A Mexican Ricardian analysis: land rental prices or net revenues?

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Abstract

This paper examines two specifications of the Ricardian Hedonic Model (RHM) in order to identify divergences between implicit values of land attributes. The main goal of this research is to compare these values obtained from ex-ante and ex-post indicators of land productivity. To the best of our knowledge, there is no similar work on the existing literature. Our argument is that these values differ due to the former depends upon farmers' expectations formed at the beginning of the crop year while actual prices and annual weather determine the later. We combine information on 2,524 farms in Mexico with climate normals, soil types, and a set of controls, using Geographic Information System (GIS) tools. The main findings indicate that these values globally differ. Moreover, most of the significant coefficients are individually different across both equations. According to the rental price model, the annual implicit value of an extra degree Celsius is $130 Mexican pesos (2.03% of the average rental price) and $154 (2.38%) of an additional mm. of rainfall. However, exploring the results from the net revenues specification, an extra °C modifies the net revenue by $-518 (-8.89%) and $351 (6.03%) an additional mm. of rainfall.

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1   Introduction

Nowadays, empirical work on the effects of Climate Change on agriculture has been applied to developing countries using net revenues as indicators of land productivity within the Ricardian Hedonic framework (Kurukulasuriya et al., 2006; Fleischer et al., 2007; Molua and Lambi, 2007; Mendelsohn et al., 2010; Wang et al., 2014). The main argument supporting this approach is that reliable measures of land values are not commonly available in these places (Mendelsohn and Dinar, 2009a). However, this indicator may be sensitive to crop year conditions such as inputs and outputs prices and climate unexpected shocks. Thus, it may not precisely reflect long term implicit values of land features. In contrast, land rental prices are set on a long term basis (farmers' expectations) and are not highly susceptible to annual conditions. So that, the main contribution of this research is to test for statistical divergences between these implicit values of land attributes using both annual net revenues and land rental prices within the Ricardian Hedonic framework. We believe that rental prices and net revenues are comparable due to they may represent an annual measure of land productivity. Notwithstanding, the key difference is the time when one observe them, before and after the crop year take place, respectively.

Given the previous arguments, this study attempts to answer the following research question: Do the implicit land attributes values differ by using land rental prices or net revenues in the RHM? This question is worthy of investigation because the comparison between both Ricardian specifications allows us to validate o question the results from previous studies in developing countries. For answering this question, data on plots of land managed by 2,524 farmers and distributed across Mexico is utilized for estimating the previous specifications. Observed rental prices and net revenues between October 2011 and September 2012 come from the unexplored database, in terms of the Ricardian analysis, the National Survey of Agriculture 2012 (ENA 2012)[1]. We extract the 50 years normals of temperature, precipitation and diurnal from the 1 km resolution rasters for each plot of land (Hijmans et al., 2005). Likewise, the soil type of each plot comes from the INEGI-FAO 2013 classification, which groups chemical and physical features such as pH, Colour, clay, inclination or organic matter into a general set of 21 profiles. We also include long term extreme events on the RHM that come from 3,400 meteorological stations: storm, hail and cloudy days. Due to the nature of these variables and the spatial distribution of farms and meteorological stations, we apply Thiessen polygons as an interpolation method. Moreover, we control for irrigation, land property rights, total farmland area, electricity availability, and distances to the nearest river, city and water body. We combine this Geo-referenced information using GIS tools.

The main findings suggest that the implicit values from the rental prices and net revenues equations jointly differ. It may confirm out initial hypothesis about divergences on implicit prices of climate variables because non-expected prices or climate shocks. The remainder of this paper is structured as follows. In section 2, we develop a simple model showing under which circumstances estimations from the two equations may differ or not. Section 3 illustrates the RHM methodology. Section 4 describes data sources and variables construction process. Section 5 presents a set of findings and a comprehensive discussion of these results. In section 6, we state some preliminary conclusions and further research.

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[1]This database is not publicly available. The only access point is at the Micro Data Laboratory at the National Institute of Statistics and Geography (INEGI).

