The Farm Size – Productivity Relationship in the Wake of Market Reform: an Analysis of Mexican Family Farms

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Abstract: The hypothesis of a dynamic farm size – productivity relationship is extended to the context of Mexico, identifying the relationship in a panel of family farms from the Mexican Family Life Survey (MxFLS). We find a time invariant inverse relationship between farm size and both land productivity and total factor productivity. Stochastic frontier analysis reveals that, while technical change is expanding the frontier and technical inefficiency is growing for the entire sample, these changes are more pronounced for larger farms. An inverse relationship along the productivity frontier is disappearing in the wake of Mexico's NAFTA-era reforms to agricultural policy, yet this change has not affected the farm size – total factor productivity relationship due to growing technical inefficiency. These findings suggest that either the multiple market failure hypothesis is not an important source of the inverse relationship in Mexico or that further reform is required.

Keywords: Inverse relationship, agriculture, farm size, total factor productivity (TFP), Mexico

JEL Codes: O13, Q12

I. Introduction

Beginning with the seminal work of Sen (1962), economists have documented an inverse relationship between farm size and land productivity throughout much of the developing world (Bardhan, 1973; Berry and Cline, 1979; Deolalikar, 1981; and Barrett et al., 2010, among others). This inverse relationship has been found in a broad range of geographies, time periods, and crop mixes, and has been featured in discussions of development policy, including land reform (Lipton, 2009) and the future of small farms (Wiggins et al., 2010).

The regularity with which an inverse relationship between farm size and land productivity is observed led to many theoretical explanations for the phenomenon. Early explanations centered around multiple market failures (Sen, 1966; Eswaran and Kotwal, 1986), asymmetric information (Feder, 1985), and risk aversion among farmers (Barrett, 1996). A second set of explanations emphasized empirical issues such as systematic measurement error in farm size and/or output (Lamb, 2003; Carletto et al., 2013; Gourlay et al., 2017; Desiere and Jolliffe, 2018) and omitted variables (Bhalla and Roy, 1988; Benjamin, 1995; Assunção and Braido, 2007). Empirical studies have typically found that existing theory fails to fully explain the observed inverse relationship, generating a body of mixed and at times contradictory evidence.

Helfand and Taylor (2019) illustrate how the choice of productivity measure can alter the relationship observed and how it can obscure a changing relationship between farm size and total factor productivity, the more relevant productivity measure. They find a dynamic relationship between farm size and total factor productivity in the rapidly modernizing agricultural regions of Brazil, contributing to an emerging literature that documents changing farm size – productivity relationships as agricultural sectors modernize and develop (Foster and Rosenzweig, 2017; Deininger et al., 2018; Rada and Fuglie, 2019). This is consistent with Helfand et al. (2015), whose findings suggest that both the larger commercial farms and smaller family farms in Brazil have advantages in harnessing technical change and achieving rapid gains in productivity.

In this paper the hypothesis of a dynamic farm size – productivity relationship is extended to the context of Mexico, identifying the relationship in a panel of family farms from the Mexican Family Life Survey (MxFLS) and testing for changes over the sample period of 2002-2009. Mexico is an interesting case for assessing changes in the farm size – productivity relationship because of its long history of land reform and the recent agricultural policy reform associated with the North American Free Trade Agreement (NAFTA) in the 1990s. These policies are a prime example of the Washington Consensus, liberalizing markets for land, agricultural inputs, and agricultural output in Mexico with the objective of spurning the modernization, competitiveness, and productivity of the agricultural sector and the broader economy. An environment with such market reforms, if successful, is expected to diminish the multiple market failure explanation of the inverse relationship between farm size and productivity, and any observed inverse relationship might weaken accordingly.

We test for changes in the farm size – productivity relationship and, contrary to expectations, find that an inverse relationship exists and has remained strong in the wake of Mexico's market reforms. We explore the relationship further by estimating a stochastic production frontier, an approach often applied in developed economy agriculture but infrequently applied in developing economy contexts. While frontier productivity growth has increased rapidly for larger farms, eliminating the inverse relationship at the frontier, the average relationship has remained unchanged due to more rapidly increasing technical inefficiency amongst the larger farms in the sample. This finding highlights the need for, and echoes calls for, policies that support family farms' transitions towards modern agriculture and adaptation to market liberalization in Mexico.

The proceeding section discusses agriculture and agricultural policy in Mexico, providing important context for the empirical analysis. This is followed by an introduction of the empirical methodology, a description of the data, and the presentation of empirical results. Policy recommendations for Mexican agriculture and research implications conclude.

II. The Mexican Agricultural Experience

The institutional structure of Mexican agriculture continues to reflect agricultural policies implemented after the Mexican Revolution of the early 20th century. Land policy of the 1934 Agrarian Code established the *ejidos* – tracts of communally held land with individual plots farmed by designated households – as a principle tool for redistributing land and property rights to peasants. Agrarian communities, a distinct form of land tenure located predominantly in the South where farmers had pre-existing claims to agricultural land, were similarly formed although to a lesser extent. A dual system of agricultural tenure emerged, with ejido farmers on the one hand

and private land-owners on the other. Within both the ejido and private farm sectors there exists both the larger, commercially-oriented farms and the smaller predominantly subsistence farms.

It is in this context that Berry and Cline (1979) first studied the farm size – productivity relationship in Mexico. Drawing from the Mexican Agricultural Census of 1940 and of 1960, they compared land productivity of small and large private farms. They found land productivity of small farms to be 6.5 times larger than that of larger farms in 1940, but just 3.5 times as large by 1960. More importantly, when output per unit of land *and* capital was measured, a more comprehensive measure of productivity, small farms were 1.7 times more productive than large farms in 1940 but just 0.8 times as productive in 1960. This early evidence illustrates that an inverse relationship between farm size and land productivity is neither necessary nor sufficient for an inverse relationship between farm size and more comprehensive productivity measures, similar to the findings of Helfand and Taylor (2019) in the context of Brazil.

Berry and Cline (1979) hypothesized that the changing productivity ratios reflected a shift from livestock to crops on large farms, facilitated by government investment in infrastructure, provision of credit, and other supportive policies. As the birthplace of the Green Revolution, Mexican agriculture experienced productivity growth throughout this period, notably becoming net exporters of important staples such as wheat and maize. A weakening of the IR between farm size and land productivity accompanied this period of agricultural modernization and development, as did a reversal of the IR between farm size and output per unit of capital and labor.

More recent research using farm-level panel data from the Mexico National Rural Household Survey (ENHRUM), a household survey statistically representative of 80% of rural Mexico, showed evidence of an inverse relationship between farm size and productivity in 2003 and 2008 (Kagin et al., 2016). By estimating an average production function and a stochastic production frontier, they find an inverse relationship between farm size and land productivity, farm size and average TFP, and farm size and TFP along the production frontier. They conclude that the observed farm size – TFP relationship was driven, in part, by larger farms being further from the frontier (i.e. smaller farms being more efficient than their larger counterparts).

Mexican agriculture in the early 20th century is an interesting setting for studying the farm size – productivity relationship because of the policy changes and market reforms associated with The North American Free Trade Agreement (NAFTA) going into effect in 1994. As part of an economy-wide reduction in tariffs, agricultural tariffs were gradually eliminated over a 14-year span ending in 2008. The liberalization of agricultural trade between countries exposed the Mexican agricultural sector to increased competition and imports from Northern neighbors. As a result, a flood of cheap imports has led to a decline in the price of staple crops for many Mexican farmers (Pérez et al., 2008).

For Mexican agriculture, NAFTA was part of a broader program of reform and market liberalization. One important change was the Program for the Certification of Ejido Rights and Titling of Urban Plots (Procede), which included reform of the ejido system of land tenure. Following a constitutional amendment, Procede facilitated the new option for ejidos to privatize individual parcels that could then be mortgaged, rented, or sold. Further, agricultural rights to ejido parcels ceased being contingent upon actual agricultural production, strengthening property rights for the ejido sector. Importantly for the private sector, the practice of expropriating large private holding for the formation of ejidos was ended. By securing property rights and integrating ejidos into the market, these changes were expected to increase opportunities throughout the rural farm sector. A World Bank (2001) evaluation of the ejido reforms found that, while Procede had been widely successful in securing property rights, often in the form of certificates of agricultural rights, the program had not led to widespread land transfers and ejido farms remained credit constrained at the turn of the century.

A second set of policy changes affected the manner in which government supported agricultural input and output markets. Policy shifted away from heavily subsidizing inputs and providing price supports for output towards a system of direct transfers for those impacted by increased international competition. In general, producers of staple products have suffered due to increased competition with relatively cheap imports whereas exports of high-valued horticultural products have benefited (Pérez et al., 2008). The Program for Direct Assistance in Agriculture (Procampo), primarily an income support program, offered per hectare payments to any farms with a history of producing any of nine key staples prior to 1993 that were actively farming one of those crops. An important change to the program in 1995 allowed participation of any farm producing any legal crop that had previously qualified for the program. Further changes to the program in 2001 included higher per-hectare payments for farms under 5 hectares and a shift of the timing of payments to the start of the planting season. Upper limits on land size included for payments are larger for corporate-run than for family-run farms. Alongside Procampo is *Alianza para el Campo*, a suite of programs designed to increase agricultural productivity primarily through investment in infrastructure and extension assistance.

As government programs withdrew, farms became increasingly reliant upon markets for access to key agricultural inputs such as fertilizer, pesticides, and seed, and for access to credit. While government credit programs have withdrawn, a well-functioning credit market has not appeared in rural Mexico and access to private credit markets is not widespread, inhibiting access to key inputs and modern technologies for Mexican farms. As in other developing country contexts, market concentration in both input markets and post-harvest processing and marketing has hurt the profitability of family farms and generated economies of scale in transacting with the agricultural supply chain..

We hypothesize that the farm size – TFP relationship is likely to be changing over time in the wake of Mexico's NAFTA-era reforms, much as it appears to have done in Mexico during the Green Revolution (Berry and Cline, 1979) and in Brazil's modernizing agricultural regions (Helfand and Taylor, 2019). This hypothesis rests upon the assumptions that (i) market imperfections contribute to any pre-existing IR in Mexican agriculture and (ii) Mexico's NAFTA-era market liberalization has improved the efficiency of these markets and enabled development of agricultural production. Beyond the farm size – productivity relationship, agricultural productivity is important to Mexico for both rural economic development and poverty reduction. According to data from the World Bank,[1] agricultural output made up 3.6% of Mexico's GDP but employed 13-14% of the workforce in 2015. Further, approximately 62% of Mexico's rural population is impoverished when using the national poverty line, suggesting that agricultural productivity has a potentially important role in Mexico's rural economic development and efforts to reduce poverty. There are similar implications for trends in migration, as increasing agricultural productivity on family farms facilitates the ability to generate adequate livelihoods and effectively support families, reducing an important push factor in migration decisions.

[1] All data taken from the World Bank: http://data.worldbank.org/.

III. Empirical Methodology

As discussed in Helfand and Taylor (2019), land productivity is a partial measure of productivity and does not account for the use of inputs other than land. Where other inputs are used in production, failing to account for the use of those resources potentially introduces bias into estimates of the relationship between farm size and productivity if the intensity of input use (inputs per hectare) varies with farm size. Controlling for all inputs in agricultural production can be accomplished with estimation of a production function, uncovering TFP, the comprehensive and preferable measure of productivity.

