the area under cultivation, but are blind to the crops being cultivated, agricultural support programs can include targeted compensation payments or contracts for conservation-related to particular crop types (Pascual and Perrings, 2007; Narloch et al., 2011). Payments need to be substantial enough to outweigh the benefits to be had from switching to the production of high yielding varieties for the market.

Second, public programs can strengthen the rights farmers have in landraces. The critical importance of intellectual property rights regimes for the incentive to conserve is well established (Timmermann and Robaey, 2016). Traditional farmers have used selection and breeding to improve locally important traits, and have exchanged seeds to maintain the intra-specific genetic diversity needed to protect crops against environmental fluctuations. The Plant Treaty currently that farmers have rights 'to save, use, exchange and sell farm-saved seed and other propagating material, and to participate in decision-making regarding, and in the fair and equitable sharing of the benefits arising from, the use of plant genetic resources for food and agriculture' (International Treaty on Plant Genetic Resources for Food and Agriculture, 2009). At present, however, farmers' rights are limited by national policies that are primarily focused on the results of modern plant breeding and genetic engineering (Santilli, 2012). An important dimension of the incentive to conserve is the strengthening of farmers rights and seed exchange between farmers (Hodgkin et al., 2007; Jarvis and Hodgkin, 2008; Smale et al., 2004).

Third, although the conservation of maize landraces in Mexico confers benefits to consumers world-wide, the Mexican government has no incentive to take account of conservation benefits beyond Mexico. In the absence of international payments for the conservation of landraces in Mexico, too few resources will be committed to the problem (Perrings, 2018). There is scope for engaging other maize producing countries in efforts to conserve traditional varieties in the Mexican center of origin.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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