We use two complementary approaches to explore the relationship between farm size and TFP with a panel of Mexican farms. First, we use an average production function to estimate average TFP and its relationship with farm size. Second, we use a stochastic production frontier to estimate both TFP along the technological frontier and technical inefficiency, identified as deviations from the frontier. The frontier analysis identifies any relationship between farm size and frontier TFP and any relationship between farm size and technical inefficiency. As is standard in the literature (Coelli et al., 2005 and Kumbhakar et al., 2015), we view TFP change as a combination of changes in the technological frontier and changes in the deviations from the frontier.

We identify TFP by estimating a Cobb-Douglas production function with inputs measured per hectare, implicitly imposing constant returns to scale on the production technology. In such a setting, the inclusion of a measure of farm size as an explanatory variable identifies any relationship between farm size and TFP (Helfand and Taylor, 2019). Any deviation from constant returns to scale is effectively forced into the farm size term so that the estimated farm size – TFP relationship includes any non-constant returns to scale. We estimate the following production function using OLS regression:

$$y_{ict} = \beta_0 + \boldsymbol{\beta}\boldsymbol{x}_{ict} + \boldsymbol{\omega}\boldsymbol{Z}_{ict} + \boldsymbol{\theta}_t + \boldsymbol{\gamma}_c + f(A_{ict}) + \boldsymbol{\theta}_t \times f(A_{ict}) + \varepsilon_{ict} \tag{1}$$

where y_{ict} is log of output per ha for farm i in community c in year t and x_{ict} is log of input per ha for the $k = 1, \dots, 5$ non-land inputs: purchased intermediate inputs, physical capital, draft animals, family labor, and non-family labor.[2] The variable of interest, $f(A_{ict})$, is a measure of farm size, A_{ict}, taking various functional forms including linear, quadratic, cubic, and a flexible dummy variable structure. Community-level fixed effects, $\boldsymbol{\gamma}_c$, allow for the inclusion of household-level explanatory variables, $\boldsymbol{Z}_{ict}$.[3] We use survey year dummies, $\boldsymbol{\theta}_t$, and interact survey year with the measurement of farm size to allow the farm size – productivity relationship to vary over time. Omitting survey year interactions with inputs effectively assumes that the technology is time-invariant, forcing any changes in technology into the TFP term. The standard normal error term is given by ε_{ict}, clustered at the community level.

Additionally, a set of production functions is estimated that interacts household explanatory variables with the measure of farm size. These models explore the potential for heterogeneity in the farm size-productivity relationship across important subgroups:

$$y_{ict} = \beta_0 + \boldsymbol{\beta x}_{ict} + \boldsymbol{\omega Z}_{ict} + \boldsymbol{\theta}_t + \boldsymbol{\gamma}_c + f(A_{ict}) + \boldsymbol{\theta}_t \times f(A_{ict}) + \boldsymbol{Z}_{ict} \times f(A_{ict}) + \varepsilon_{ict} \quad (2)$$

The second approach to exploring the farm size – productivity relationship estimates a stochastic *production frontier*. We take an output-oriented perspective, measuring technical inefficiency as the difference between what is actually produced by a farm, Y, and the maximum possible production given the inputs used by that farm, $f(\boldsymbol{X})$:

$$Technical\ Inefficiency = \frac{f(\boldsymbol{X})}{Y} \quad (3)$$

Rearrangement of the log of technical inefficiency generates the following relationship:

$$lnY = lnf(\boldsymbol{X}) - \ln\,(Technical\ Inefficiency) \quad (4)$$

Stochastic production frontier analysis differs from the estimation of an average production function because of the use of a two-part error term – a standard idiosyncratic error term, v, coupled with a one-sided error term, u, that measures inefficiency or deviations from the production frontier:

$$lnY = lnf(\boldsymbol{X}) + v - u \quad (5)$$

Econometric estimation requires the assumption of a functional form for the frontier, a distributional assumption for v, and a distributional assumption for u. Functional forms for the

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[3] A model with household-level fixed effects is estimated as a robustness check.

frontier are typically Cobb-Douglas or the more general translog functional form, and the standard normal distribution is generally assumed for v. Common assumptions for the distribution of u include the exponential distribution, the half normal distribution, and a more general truncated normal distribution.

Stochastic frontier models allow for the simultaneous estimation of the frontier and heterogeneity in the inefficiency as a function of explanatory variables, and are estimated with maximum likelihood methods. We employ Greene's (2005) "true" fixed effects model with community-level fixed effects using the *sfpanel* command in Stata.[4] Working with community level fixed effects has the advantage of allowing the inclusion of household-level explanatory variables. A half-normal distribution is used for the inefficiency component of the error term, allowing for estimation of the variance of the inefficiency term simultaneously with the stochastic frontier.[5] A Cobb-Douglas functional form is assumed for the production frontier with inputs and output measured in logs per unit of land. The idiosyncratic component of the error term is assumed to follow a normal distribution and standard errors are clustered at the community level. More formally, the model is given by:

$$y_{ict} = \beta_0 + \boldsymbol{\beta}\boldsymbol{x}_{ict} + \boldsymbol{\omega}\boldsymbol{Z}_{ict} + \boldsymbol{\theta}_t + \delta A_{ict} + \boldsymbol{\gamma}_c + v_{ict} - u_{ict} \qquad (6)$$

$$v_{ict} \sim N(0, \sigma^2_{v,c}) \qquad (7)$$

$$u_{ict} \sim N^+(0, \sigma^2_{u,ict}) \qquad (8)$$

$$\sigma^2_{u,ict} = \alpha_0 + \alpha_1 A_{ict} + \boldsymbol{\theta}_t + \boldsymbol{\varphi}\boldsymbol{V}_{ict} + \epsilon_{ict} \qquad (9)$$

where $\boldsymbol{x}_{ict}$ are inputs per ha in logs, A_{ict} is log farm size, $\boldsymbol{Z}_{ict}$ and $\boldsymbol{V}_{ict}$ are vectors of household level controls used in the frontier and inefficiency equations, respectively, $\boldsymbol{\theta}_t$ are time dummies, $\boldsymbol{\gamma}_c$ are community dummies, v_{ict} is the standard normal idiosyncratic component of the error term, u_{ict} is the half normal inefficiency component of the error term, and ϵ_{ict} is a standard normal error

[4] See Belotti et al. (2012) for a discussion of *sfcross* and *sfpanel*.

[5] We attempted to estimate a frontier with a more flexible truncated normal distribution for the inefficiency term, allowing us to estimate its mean and/or variance (Wang, 2002). These models failed to converge with the MxFLS data.

term used in the inefficiency equation. For simplicity, we assume farm size (A_{ict}) enters linearly in the frontier model.[6]

The current analysis of the farm size – productivity relationship in Mexico using the MxFLS takes a similar approach to that of Kagin et al. (2016). An important difference is that we assess how the relationship may have changed over time as it has done in the modernizing agricultural regions of Brazil (Helfand and Taylor, 2019). This extension is important for the case of Mexico in the wake of NAFTA and other significant reforms to Mexican agricultural policy since the 1990s.

IV. Data

The Mexican Family Life Survey (MxFLS) is a longitudinal survey of Mexican households, representative of the Mexican population at the national, urban, and rural levels.[7] The MxFLS is a rich source of data for this analysis, as controlling for unobservable farm and community level characteristics using fixed effects is potentially important for determining the farm size – productivity relationship. Further, the decade long span of the surveys allows for a careful analysis of how the size-productivity relationship has evolved in the wake of NAFTA and contemporaneous reforms affecting the Mexican agricultural sector.

The three survey rounds – 2002, 2005-06, and 2009-12[8] – tracked a broad range of individual, family, and community characteristics for the 8,437 initial households. The second (2005) and third (2009) waves of the survey successfully re-interviewed 90% and 94% of first wave households, respectively. Individuals from the first wave formed new households at annual rates of 3.6% and 4.7% between the first and second and the second and third waves, with 83% of newly formed households being re-interviewed in the third survey wave.

While not representative of the Mexican agricultural sector per se, the MxFLS is representative of both rural and non-rural Mexican households. As such, the use of the dataset to study Mexican agriculture has the important caveat that it underrepresents the larger, commercial

[6] The results with farm size dummies are largely equivalent.
[7] MxFLS was designed, implemented, and is managed by the Iberoamerican University and the Center for Economic Research and Teaching in Mexico, in conjunction with Duke University researchers.
[8] The vast majority of third wave interviews, 95%, were conducted in 2009 and 2010.

agricultural operations to the degree that they are not family farms.[9] A comparison with the 2007 Agricultural Census reveals that both the census and MxFLS have less than 5% of farms that are greater than 50 ha. However, it is important to note that these "large" farms are not necessarily the same as those in the census because they are family-run farms and do not include corporate-run, commercial agricultural operations. In comparison to the 2007 census, the MxFLS over-represents farms less than 2 ha and under-represents farms between 20 ha and 50 ha. This is true for each survey wave, highlighting that while the MxFLS is not representative of the Mexican agricultural sector in its entirety, it is appropriate for studying household farms in Mexico.

We employ a farm (i.e. household) level analysis using all MxFLS households engaged in agricultural production. A plot-level analysis is not feasible because agricultural input data is recorded at the household level and is therefore not plot specific. However, as we are primarily concerned with documenting the farm size – productivity relationship in Mexico and how it has changed over time, and we are less concerned with fully explaining its determinants, a farm level analysis will suffice. Households in the MxFLS move in and out of agricultural production between survey waves. An unbalanced panel is constructed through two stages of restricting the MxFLS data: first, cross-sections of households with complete farm data are identified and cleaned to eliminate outliers, and second, the unbalanced panel is formed out of all households that appear in two or more MxFLS survey waves.[10]

Table 1 shows all households using plots for agricultural production in a given survey wave are referred to as agricultural households, whereas all households with plot size and output data for all non-fallow plots are referred to as complete farms. The intermediate group, farms with farm size data, includes all farms with complete farm size data but not necessarily complete production data – this less restricted dataset increases the sample size at the expense of potentially introducing some measurement error, and is an alternative treatment of the data that is pursued below. Lastly, the number of farms in the panel includes the number of households with complete farm data in

[9] This is similarly true of the Mexico National Rural Household Survey (ENHRUM) used by Kagin et al. (2016), which is representative of rural communities in Mexico with between 500 and 2,500 inhabitants.

[10] Some households have incomplete data on the size and/or output for one or more plots used in agricultural production in a given period, making the inclusion of these households in a farm-level analysis problematic. With inputs recorded at the household level and output and plot size data recorded at the plot level, the inclusion of farms with missing data on any plot used in production will introduce measurement error. After removing such households, we eliminate outliers by trimming the extremes of the farm size and land productivity distributions.

two or more of the survey years. These restrictions on the data leave us with a sample of 566 farms reappearing in two or more survey years. Table 2 describes these farms according to the combination of survey years in which they appear.

Table 1: Agricultural Households and Complete Farms by Survey Year

	2002	2005	2009
N Households	8,440	8,437	10,119
N Agricultural Households	1,586	1,303	1,410
N with Farm Size Data	1,042	713	696
N Complete Farms	887	626	596
N Farms in Panel	483	412	359

*Note that *N Complete Farms* and *N Farms in Panel* are after respective rounds of cleaning for outliers.

Table 2: Panel Sample Size for Complete Farms

	N
All Survey Years	*122*
First and Second Surveys Only	207
First and Third Surveys Only	154
Second and Third Surveys Only	83
Total	*566*

Input and Output Variables

Farms are classified into one of 7 farm size groups, as shown below in Table 3. The distribution of farms across these bins is roughly constant over time and across treatments of the data, although the share of farms between 0 and 0.5 ha is falling over time while the share of farms between 0.5 and 1 ha is increasing. More importantly, with the exception of the share of farms between 0.5 and 1 ha in 2002, the distribution does not change in any notable way as we restrict the cross section to form the panel, an indication that use of the panel has not introduced bias along this dimension. There is a considerable range in farm sizes in the sample, ranging from less than one hundredth of a hectare to 45,000 hectares. The median farm size in the panel is 2.5, 2.1, and 3.0 hectares in 2002, 2005, and 2009, respectively, with mean farm sizes of 101, 232, and 218 hectares. Around 75 percent of farms utilize only one plot for production in any given year.

Table 3: Sample Size by Farm Size Group for Complete Farms

	Cross Sections			Panel		
Farm Size Group	2002	2005	2009	2002	2005	2009
0 to 0.5 ha	199 (22%)	116 (19%)	110 (18%)	103 (21%)	66 (16%)	55 (15%)
0.5 to 1 ha	108 (12%)	102 (16%)	101 (17%)	45 (9%)	60 (15%)	57 (16%)
1 to 2 ha	141 (16%)	109 (17%)	96 (16%)	83 (17%)	75 (18%)	58 (16%)
2 to 5 ha	182 (21%)	133 (21%)	122 (20%)	108 (22%)	88 (21%)	75 (21%)
5 to 10 ha	143 (16%)	93 (15%)	91 (15%)	79 (16%)	76 (18%)	65 (18%)
10 to 20 ha	65 (7%)	34 (5%)	40 (7%)	39 (8%)	23 (6%)	27 (8%)
> 20 ha	49 (6%)	39 (6%)	36 (6%)	26 (5%)	24 (6%)	22 (6%)
Total	*887*	*626*	*596*	*483*	*412*	*359*

The preferred measure of agricultural output is a Fisher quantity index that includes all crop and livestock production for each farm in the MxFLS panel. Crop prices from the Food and Agriculture Organization of the United Nations are used to aggregate crop output. Together with a measure of the value of livestock production, an output index is constructed as detailed in Appendix 1.

The MxFLS offers data on five agricultural inputs other than land: physical capital, draft animals, purchased intermediate inputs, family labor, and non-family labor. Physical capital is measured as the value of tractors and other machines and equipment owned and draft animals is the value of horses, donkeys, and mules owned by each household in each survey year, deflated to 2002 values. Purchased intermediate inputs are measured using reported expenditures on each of 9 agricultural inputs over the course of the previous year, again deflated to 2002 values. An index of family labor is constructed using household members' time use and employment data in the MxFLS, and is an estimate of annual hours worked on the farm by all household members. In contrast, the non-family labor index is a measure of the number of non-household individuals that worked on each farm in each year, measured in workers and not labor hours. Appendix 2 provides a detailed discussion of the source and construction of the family labor and non-family labor indices, including a set of alternative family labor indices.

Table 4 shows the share of panel households using the different input categories in each year, with purchased intermediate inputs shown collectively, and then also disaggregated into their

9 components.[12] For all of the inputs there exist at least some, if not a majority, of households that have zeros for that input category. This is expected, as farms in the sample are expected to span a range from low technology subsistence agriculture to more modern and input intensive operations. Furthermore, many inputs may be substitutes for each other, and farms can access these inputs by owning them or by purchasing them in factor markets. Tractor services, for example, may be substituted for with draft animals. Households can either own some combination of these capital stocks, or purchase their services from the market. We follow Battese (1997) to estimate production functions with observations having zero inputs.[13]

Table 4: Percent of Households Using Selected Intermediate Inputs

Input Category	Panel		
	2002	*2005*	*2009*
Family Labor	94%	94%	91%
Non-family Labor	52%	49%	39%
Physical Capital	13%	12%	14%
Draft Animals	35%	30%	27%
Purchased Intermediate Inputs	70%	70%	71%
Fertilizer	51%	48%	46%
Manure	17%	17%	18%
Pesticides	33%	26%	27%
Seeds	24%	23%	25%
Tractor Services	32%	25%	36%
Animal Power	3%	10%	11%
Labor	5%	25%	27%
Water	3%	16%	20%
Fuel	2%	10%	15%

Of principle importance is any relationship between inputs per hectare and farm size, as systematic relationships between input intensity and farm size potentially drive a wedge between

[12] A comparison of input usage and patterns over time between the cross section and the panel shows broad consistency across the treatments of the data, again showing that use of the panel does not appear to bias the sample along this dimension.

[13] For each input, k, for each farm in each survey year, we generate a dummy variable, D_{ict}, equaling 1 if there is zero input for that farm in that survey year and zero otherwise. We then define a new measure of the input, x^*_{ict}, equaling 0 if $D_{ict} = 1$ and the log of that input per ha (x_{ict}) otherwise. The inclusion of the dummy variables and newly constructed inputs allows for unbiased estimation of the production function's parameters in the presence of zeros while using the full sample.

the farm size – land productivity and farm size – total factor productivity relationships (Helfand and Taylor, 2019). We calculate the correlation coefficients between logged input per hectare and logged farm size for those farms with non-zero values of usage of each input. These correlations are shown in Table 5. Conditional on using the input, the intensity (per hectare) of all inputs used declines with farm size, emphasizing the importance of moving from partial measures of productivity to a comprehensive measure such as TFP.

Table 5: Correlation Coefficients between Logged Farm Size and Logged Inputs per ha

Input Category	Farms with Non-zero Values		
	2002	*2005*	*2009*
Family Labor	-0.93*	-0.90*	-0.89*
Non-family Labor	-0.90*	-0.91*	-0.89*
Physical Capital	-0.34*	-0.20	-0.28*
Draft Animals	-0.84*	-0.84*	-0.62*
Purchased Intermediates	-0.69*	-0.65*	-0.68*

*Note: * indicates statistical significance at the 10% level*

Additional Household Controls

The vast majority of plots are either privately owned property or are part of an *ejido* – a piece of communally held land where plots are farmed by designated households.[14] It is commonly accepted that ejidos are less productive than privately held farms, although there is little empirical evidence comparing the TFP of these farms with micro data. At least 91% of privately held plots in the MxFLS have some form of formal documentation in any given year, while just 75-84% of MxFLS ejido properties do. Privately held plots primarily have a formal deed or title to the land as documentation, whereas ejido plots primarily have a certificate of ejido status or agricultural rights. Formal documentation of property rights is important for accessing credit and is expected to be positively correlated with TFP. How property rights are formally documented matters, however, as a certificate of ejido status is often not acceptable to private financial institutions for use as collateral whereas formal deeds are. We control for both separately in the core empirical analysis. Because ejidos may function differently than privately owned parcels, we control for

[14] Other ownership categories include rented land, borrowed land, sharecropped land, and other.

ejido status. Ejido farms make up 58% of the panel, and ejido status of farms does not change for almost all of the farms in the panel.

Panel farms are located in 92 distinct communities and are grouped into five regions in Mexico: the North, Center, Pacific, South, and Gulf. In the first survey wave, 26% of panel farms are in Northern states where agriculture is characterized by having larger commercial farms with greater importance of the commercial production of maize. In comparison, 50% of first wave farms are in Southern and Central states where agriculture is characterized by more traditional, smallholder maize producers and the commercial production of fruits and edible vegetables (Prina, 2013). The distribution of farms in the panel is stable across both states and regions. In tests of heterogeneitywe introduce regional interactions with farm size in estimations of equation (2), allowing the farm size – TFP relationship to vary across agricultural regions.

Additional household level controls are grouped into two broad categories: variables describing agricultural practices that are mostly endogenous, and demographic variables that are largely exogenous. Household demographic variables are based on pre-determined characteristics of the household head. The panel farms predominantly have male, married, and Spanish speaking heads of household, with little differences across farm sizes or ejido status. Table 3.5 in Appendix 3 shows that farms larger than about 5 ha appear to be less likely to have an indigenous household head and more likely to have a literate household head than do smaller farms. Literacy is just one way to measure educational attainment of the household head, and it captures a rather low bar. We measure the education of household head by creating indicator variables for the highest level of formal schooling attended, from no formal education to elementary school, secondary school, high school, or college education. With little variation across survey years, Table 3.6 in Appendix 3 shows educational attainment by farm size for 2002 only, showing that a majority of farms have household heads with no more than an elementary school education, while almost one quarter of the panel's household heads have no formal education at all.

The following variables describing agricultural practices of farms are potentially endogenous, and for this reason are not included in the base specifications. They are introduced to shed light on potential channels affecting TFP and the farm size – TFP relationship. Any farm that does not bring any of its crop to market is classified as a subsistence farm, identifying farms that may behave differently than those who do. There is little difference in the prevalence of subsistence farming between ejido and non-ejido farms. As shown in Table 3.1 in Appendix 3, subsistence farming decreases with farm size, as expected. We calculate the share of each farm's crop that is marketed – on average, those farms in the sample that do participate in the market sell around 75% of their production. This appears relatively constant across farm size bins.

Alongside subsistence farming practices, Table 3.1 in Appendix 3 shows the share of farms engaged in monocropping. The farms in the sample that monocrop do so on the vast majority of their farm, not just on specific plots. In each survey year over half of the plots being monocropped are growing maize, with approximately 10% each growing beans and coffee. As shown in Table 3.1 of Appendix 3, there is no discernible difference in monocropping across farm sizes, although ejido farms are marginally more likely to employ monocropping than non-ejido farms. The MxFLS asks households about crop and livestock loss in recent years. To account for potentially persistent negative productivity shocks we generate a dummy variables for whether the household suffered crop or livestock loss in either of the previous two years.

The MxFLS asks households about their participation in a variety of government programs. The two most important programs are Procampo and Progresa/Oportunidades. Procampo is an income transfer program designed to support agricultural producers of staple crops. Progresa, later renamed Oportunidades, is a conditional cash transfer program designed to combat poverty and incentivize investments in children. Data limitations do not allow us complete information on participation in Progresa[16] so we focus exclusively on participation in Procampo. Table 3.1 in Appendix 3 shows the share of farms participating in Procampo by year and farm size. With the exception of the largest farms, participation increases with farm size. In addition, we consider participation in Alianza, a government-run program designed to aid farmers in diversifying into crops for export. While less than 3% of the sample participated in this program in any survey round, we consider participation in this program for its potentially important impact on farmers.

Having access to credit is an important determinant of agricultural productivity, and the existence of credit constraints and differential access to credit is one theoretical source of a relationship between farm size and productivity. Table 3.3 in Appendix 3 shows "access to credit" by farm size, where a household is considered to have access if the household head knows where

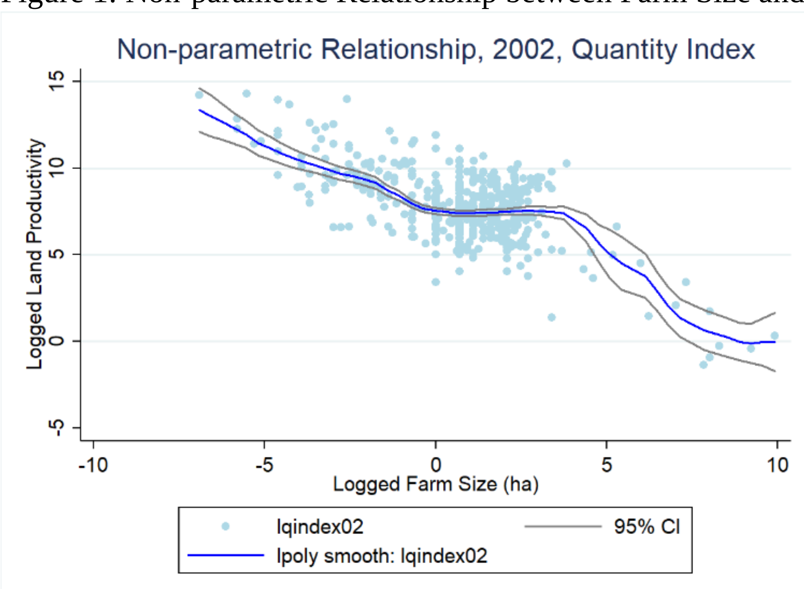
[16] In the MxFLS, data is available for participation in 2005 only.

they can go to borrow or ask for a loan. This is a crude measure as it does not account for credit rationing and the likelihood that a household could succeed in obtaining a loan. A follow up question regarding the source of that credit allows us to identify if access is through a formal or an informal financial institution.[17] There are no clear relationships between farm size and this measure of access to credit. We introduce an indicator variable to control for access to formal lines of credit in the empirical analysis.

V. Empirical Results

As with much of the literature, we begin the discussion of the farm size – productivity relationship using land productivity, measured as output per hectare. Figure 1 shows the non-parametric relationship between the log of farm size and the log of output per hectare in 2002, where output is measured using the Fisher quantity index.[19] There is a clear inverse relationship between farm size and land productivity over the entire range of farm sizes, and while not shown here this relationship is strikingly consistent across the three survey waves. Land productivity falls rapidly up to approximately 1 ha, at which point the relationship levels before resuming a dramatic decline in land productivity after approximately 20 ha.

Figure 1: Non-parametric Relationship between Farm Size and Productivity, Panel (2002)



[17] Formal sources of credit include banks, cooperative savings funds, and government credit programs.
[19] Estimated using the default local polynomial regression in Stata.

Production Function Analysis

As discussed in Helfand and Taylor (2019), an inverse relationship between farm size and land productivity is neither necessary nor sufficient for the existence of an inverse relationship between farm size and total factor productivity. For reference, the linear relationship between land productivity and farm size is estimated. Farm size is inversely related to land productivity at the 1% level of significance, as shown in column 1 of Table 6, where we estimate the elasticity of land productivity with respect to farm size to be -0.82. We then estimate the average production function identified by equation (1) assuming four alternate specifications of the farm size – productivity relationship that vary in their flexibility. These regressions measure output using the quantity index, weight observations by the expansion factors provided by MxFLS, use the preferred measure of the family labor index,employ community fixed effects, and cluster standard errors at the community level. Coefficients for the farm size variables, the primary variables of interest, are displayed in Table 6. Table 7 displays the coefficients for additional household controls, and technology coefficients are included as Table 4.1 of Appendix 4.

The results indicate an inverse relationship between farm size and TFP, as shown by the negative and statistically significant coefficient on the linear Farm Size variable in model 2. In the sample, a 1% increase in farms size is associated with a 0.81% decrease in output per hectare, *ceteris paribus*. These coefficients on farm size are slightly less negative than in model 1, but not statistically different, indicating that the relationships between farm size and land productivity and farm size and TFP are almost identical in this sample.

Models 3 and 4 allow for a quadratic and cubic relationship between farm size and TFP, but the coefficients on the higher ordered terms are either not statistically significant or do not have a noticeable impact on the linear model. Model 5 captures some non-linearity in the farm size – TFP relationship by using dummy variables for 7 farm size bins. The smallest of farms, those less than one half of a hectare, are significantly more productive than all other farms, while the largest, those greater than 20 hectares, are significantly less productive than all smaller farms. Productivity between these two extremes, however, appears relatively stable. This closely mirrors the non-parametric relationships between farm size and land productivity shown in Figure 1, highlighting the need to assume a flexible functional form to fully understand the farm size –

productivity relationship. The linear relationships identified in the parametric specifications 2 through 4 do not capture these subtleties.

We see little change in the inverse relationship over time across all models, as none of the farm size and survey year interaction terms are statistically significant. The finding of a time invariant inverse relationship between farm size and productivity – when using both land productivity and TFP – suggests that the IR is alive and well in Mexico. There is, however, evidence for a decline in average productivity over time in this sample, as the 2009 dummy variable is negative and statistically significant.

Table 6: Farm Size Coefficients, Community Fixed Effects with Household Controls

	(1) Linear w/o Inputs	(2) Linear	(3) Quadratic	(4) Cubic	(5) Dummies
Farm Size	-0.822***	-0.814***	-0.795***	-0.773***	
	(0.039)	(0.068)	(0.060)	(0.073)	
0.5 to 1 ha					-1.583***
					(0.265)
1 to 2 ha					-2.185***
					(0.226)
2 to 5 ha					-2.150***
					(0.269)
5 to 10 ha					-2.542***
					(0.402)
10 to 20 ha					-2.387***
					(0.539)
20+ ha					-5.264***
					(0.950)
2005 Dummy	-0.298*	-0.208	-0.264	-0.289	-0.192
	(0.168)	(0.158)	(0.190)	(0.220)	(0.209)
2009 Dummy	-0.677***	-0.551***	-0.639***	-0.672***	0.199
	(0.130)	(0.121)	(0.155)	(0.190)	(0.517)
2005*Farm Size	0.018	0.031	0.014	0.049	
	(0.043)	(0.050)	(0.046)	(0.084)	
2009*Farm Size	-0.073	-0.069	-0.093	-0.067	
	(0.070)	(0.074)	(0.072)	(0.109)	
Farm Size^2			-0.018*	-0.015	
			(0.009)	(0.013)	
2005*Farm Size^2			0.013	0.016	
			(0.012)	(0.017)	
2009*Farm Size^2			0.020	0.024	
			(0.013)	(0.020)	

Farm Size^3				-0.001	
				(0.002)	
2005*Farm Size^3				-0.001	
				(0.003)	
2009*Farm Size^3				-0.001	
				(0.003)	
2005*Bin 2					-0.224
					(0.566)
2005*Bin 3					0.564
					(0.484)
2005*Bin 4					-0.402
					(0.302)
2005*Bin 5					0.137
					(0.268)
2005*Bin 6					0.083
					(0.593)
2005*Bin 7					-0.424
					(0.841)
2009*Bin 2					-0.855
					(0.667)
2009*Bin 3					-0.921
					(0.729)
2009*Bin 4					-0.854
					(0.622)
2009*Bin 5					-1.053
					(0.779)
2009*Bin 6					-1.286
					(0.797)
2009*Bin 7					-1.554
					(1.353)
Constant	8.004***	9.289***	10.000***	10.494***	6.309***
	(0.466)	(1.067)	(1.287)	(1.473)	(1.193)
Community FE	Yes	Yes	Yes	Yes	Yes
R^2	0.69	0.72	0.72	0.72	0.68
N	1235	1235	1235	1235	1235

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Results for the household explanatory variables, displayed in Table 7, show that monocropping and operating as a subsistence farm have a consistently negatively relationship with TFP. In contrast, participating in Procampo is positively associated with productivity (as is participation in Alianza, although the relationship is not statistically significant). It is important to reiterate that these are potentially endogenous explanatory variables, and we should not interpret the coefficients as identifying causal relationships. Having more education is positively related to TFP, although with the exception of a college education these impacts are not consistently statistically significant at standard levels.

Table 7: Coefficients on Household Controls

	(1) None	(2) Linear	(3) Quadratic	(4) Cubic	(5) Dummies
Monocrop	-0.397**	-0.386**	-0.381**	-0.368**	-0.451***
	(0.155)	(0.159)	(0.156)	(0.160)	(0.146)
Subsistence	-0.562***	-0.439***	-0.435***	-0.431***	-0.279
	(0.182)	(0.156)	(0.157)	(0.161)	(0.183)
Crop Loss	0.032	0.031	0.024	0.021	-0.041
	(0.243)	(0.206)	(0.200)	(0.203)	(0.200)
Procampo	0.478***	0.397**	0.384**	0.378**	0.283*
	(0.147)	(0.158)	(0.159)	(0.159)	(0.163)
Alianza	0.544	0.328	0.377	0.383	0.307
	(0.339)	(0.325)	(0.334)	(0.331)	(0.330)
Formal Credit	0.100	0.054	0.045	0.039	0.125
	(0.264)	(0.252)	(0.259)	(0.257)	(0.239)
Ejido	0.047	0.039	0.003	0.009	-0.103
	(0.163)	(0.162)	(0.155)	(0.157)	(0.169)
Documentation	-0.084	-0.041	-0.038	-0.052	-0.065
	(0.270)	(0.222)	(0.219)	(0.223)	(0.227)
Age	0.001	-0.002	-0.002	-0.002	-0.001
	(0.005)	(0.005)	(0.004)	(0.005)	(0.006)
Male	0.043	0.016	0.027	0.029	-0.003
	(0.245)	(0.209)	(0.213)	(0.215)	(0.203)
Married	0.236	0.174	0.171	0.159	0.170
	(0.210)	(0.185)	(0.185)	(0.187)	(0.189)
Indigenous	-0.082	-0.099	-0.106	-0.125	-0.169
	(0.199)	(0.211)	(0.209)	(0.212)	(0.233)
Elementary School	0.097	0.018	-0.001	0.005	0.034
	(0.175)	(0.168)	(0.167)	(0.167)	(0.182)
Secondary School	0.632*	0.404	0.361	0.379	0.181
	(0.355)	(0.413)	(0.415)	(0.412)	(0.479)
High School	0.383	0.314	0.331	0.367	0.079
	(0.336)	(0.334)	(0.347)	(0.342)	(0.404)
College	1.359**	1.348**	1.329**	1.374**	0.833
	(0.533)	(0.548)	(0.561)	(0.556)	(0.517)
Community FE	Yes	Yes	Yes	Yes	Yes
R^2	0.69	0.72	0.72	0.72	0.68
N	1235	1235	1235	1235	1235

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Estimates of equation (2) explore heterogeneity in the farm size – productivity relationship across different groups of Mexican family farms by interacting indicator variables for those groups with farm size. For simplicity, we assume the farm size – TFP relationship to be linear and time invariant.[20] Table 8 displays the results from interacting farm size with being located in the more commercially oriented agricultural region of Northern Mexico, participation in Procampo, practicing monocropping, operating as a subsistence farm, and whether or not the household head has any education beyond secondary school. Overall, the farm size – TFP relationship remains stable, as none of these additional interactions contribute to explaining the farm size – TFP relationship that we have identified.[21]

In addition, we interact controls for farms having ejido status, various forms of property rights, and access to credit in Table 9. These are of special interest given the reforms of the ejido system and rural credit markets. Again, the IR is unaltered across these subgroups as these interactions are not statistically significant. The relationship between farm size and TFP is the same for ejido farms as for non-ejido farms, is the same regardless of how property rights are documented, and is the same whether or not farms have access to formal credit markets.

Table 8: Community Fixed Effects with Household Control Interactions

	(1) North	(2) Procampo	(3) Monocrop	(4) Subsistence	(5) Higher Education
Farm Size	-0.813***	-0.841***	-0.819***	-0.816***	-0.812***
	(0.067)	(0.076)	(0.090)	(0.081)	(0.069)
Farm Size*North	-0.013				
	(0.196)				
Farm Size*Procampo		0.090			
		(0.068)			
Farm Size*Monocrop			0.009		
			(0.074)		
Farm Size*Subsistence				0.004	
				(0.057)	
Farm Size *Education					-0.038
					(0.083)
2005 Dummy	-0.208	-0.214	-0.208	-0.209	-0.209

[20] Relaxing the assumption of a linear relationship does not qualitatively alter the results presented here.
[21] In addition, we estimate separate regional models using household fixed effects, resulting in the same conclusion of a homogenous farm size – TFP relationship across regions.

	(0.158)	(0.157)	(0.160)	(0.157)	(0.158)
2009 Dummy	-0.550***	-0.575***	-0.553***	-0.551***	-0.555***
	(0.121)	(0.125)	(0.115)	(0.121)	(0.121)
Community FE	Yes	Yes	Yes	Yes	Yes
R^2	0.72	0.72	0.72	0.72	0.72
N	1235	1235	1235	1235	1235

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 9: Community Fixed Effects with Credit/Property Rights Interactions

	(1) Ejido	(2) Deed/Title	(3) Ag. Rights Certificate	(4) Any Documentation	(5) Access to Credit
Farm Size	-0.820***	-0.805***	-0.815***	-0.799***	-0.814***
	(0.076)	(0.073)	(0.076)	(0.115)	(0.069)
Farm Size*Ejido	0.025				
	(0.069)				
Farm Size*Deed		-0.016			
		(0.047)			
Farm Size*Certificate			0.004		
			(0.055)		
Farm Size*Documentation				-0.018	
				(0.079)	
Farm Size*Credit					0.016
					(0.078)
2005 Dummy	-0.199	-0.203	-0.207	-0.208	-0.208
	(0.166)	(0.157)	(0.163)	(0.157)	(0.158)
2009 Dummy	-0.548***	-0.548***	-0.550***	-0.554***	-0.550***
	(0.121)	(0.120)	(0.125)	(0.126)	(0.122)
Community FE	Yes	Yes	Yes	Yes	Yes
R^2	0.72	0.72	0.72	0.72	0.72
N	1235	1235	1235	1235	1235

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Robustness Tests

In the tables below, we subject the estimated the farm-size – TFP relationship to a series of robustness tests. We assume the farm size – TFP relationship is best captured by the linear and dummy variable models used above, as the quadratic and cubic models provide little additional information. Table 10 contains the results from the linear models and Table 11 from the dummy variable specification.

First, model 1 introduces household-level fixed effects to control for time-invariant, unobserved, household heterogeneity. The model omits time-invariant household controls, clusters standard errors at the household level, and provides a superior approach to addressing potential omitted variable bias relative to the model with community level fixed effects. Second, model 2 tests the sensitivity of the relationship to decisions regarding the construction of the family labor index by using an alternative index of family labor described in Appendix 2. Third, we test the impact of choice of weighting of the observations. Whereas the core results apply the MxFLS weights designed to make the sample statistically representative of Mexican households in each survey year, model 3 shows results when we apply no weighting at all. We explore sensitivity to the use of weights because (a) we are interested in Mexican agriculture, not rural Mexican households, and (b) the treatment of the data reduces the sample size; therefore, it is not clear that these weights remain appropriate. Fourth, model 4 uses an alternative measure of the dependent variable – farm output. Whereas the core results uses the preferred approach of calculating a quantity index for each household (see Appendix 1 for more detail), model 4 deflates the nominal value of production in each year for each household and uses the real value of output (in 2002 Mexican pesos). Lastly, model 5 uses the real value of output as in model 4, but estimates the relationship over the repeated cross-sections. This final robustness check speaks to the potential for households to be selecting into or out of the unbalanced panel.

Overall, these alternative treatments of the data generate qualitatively similar results to the core regressions in Table 6 for our primary variables of interest. This is true in terms of the coefficient signs and orders of magnitude. The exception is model 2 using the alternative index of family labor, for which the farm size coefficients are diminished in magnitude although negative and still statistically significant. The consistency across models is reassuring that treatment of the data is not driving the core results regarding the farm size – TFP relationship. In similar fashion, estimated coefficients on household explanatory variables are quite robust. The coefficients identifying farms engaged in monocropping and operating as subsistence farms remain negative and statistically significant in almost all of the robustness exercises, while the coefficients for participation in Procampo and college education remain positive and statistically significant. In results not shown here, we estimate the core models using crop production only in measuring output and the conclusions regarding the farm size – productivity relationship are robust to this dimension as well.

Table 10: Farm Size Coefficients, Linear Robustness Checks

	(1) Household FE	(2) Alt. Labor Index	(3) No Weights	(4) Alt. Output	(5) Alt. Output Cross Section
Farm Size	-0.825***	-0.602***	-0.732***	-0.814***	-0.668***
	(0.103)	(0.085)	(0.054)	(0.069)	(0.060)
2005 Dummy	-0.241	-0.135	-0.130	-0.290*	-0.313**
	(0.175)	(0.096)	(0.095)	(0.160)	(0.126)
2009 Dummy	-0.388*	-0.328***	-0.318***	-0.324**	-0.380***
	(0.213)	(0.112)	(0.110)	(0.126)	(0.126)
2005* Farm Size	0.089	0.041	0.038	0.035	-0.030
	(0.089)	(0.043)	(0.043)	(0.050)	(0.037)
2009* Farm Size	-0.110	0.012	0.007	-0.069	-0.084
	(0.118)	(0.052)	(0.053)	(0.074)	(0.052)
Constant	11.437***	6.507***	7.062***	9.385***	7.042***
	(2.010)	(1.090)	(1.136)	(1.064)	(1.160)
Household FE	Yes	No	No	No	No
Community FE	No	Yes	Yes	Yes	Yes
R^2	0.86	0.67	0.67	0.71	0.68
N	1235	1235	1235	1235	2090

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 11: Farm Size Coefficients, Dummy Variable Robustness Checks

	(1) Household FE	(2) Alt. Labor Index	(3) No Weights	(4) Alt. Output	(5) Alt. Output Cross Section
0.5 to 1 ha	-1.801***	-0.653**	-1.433***	-1.598***	-1.329***
	(0.648)	(0.262)	(0.248)	(0.268)	(0.178)
1 to 2 ha	-2.405***	-0.860***	-1.895***	-2.192***	-1.863***
	(0.582)	(0.225)	(0.195)	(0.224)	(0.220)
2 to 5 ha	-2.126***	-0.801***	-1.954***	-2.139***	-1.746***
	(0.591)	(0.232)	(0.236)	(0.266)	(0.199)
5 to 10 ha	-2.869***	-0.974***	-2.403***	-2.547***	-2.326***
	(0.745)	(0.299)	(0.305)	(0.403)	(0.216)
10 to 20 ha	-2.295**	-0.722**	-2.401***	-2.383***	-2.593***
	(1.056)	(0.305)	(0.337)	(0.553)	(0.344)
20+ ha	-6.191***	-1.842***	-4.230***	-5.270***	-5.568***
	(1.356)	(0.546)	(0.648)	(0.961)	(0.638)
2005 Dummy	-0.184	-0.296	-0.112	-0.287	-0.082
	(0.448)	(0.253)	(0.263)	(0.206)	(0.194)
2009 Dummy	0.080	-0.093	0.295	0.418	0.120
	(0.635)	(0.314)	(0.402)	(0.504)	(0.299)

2005*Bin 2	-0.178	0.025	-0.147	-0.199	-0.490
	(0.704)	(0.376)	(0.381)	(0.571)	(0.386)
2005*Bin 3	0.646	0.265	0.156	0.589	-0.057
	(0.671)	(0.390)	(0.411)	(0.492)	(0.468)
2005*Bin 4	-0.453	0.117	-0.119	-0.401	-0.657**
	(0.608)	(0.329)	(0.329)	(0.294)	(0.285)
2005*Bin 5	0.406	0.496	0.252	0.161	-0.079
	(0.591)	(0.316)	(0.316)	(0.274)	(0.233)
2005*Bin 6	-0.536	0.505	0.296	0.148	0.118
	(0.853)	(0.358)	(0.399)	(0.591)	(0.514)
2005*Bin 7	0.186	-0.016	-0.697	-0.407	0.002
	(1.059)	(0.623)	(0.722)	(0.842)	(0.773)
2009*Bin 2	-0.629	-0.717	-1.073**	-0.891	-0.656
	(0.867)	(0.449)	(0.532)	(0.687)	(0.424)
2009*Bin 3	-0.510	-0.341	-0.754	-0.884	-0.625
	(0.796)	(0.451)	(0.522)	(0.724)	(0.543)
2009*Bin 4	-0.675	0.004	-0.460	-0.866	-0.632
	(0.886)	(0.426)	(0.505)	(0.607)	(0.472)
2009*Bin 5	-0.785	-0.160	-0.651	-1.031	-0.926*
	(0.851)	(0.439)	(0.488)	(0.774)	(0.525)
2009*Bin 6	-0.847	-0.099	-0.470	-1.227	-0.543
	(1.069)	(0.463)	(0.560)	(0.795)	(0.566)
2009*Bin 7	-1.756	-0.433	-0.972	-1.596	-1.072
	(1.689)	(0.684)	(0.900)	(1.359)	(1.003)
Constant	11.031***	4.359***	4.720***	6.427***	7.549***
	(2.662)	(1.089)	(1.288)	(1.170)	(0.833)
Household FE	Yes	No	No	No	No
Community FE	No	Yes	Yes	Yes	Yes
R^2	0.85	0.66	0.63	0.68	0.67
N	1235	1235	1235	1235	2090

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Frontier Analysis

Estimating a stochastic frontier complements analysis of the average production function by identifying productivity at the frontier and production inefficiencies. Together, these components determine average TFP identified with the average production function. In similar fashion, whereas the estimation of the average production function allows us to assess the relationship between farm size and average productivity, stochastic frontier analysis allows us to assess any relationships between farm size and productivity at the technical frontier and between farm size and technical inefficiency.

The results of five specifications of the stochastic production frontier are shown in Table 12, with the top and bottom panels displaying the results from the frontier and variance of inefficiency equations, respectively. Model 1, the baseline model, has no additional household controls in either the frontier (**Z**) or the inefficiency equations (***W***). Model 2 includes dummy variables for the household head's level of education in the frontier equation and includes a dummy variable for the household head being of indigenous ethnicity in the inefficiency equation. Model 3 alternatively assumes that education of the household head should be included as a control in the inefficiency equation but not the frontier equation. Model 4 assumes that education belongs in both equations. Model 5 includes education in the frontier equation only, adding interaction terms between farm size and the survey year dummies in both the frontier and the inefficiency equations. The models all use community fixed effects and, for simplicity, have farm size entering linearly.

The estimated coefficients from models 1 – 5 are largely consistent. They indicate a strong inverse relationship between farm size and frontier TFP and that the frontier is increasing over time, reflecting positive technical change. The coefficients on inputs are positive and stable across specifications, with family labor and purchased intermediate inputs being significant. The variance of the inefficiency term σ_u^2 is roughly double the size of the variance of the noise σ_v^2 in all models, and lambda – the ratio of the two variances – indicates that estimation of a stochastic frontier is appropriate with the MxFLS data.[22]

The models indicate an inverse relationship between farm size and productivity at the technological frontier of the same order of magnitude as the farm size-TFP relationship estimated in the preceding analysis of the average production function. The coefficients on survey year dummies in Table 12 are all positive and significant, indicating that the frontier is increasing over time. Thus, in contrast to the results from the average production function analysis where evidence of declining average TFP over time was found, here we find evidence of positive technical change at the frontier. The interaction between farm size and the survey year dummies in model 5 identifies a positive and significant relationship between farm size and technical change,

[22] In models estimated with a constant variance of the inefficiency distribution (σ_u^2), and thus no explanatory variables, Stata provides a p-value for the test of lambda equal to zero. This hypothesis is rejected at greater than the 1% level of significance, providing evidence in support of the stochastic frontier model.

suggesting that technical change has been biased towards larger farms and that the inverse relationship along the frontier became less steep over time.

Models 1 through 4 show that, while the variance of the inefficiency distribution increased over time, there is no relationship between farm size and inefficiency. The inclusion of interactions between farm size and survey year dummy variables in model 5, however, reveals a more nuanced dynamic relationship between farm size and technical inefficiency. Larger farms were indeed more efficient than smaller farms in 2002 (i.e. they operated closer to the frontier) but inefficiency is increasing faster for larger farms. These differential changes in inefficiency across the farm size distribution have caused the farm size - inefficiency relationship to disappear in the latter waves of the MxFLS.[23] Model 5 reveals that rising technical inefficiency has accompanied technological change, suggesting that the majority of farms have been unable to keep up with the TFP growth of the most productive farms. This is particularly true for larger farms, who have experienced faster growth in both frontier productivity and technical inefficiency.

Having secondary or college education reduces the variance of the one-sided inefficiency term when education is included in the inefficiency equation. When education of the household head is included in the frontier specifications but not in the explanation of inefficiency (models 2 and 5), having secondary education or a college education is positively associated with higher levels of productivity among frontier producers. When education is included in both the frontier and inefficiency equations (model 4), almost none of the education dummies are significant as the model appears to struggle to identify the separate relationships with education. In models not shown here, we estimate a stochastic frontier including the household controls from Table 8 as explanatory variables of the inefficiency term. In addition to educational attainment of the household head, technical inefficiency is lower among Procampo participants and higher among farms practicing monocropping. When interacted with farm size, none of the interaction terms are statistically significant, suggesting that they do not fundamentally change the relationships observed in Table 12.

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[23] This can be seen by adding the farm size coefficient (-0.32) in model 5 with the year*size interaction from 2005 (0.37) or 2009 (0.42). In either case, the sum of the two coefficients is not statistically significantly different from zero.

Table 12: Stochastic Frontier Production Function Results

	(1)	(2)	(3)	(4)	(5)
Frontier Equation					
Farm Size	-0.642***	-0.653***	-0.638***	-0.646***	-0.805***
	(0.051)	(0.050)	(0.052)	(0.053)	(0.062)
2005 Dummy	0.477**	0.475**	0.458**	0.446**	0.400**
	(0.186)	(0.177)	(0.186)	(0.174)	(0.201)
2009 Dummy	0.790***	0.799***	0.765***	0.769***	0.711***
	(0.212)	(0.207)	(0.210)	(0.201)	(0.223)
2005*Farm Size					0.192***
					(0.064)
2009*Farm Size					0.204*
					(0.108)
Family Labor	0.077**	0.077**	0.074**	0.072**	0.068**
	(0.032)	(0.033)	(0.034)	(0.034)	(0.033)
Physical Capital	0.008	0.012	0.019	0.016	0.037
	(0.047)	(0.042)	(0.045)	(0.044)	(0.046)
Draft Animals	0.028	0.026	0.023	0.022	0.006
	(0.034)	(0.032)	(0.033)	(0.032)	(0.030)
Purchased Intermediates	0.148***	0.139***	0.148***	0.146***	0.145***
	(0.038)	(0.038)	(0.039)	(0.040)	(0.041)
Non-family Labor	0.045	0.041	0.053	0.051	0.024
	(0.034)	(0.034)	(0.034)	(0.034)	(0.033)
Elementary School		0.044		-0.048	0.057
		(0.090)		(0.142)	(0.094)
Secondary School		0.517**		0.293	0.531**
		(0.205)		(0.332)	(0.209)
High School		0.008		-0.069	0.083
		(0.204)		(0.344)	(0.207)
College		0.703**		-0.334	0.699**
		(0.307)		(0.494)	(0.302)
Inefficiency Equation					
Farm Size	0.037	0.031	0.040	0.035	-0.317***
	(0.062)	(0.060)	(0.061)	(0.060)	(0.119)
2005 Dummy	1.152***	1.163***	1.146***	1.112***	1.198***
	(0.377)	(0.361)	(0.403)	(0.359)	(0.430)
2009 Dummy	1.838***	1.878***	1.871***	1.840***	1.870***
	(0.407)	(0.387)	(0.431)	(0.379)	(0.401)
2005*Farm Size					0.368**
					(0.149)
2009*Farm Size					0.417**
					(0.167)
Indigenous		0.001	-0.046	-0.038	0.001

		(0.230)	(0.245)	(0.238)	(0.233)
Elementary School			-0.142	-0.193	
			(0.193)	(0.271)	
Secondary School			-0.882**	-0.499	
			(0.411)	(0.549)	
High School			-0.118	-0.190	
			(0.579)	(0.819)	
College			-1.603***	-1.680*	
			(0.480)	(0.451)	
$E(\sigma_u^2)$	1.679	1.666	1.641	1.661	1.620
σ_u^2	0.846	0.840	0.852	0.838	0.853
λ	1.985	1.983	1.926	1.982	1.899
N	1235	1235	1235	1235	1235

Standard errors in parentheses
$*$ p<0.10, $**$ p<0.05, $***$ p<0.01

Discussion

The analysis of Mexican data reveals an inverse and time-invariant relationship between farm size and TFP. Underlying this IR is a negative relationship between farm size and frontier productivity that has diminished over time and a positive relationship between farm size and technical efficiency that disappeared over the sample period. This evidence suggests that, in the wake of NAFTA era reforms, the IR is weakening for the most productive farms along the production frontier but that this change is not widespread. Although frontier productivity is increasing most rapidly for larger farms, the higher growth of inefficiency for large farms leaves the farm size – TFP relationship unchanged over the period. The evolving relationships between farm size and frontier productivity and technical efficiency cast doubt on the ability to exploit the existing inverse relationship between farm size and TFP to generate productivity gains.

These results are complemented by previous work on the farm size – productivity relationship in Brazil. Whereas the Brazilian experience suggests a dynamic farm size – TFP relationship, with an inverse relationship in traditional agriculture becoming flat and potentially positive with modernization, we observe no such dynamics in the Mexican sample. The relationship observed in the MxFLS is time invariant and persistently negative, contrasting with the emerging U-shaped relationship observed in the modernizing regions of Brazil. It is quite similar, however, to the more traditional agricultural regions in Brazil that display a persistent inverse relationship between farm size and TFP. The lack of corporate-run commercial farms is one limitation of using the MxFLS data, inhibiting analysis of the farm size-productivity relationship across all sectors of Mexican agriculture. This is especially true in light of findings that, in Brazil, larger commercial farms (along with the smallest of family farms) exhibit distinct advantages in achieving productivity growth (Rada et al., 2019).

The frontier analysis using MxFLS data finds that technical change has been biased towards larger farms, weakening the farm size – productivity relationship at the frontier. This indicates that if inefficiency had not increased, the average inverse relationship between farm size and productivity would have weakened with modernization of the agricultural sector. This analysis indicates the potential for larger farms to be the key drivers of future productivity growth in Mexico. Policies geared towards smaller family farms may not have large returns in terms of increasing overall agricultural productivity, but they are likely very important for poverty reduction. Even if small farms generate an increasingly smaller share of agricultural output, they are likely here to stay in the near future because of their roles in generating livelihoods for rural households. Increasing their productivity remains an important component of facilitating poverty reduction in rural areas.

These findings are largely consistent with earlier empirical work by Kagin et al. (2016), who estimate both an average production function and a stochastic production frontier using a different panel of Mexican family farms. They find that both technical change and technical inefficiency increased over time and, as with the current analysis, their fixed effects estimates show inverse relationships between farm size and both TFP and frontier productivity. Similarly, they find that smaller farms are more efficient than larger farms. In addition to highlighting the non-linearity in the farm size – TFP relationship, we provide evidence of a more nuanced and dynamic relationship between farm size and technical inefficiency and between farm size and productivity at the frontier. Larger farms have both more rapidly growing frontier productivity and technical inefficiency than their smaller counterparts, and these considerations are important for effective policy.

We find evidence of declining average TFP over the period of analysis for the MxFLS sample of family farms. This appears to be driven by increasing average technical inefficiency offsetting the positive technical change and expansion of the productivity frontier. The largest farms in the sample and their relatively rapidly growing technical inefficiency are an important factor here, indicating a growing advantage for some larg farms in harnessing more modern agricultural practices that has not been widespread enough to translate into sector-wide average TFP growth. Policies enabling broader inclusion in the benefits from technical change would both increase average TFP and likely further diminish the IR. Whereas policies promoting technical change are more relevant for smaller farms, policies improving technical efficiency, such as extension services, are exceptionally important for larger farms. The growing technical inefficiency observed in Mexico indicates the potential for policies designed to promote and support the adoption and efficient use of best practices to achieve gains in agricultural productivity.

The finding of declining average TFP over time is a curious result, running counter to both the body of long-run country-level analyses and the micro-level analysis of Kagin et al. (2016) over similar time periods. One important caveat is the MxFLS sample does not include corporate run commercial farms as do national-level studies such as an agricultural census. To the extent that such farms have more effectively harnessed the gains from technological change, as with larger family farms on the frontier, the potentially heightened productivity of such large farms is not included in the current evaluation of the farm size – TFP relationship in Mexican agriculture or growth in average TFP over time. This has important policy implications for the development impacts of agriculture productivity gains – if these gains are experienced primarily by corporate-run commercial farms and not by family-run farms, the potential impacts on poverty and broader rural economic development will not be fully realized. Productivity gains for smaller family farms not only reduce poverty directly but are also likely to contribute more to local development because of how they interact with the local economy. To be most effective, policy directed at spurring development and poverty reduction through agricultural productivity gains should be inclusive of smaller family farms.

The lack of commercial farms does not, however, reconcile this finding with that of Kagin et al. (2016), who find rising average TFP over a similar period in a different sample of rural households. One difference is the MxFLS used here includes more larger family farms, and these farms are experiencing the most rapid increase in technical inefficiency. The inclusion of more large family farms may be the source of this result. One possible explanation of the finding of declining average TFP over the first decade of the 21st century is that the productivity of Mexican family farms has declined in the wake of the NAFTA era reforms. This interpretation is consistent with findings that is consistent with claims that NAFTA era reforms were insufficient for generating positive change in Mexico's agricultural sector, and that these reforms may have been detrimental to some segments of Mexican agriculture.

Participation in Procampo and increased education are found to be positively correlated with the agricultural productivity of Mexican family farms, whereas the practices of monocropping and operating as a subsistence farm are found to be negatively correlated with TFP. We are tentative in drawing stronger conclusions about the causal impact of these variables, as they are likely endogenous. However, the frontier analysis suggests how these controls relate to productivity. Education appears to increase the efficiency with which inputs are used on family farms, and monocropping is found to be an inefficient use of inputs. In this light, farmer education – particularly in methods such as intercropping – is expected to increase technical efficiency on family farms. Procampo is primarily an income support program it is unclear how participation would affect agricultural productivity. On the one hand, participation may relax income constraints and allow for adopting more productive methods because payments are distributed prior to planting season. This would suggest an emphasis on improving access to credit to improve the efficiency of Mexico's family farms. On the other hand, the historical production requirements of Procampo participation may mean that participants are simply more experienced producers.

A significant share of farms do not have formal documentation of property rights. Policies to ensure that farms have the necessary documentation could potentially help provide farms with the opportunity to keep abreast of technical change, as documented property rights are an important condition for accessing credit and thus facilitating adoption. This is especially true for ejido farms transitioning into participation with private credit and land markets. Nevertheless, we find no correlation here between agricultural TFP and property right documentation, access to credit, or ejido status, as we would have expected.

VI. Conclusions

Working with a sample of family farms from the Mexican Family Life Survey (MxFLS), we document a persistent inverse relationship between farm size and land productivity over the period 2002 to 2009. Similarly, when estimating an average production function we find a time-invariant inverse relationship between farm size and TFP, driven by the relatively high productivity of the smallest farms relative to those in the middle, and relatively low productivity of the largest farms. This is complemented by a stochastic frontier analysis, allowing for estimation of the relationship between farm size and frontier productivity and between farm size and technical inefficiency. Analysis of the production frontier reveals a dynamic inverse relationship between farm size and frontier productivity, where technical change has increased the frontier for larger farms at a faster rate than for smaller farms, weakening the inverse relationship along the frontier of productivity. Despite these changes at the frontier, the farm size – average TFP relationship has remained constant due to technical inefficiencies growing faster for larger rather than smaller farms. In essence, many of the larger farms were not able to keep up with technical change at the frontier, suggesting that successfully reducing technical inefficiency for this group could mediate, if not reverse, the farm size - productivity relationship.

To the extent that the inverse relationship between farm size and TFP has flattened along the frontier for Mexican family farms, it suggests that size may fade as one of the key determinants of productivity differences as agricultural sectors modernize. Policies that help family farms keep abreast of improvements in agricultural technology, such as farmer education, will be needed to reduce growing technical inefficiency. These findings support the claim that family farms have struggled in the wake of NAFTA era market liberalization, and we echo the calls of Pérez et al. (2008) that investment in rural infrastructure and assistance for smallholder transition into niche markets would support productivity growth for family farms.

Robust agricultural TFP growth is also important for poverty reduction. By growing the food supply more rapidly than demand, falling prices benefit poor consumers wherever they may live. And for the small farms that continue to exist, either because they are competitive or because they have few other opportunities, TFP growth helps to boost income. Where farms are too small, as in many parts of Mexico, increased productivity may still be insufficient to lift households out of poverty. Households in regions with access to non-agricultural employment may persist, and some will escape poverty, but migration is likely to continue. An important extension of this work would assess the potential impact of productivity growth on rural economic development and poverty alleviation.

An important limitation of analysis conducted here is the absence of non-family commercial farms in the Mexican sample. Future research should extend this analysis to a nationally representative sample of farms, such as the 2007 Mexican Agricultural Census, which would include family and non-family agricultural operations. Extending the analysis to the entire range of farm sizes and farm types would allow for a more complete analysis of the farm size – productivity relationship. Together with a theoretical analysis of a dynamic farm size – TFP relationship, such extensions would inform policy efforts to increase agricultural productivity.

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Appendix 1: Construction of the Output Index

There are three components to the construction of the output index. First, the valuation of crop production for each farm. Second, the valuation of livestock production. Third, the construction of the quantity index.

Valuing Crop Production

The three most important crops produced on each parcel used in production were aggregated into 90 groups, with a residual group for a set of relatively minor products. . The construction of the quantity index requires a price from each of the three periods for each product produced, regardless of whether or not it was produced in all periods. Whereas there was quite good coverage of prices for MxFLS crops produced within any given year, many crops did not have prices in all three years. More importantly, marked fluctuations in the crop prices generated across years raised concerns about using MxFLS generated prices for generating consistent crop valuations. In their place, we use price data from the Food and Agriculture Organization of the United Nations (FAO)[24] which provides Mexican producer prices over the relevant time period for approximately 110 crops, resulting in a near one to one mapping to the MxFLS crop grouping. The FAO prices are a vetted and defensible data series of average Mexican crop prices in each period, allowing for consistent valuation of MxFLS crop production. .[26]

The value of production of each crop on each parcel for each farm is valued using each of the three periods' prices. Value of production is then aggregate across crops for each parcel using each year's prices, and then aggregated across parcels for each farm for each set of prices. The result is three valuations for the crop production of each farm in each year, one using the price from each of the three survey years, providing the basis for construction of quantity indices.

Valuing Livestock Production

The MxFLS records the existence and value of the stock of many household assets. These asset categories include horses, cows and bulls, pigs and goats, and chickens. Whereas horses are

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[24] See http://www.fao.org/faostat/en/#data/PP.

[26] For the "Blackberries" and "Nuts" crop groupings the FAO price data is supplemented using prices generated by the Mexican government, found at http://www.economia-sniim.gob.mx/2010prueba/Agricolas.asp. For the "Herbs" crop grouping we generate average prices from the MxFLS data itself. The "Pasture" grouping is not valued, and the "Other" and "Flowers" groupings are not valued either.

most likely an input in the agricultural production process, the latter three categories constitute the production of livestock and their related goods. For the 20% - 25% of households owning cows and/or bulls in any period, the 23% - 28% owning pigs and goats, and the 37% - 46% of households owning chickens, the MxFLS provides a valuation of those asset stocks and some measures of the product of those asset stocks. A final value of nominal livestock production is calculated by summing the value of livestock sales with the value of livestock consumption. Nominal values are deflated to 2002 values, generating the value of livestock production to be used in the calculation of the quantity index.

The value of product sold is measured as the previous year's sales of dairy products, meat products, and fattened animals. The value of product consumed is calculated as the value of meat, dairy, and other animal products received as gift, as payment, or obtained from crops and animalsover the previous week. Aggregating across these categories for each household in each year and then multiplying by 52 generates the value of livestock production consumed. Treating this summation as the annual value of livestock production consumed implicitly assumes that (i) all, or nearly all, of these consumption values come from home production and not gifts or as payment, and (ii) the previous week's consumption patterns are representative of consumption patterns over the course of the year.

Construction of the Quantity Index

In each period, we begin by aggregating the total value of production for each farm in each survey year. For those households that have complete farm data in two or more years (i.e. complete farm size data on all parcels and valuation data of all crops on all parcels) we then construct a Fisher quantity index. Having identified "complete farms" in the panel, we then generate the following Panel IDs:

- 1 if the farm is in the panel in 2002 and 2005 only
- 2 if the farm is in the panel in 2002, 2005, and 2009
- 3 if the farm is in the panel in 2005 and 2009 only
- 4 if the farm is in the panel in 2002 and 2009 only
- 0 otherwise

We generate the quantity index for farm, f, producing crop, i, by first calculating changes in the Fisher quantity index over all relevant pairs of periods. These changes are then applied to base year values. The changes in the Fisher quantity index are calculated as follows:

- $Q^f_{02,05} = \sqrt{\left(\frac{\sum_i p_{i,2002} q_{fi,2005}}{\sum_i p_{i,2002} q_{fi,2002}}\right)\left(\frac{\sum_i p_{i,2005} q_{fi,2005}}{\sum_i p_{i,2005} q_{fi,2002}}\right)}$ … if Panel = 1 or 2

- $Q^f_{02,09} = \sqrt{\left(\frac{\sum_i p_{i,2002} q_{fi,2009}}{\sum_i p_{i,2002} q_{fi,2002}}\right)\left(\frac{\sum_i p_{i,2009} q_{fi,2009}}{\sum_i p_{i,2009} q_{fi,2002}}\right)}$ … if Panel =2 or 4

- $Q^f_{05,09} = \sqrt{\left(\frac{\sum_i p_{i,2005} q_{i,2009}}{\sum_i p_{i,2005} q_{i,2005}}\right)\left(\frac{\sum_i p_{i,2009} q_{i,2009}}{\sum_i p_{i,2009} q_{i,2005}}\right)}$ … if Panel=2 or 3

With changes in the quantity index in hand we then generate the level of the quantity index for each year as follows. Here $Value^f_{year}$ is the value of output in a given year using nominal prices for farm f:

- $QI^f_{2002} = Value^f_{2002}$ *... if Panel = 1, 2, or 4*

- $QI^f_{2005} = \begin{cases} Value^f_{2002} * Q^f_{02,05} & if\ Panel = 1\ or\ 2 \\ Value^f_{2005}/Deflator & if\ Panel = 3 \end{cases}$

- $QI^f_{2009} = \begin{cases} Value^f_{2002} * Q^f_{02,09} & if\ Panel = 4 \\ Value^f_{2005} * Q^f_{05,09} & if\ Panel = 3 \\ QI^f_{2005} * Q^f_{05,09} & if\ Panel = 2 \end{cases}$

Appendix 2: Construction of Inputs

Family Labor Index

Two approaches are used to generate a measure of family labor as an input to the production process. The first uses categorical variables for whether or not household members helped farm each plot. These measures are plot specific providing a measure of household labor on the extensive margin, but do not include any intensive measure of labor use. The second approach uses time-use data for each household member. While this approach has advantages on the intensive margin, it is less comprehensive and less complete on the extensive margin.

We develop a set of three indicators. The first uses time-use data and is the preferred approach, whereas the second and third use the binary yes/no data regarding family members' participation on each plot. The construction of Family Labor Index 1 is as follows estimates annual hours worked on the farm by each household member. If a core household member indicates that agricultural work on the family farm was either their primary or secondary job then average hours worked per week is the basis for that individual's annual agricultural labor.[28] If not, then hours spent on household agricultural activities in the previous week provides the basis for the individual's annual agricultural labor.[29] For non-core family members the most comprehensive data comes at the plot level - annual hours worked for these family members are estimated using group averages of time spent on household agricultural activities and the number of family members in each group, by type of family member.[30]

Summing hours worked by the core family members and the non-core family members generates Family Labor Index 1. This approach prioritizes employment data over the time use data, avoids double-counting of those two measures, and uses as much of the data as possible. Equation (1) summarizes this preferred Family Labor Index:

$$Family\ Labor\ 1_i = H_i^h * 52 + H_i^s * 52 + \sum_k H_{ik}^c * 52 + \sum_{j=1}^{10} N_{ij} * \overline{H}_j * 52$$

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[28] This includes not only those who claim that their job is as a "peasant on your own plot", but also those who work in agriculture as a "family worker in a household owned business, without remuneration" or a "boss, employer, or business proprietor."

[29] Individuals are asked about the use of their time on different activities over the previous week, one of which is "make any agricultural activity like weeding hoe[ing], cleaning, sowing, [etc.]."

[30] The average number of hours spent engaged in agriculture in the past week is 18.99 hours for non-core family members.

where H_i^h, H_i^s, and H_{ik}^c are the weekly hours worked of household i's household head, household head's spouse, and household head's k^th children as described above, $\overline{H}_j$ is the average weekly hours worked of non-core family member type j (unique for each of the 10 possible categories)[31], and N_{ij} is the number of non-core family members in group j of household i.

The construction of indices two and three creates an indicator for the involvement of family members in household production followed by aggregation across family member types for each household in each year. These measures calculate an indicator for each of the $j = 1 \dots 14$ types of family members (identified in relation to the household head).[32] In recognition that for multi-parcel farms a given family member type may not help on all plots, we weight each family member type's indicator by the share of the farm they participated on (measured as the size of the parcels that they participated on divided by the size of the total farm). For family member type j of farm i, the indicator I_{ij} is given by:

$$I_{ij} = \frac{size\ of\ farm\ i's\ parcels\ on\ which\ group\ j\ helped}{total\ size\ of\ farm\ i}$$

When aggregating, we then have the option of summing the indicator functions for each family member type or summing with weights that reflect the number of individuals in each family member type in each household in each survey year. The second index uses the former aggregation procedure, with no weights for the number of members of each family member type. The third index uses the latter aggregation procedure, applying weights that reflect the number of individuals in each family member type, N_{ij}:

$$Family\ Labor\ 2_i = \sum_{j=1}^{14} I_{ij}^2$$

$$Family\ Labor\ 3_i = \sum_{j=1}^{14} I_{ij}^3 * N_{ij}$$

[31] These family member types are: parents, parents in law, siblings, siblings in law, grandchildren, grandparents, aunts and uncles, nephews and nieces, cousins, and ex-spouses.

[32] These family member types are: spouse, children, step children, children in law, parents, parents in law, siblings, siblings in law, grandchildren, grandparents, aunts and uncles, nephews and nieces, cousins, and ex-spouses.

Family Labor Indices 1, 2, and 3 are positively correlated with each other. The correlation coefficients between index 2 and 3 range from 0.68 in 2002 to 0.71 in 2005. Family Labor Index 1 is less highly correlated with 2 and 3 than they are with each other, but this is reasonable given that it is based upon time use and is fundamentally different than the other two. Family Labor Index 1 is a measure of annual hours of agricultural labor from family members, capturing the intensity of agricultural labor of those family members included in the individual Adult and Child surveys, whereas indices 2 and 3 measured the extent of family participation in the agricultural process. Family Labor Index 1 is the preferred measure because it is less crude and takes advantage of as much of the data as possible, and it is used in the core regression analysis. Family Labor Indices 2 and 3 provide alternative measures and are used for sensitivity analysis.

Non-Family Labor

The MxFLS records the number of non-household members that worked on each parcel used in agricultural production. This forms the basis of the index of non-family labor. For each parcel, we weight this number of individuals by that parcel's share of the farm. These parcel level indicators are then aggregated across parcels for each household in each survey year to form a final measure.

A second measure of non-family labor is recorded in the household's expenditure on agricultural inputs, one of which is expenditure on laborers. These two measures are potentially very different, the former being unpaid non-family labor and the latter being paid labor. This might be especially true for ejido farms. Prior to including both measures we check for correlation between having both expenditures on laborers and non-family laborers helping out on a farm. For those farms with non-family labor, 92%, 54%, and 39% of farms with such workers recorded no expenditure on labor in 2002, 2005, and 2009, respectively. There is a negative correlation coefficient of -0.39 between having non-household members help with agricultural production and having paid for laborers, suggesting that these are distinct measures of labor and are not redundant. There appears to be no substantive difference between the use of these types of labor across ejido and non-ejido farms.

Appendix 3: Additional Descriptive Statistics for Household Controls

Table 3.1: Prevalence of Subsistence Farming, Monocropping, and Procampo Participation, by Farm Size and Survey Year

	Subsistence Farming			Monocropping			Participation in Procampo		
Farm Size	2002	2005	2009	2002	2005	2009	2002	2005	2009
0 to 0.5 ha	70%	53%	73%	76%	89%	75%	39%	38%	25%
0.5 to 1 ha	58%	50%	54%	82%	77%	68%	42%	40%	37%
1 to 2 ha	54%	36%	38%	73%	72%	83%	67%	47%	67%
2 to 5 ha	27%	37%	30%	71%	63%	62%	56%	51%	46%
5 to 10 ha	28%	21%	23%	58%	71%	69%	82%	74%	60%
10 to 20 ha	21%	8%	44%	72%	67%	67%	85%	79%	78%
> 20 ha	24%	25%	18%	72%	67%	82%	44%	42%	68%
Total	43%	36%	41%	71%	73%	71%	45%	42%	39%

Table 3.2: Share of farms suffering crop and livestock loss

	2002	2005	2009
Crop Loss	9%	7%	15%
Livestock Loss	5%	2%	3%

Table 3.3: Share of Farms with Access to Credit, by Farm Size

	2002		2005		2009	
Farm Size	Credit	Formal	Credit	Formal	Credit	Formal
0 to 0.5 ha	31%	8%	24%	5%	95%	13%
0.5 to 1 ha	36%	7%	33%	12%	93%	7%
1 to 2 ha	27%	6%	39%	20%	90%	14%
2 to 5 ha	47%	22%	34%	19%	92%	23%
5 to 10 ha	47%	20%	26%	11%	91%	23%
10 to 20 ha	46%	21%	33%	21%	89%	15%
> 20 ha	40%	24%	29%	17%	95%	14%
Total	39%	14%	32%	14%	92%	16%

Table 3.4: Savings and Credit of Panel Households, by Farm Size

	Has Savings			Used Credit		
Farm Size	2002	2005	2009	2002	2005	2009
0 to 0.5 ha	5%	6%	2%	21%	26%	22%
0.5 to 1 ha	4%	8%	5%	13%	22%	14%
1 to 2 ha	7%	7%	7%	17%	26%	26%
2 to 5 ha	3%	5%	12%	27%	23%	26%
5 to 10 ha	15%	9%	11%	39%	22%	23%
10 to 20 ha	18%	13%	22%	23%	21%	30%
> 20 ha	20%	13%	14%	40%	17%	18%
Total	8%	8%	9%	25%	23%	23%

Table 3.5: Share of Farms with Indigenous and Literate Household Head, by Farm Size

	Indigenous Ethnicity			Literate		
Farm Size	2002	2005	2009	2002	2005	2009
0 to 0.5 ha	28%	29%	29%	75%	76%	76%
0.5 to 1 ha	38%	32%	28%	71%	77%	72%
1 to 2 ha	38%	39%	36%	77%	76%	78%
2 to 5 ha	27%	34%	26%	77%	78%	78%
5 to 10 ha	20%	12%	11%	90%	93%	83%
10 to 20 ha	13%	8%	19%	79%	92%	89%
> 20 ha	24%	13%	32%	80%	79%	91%
Total	28%	27%	25%	79%	81%	79%

Table 3.6: Share of last level of education attended, by farm size, 2002

Farm Size	None	Elementary or Less	Secondary School	High School	College
0 to 0.5 ha	24%	60%	8%	7%	1%
0.5 to 1 ha	18%	71%	9%	0%	0%
1 to 2 ha	26%	60%	12%	1%	1%
2 to 5 ha	24%	63%	7%	1%	5%
5 to 10 ha	18%	67%	9%	5%	1%
10 to 20 ha	18%	64%	13%	2%	3%
> 20 ha	28%	52%	12%	4%	4%
Total	23%	62%	10%	3%	2%

Table 3.7: Share of Farms with Paved Roads and Institutions in the Community, by Survey Year

Variable	2002	2005	2009
Paved Roads	33%	37%	51%
Public Transport	56%	65%	72%
Permanent Market	18%	18%	18%
Mobile Market	32%	25%	26%
Post Office	41%	29%	22%
Hospital	7%	7%	15%
Elementary School	97%	99%	99%
Secondary School	79%	76%	60%
High School	28%	34%	40%
College	2%	16%	10%
Library	32%	39%	39%

Table 3.8: Share of Farms with Paved Roads and Institutions in the Community, by Survey Year

	2002		2005		2009	
Variable	Non-Ejido	Ejido	Non-Ejido	Ejido	Non-Ejido	Ejido
Paved	35%	31%	43%	32%	52%	49%
Public Transport	52%	58%	63%	66%	70%	72%
Permanent Market	26%	13%	21%	15%	25%	14%
Mobile Market	35%	30%	27%	24%	32%	21%
Post Office	35%	44%	42%	15%	29%	17%
Hospital	10%	5%	10%	4%	17%	14%
Primary School	97%	97%	99%	99%	97%	100%
Secondary School	81%	77%	74%	79%	54%	63%
High School	40%	21%	39%	28%	43%	38%
College	3%	1%	26%	7%	19%	4%
Library	44%	25%	51%	27%	42%	36%

Appendix 4: Technology Coefficients Accompanying Tables 6 and 7, Preferred Models

Table 4.1: Community Fixed Effects with Household Controls

	(1) Linear w/o Inputs	(2) Linear	(3) Quadratic	(4) Cubic	(5) Dummies
Family Labor		-0.026	-0.039	-0.038	0.114**
		(0.045)	(0.047)	(0.047)	(0.051)
Physical Capital		-0.044	-0.046	-0.043	0.078
		(0.082)	(0.083)	(0.082)	(0.070)
Draft Animals		0.036	0.027	0.024	0.067
		(0.041)	(0.044)	(0.048)	(0.045)
Purchased Intermediates		0.070	0.071	0.070	0.194***
		(0.051)	(0.051)	(0.051)	(0.074)
Non-family Labor		0.009	0.015	0.011	0.120**
		(0.045)	(0.054)	(0.052)	(0.046)
Constant	7.908***	9.230***	9.913***	10.427***	6.183***
	(0.455)	(1.102)	(1.299)	(1.505)	(1.111)
Community FE	Yes	Yes	Yes	Yes	Yes
R^2	0.70	0.72	0.72	0.72	0.68
N	1235	1235	1235	1235	1235

Standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01