2 Theory

The main purpose of this section is to show under which circumstances implicit values from the rental price and profit functions are equivalent. First, it describes how the problem is addressed using two periods of time and state the initial conditions for this simple model. Then, it presents the farmers' profit maximization process. At the end of this section, we argue that uncertainty plays a crucial role on the equivalence between these values using both specifications.

For the aim of this document, lets assume the crop year is divided into two periods: t_1 and t_2. The former indicates actions taken before the crop year. In the latter, the crop year finishes and the farmer observes all relevant variables. In t_1, the farmer maximizes profits according to his expectations; accordingly, he chooses optimal quantities of variable inputs given a set of exogenoues factors; then, determines his willingness to pay (WTP) for a plot of land in line with his production plan; and, the rental price results from the two-sided optimization mechanism in the land market[2]. In t_2, the farmer observes actual values of the production level, prices and weather.

For simplicity, lets assume that: the farmer produces only one variable output (y) and sell it at a given (exogenous) price (p); for producing y, he hires workers for sowing (t_1) and harvesting (t_2) activities and the total number of workers (x_1) is fixed and split among t_1 and t_2; although, the total demand of workers is known since the beginning of the cycle and the current wage (w_1), the farmer predicts the average wage rate ($\hat{w}$) for t_2, thus, the total cost of labor is $\frac{x_1 w_1}{2} + \frac{x_1 \hat{w}_2}{2} = \frac{w_1 + \hat{w}_1}{2} x_1 = \hat{w} x_1$; non-resowing activities take place from t_1 to t_2, therefore, the total expenditure on seeds in t_1 is equals to $s x_2$, where s stands for the price and x_2 the units of seeds; the farmer also occupies a fixed input (x_3), and δ reflects its unit cost; land is also a factor of production and farmer pays a rental price, R, per unit of area in t_1.

The maximization process involves decisions on variable inputs and outputs in order to reach the optimal profit. Thus, the expected profit in t_1 or the "variables profits" as in Palmquist (1989), normalized by farmland area and excluding land costs, of each farmer is as follows[3]:

$$\hat{\pi}_{nl} = \hat{\pi} + R = \hat{p}\hat{y} - \hat{w}x_1 - sx_2 - \delta\hat{x}_3 \tag{1}$$

As equation 1 depends on the expected level production, we use a Cobb-Douglas function. Thus, the farmer maximizes profits by choosing optimal quantities of variable output and inputs:

$$\max_{\hat{y}, x_1, x_2} \quad \hat{\pi}_{nl} = \hat{p}\hat{y} - \hat{w}x_1 - sx_2 - \delta\hat{x}_3 \text{ subject to } x_1^\alpha x_2^\beta \hat{x}_3^\gamma \geq \hat{y} \tag{2}$$

Assuming $\hat{x}_3$ is fixed and equation 2 has an interior solution, the constraint holds with equality, so, one can substitute from the constraint for $\hat{y}$ in the objective function. The problem reduces to choosing two variables, x_1 and x_2, to solve:

$$\max_{x_1, x_2} \quad \hat{p}x_1^\alpha x_2^\beta \hat{x}_3^\gamma - \hat{w}x_1 - sx_2 - \delta\hat{x}_3 \tag{3}$$

from equation 4, the first order conditions are:

$$\frac{\partial \hat{\pi}_{nl}}{\partial x_1} = \alpha\hat{p}x_1^{\alpha-1}x_2^\beta \hat{x}_3^\gamma - \hat{w} = 0 \Rightarrow \alpha\hat{p}x_1^{\alpha-1}x_2^\beta \hat{x}_3^\gamma = \hat{w} \tag{4}$$

$$\frac{\partial \hat{\pi}_{nl}}{\partial x_2} = \beta\hat{p}x_1^\alpha x_2^{\beta-1} \hat{x}_3^\gamma - s = 0 \Rightarrow \beta\hat{p}x_1^\alpha x_2^{\beta-1} \hat{x}_3^\gamma = s \tag{5}$$

$$x_1^\alpha x_2^\beta \hat{x}_3^\gamma - \hat{y} = 0 \tag{6}$$

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[2]The landowner offers a parcel with specific features, if those attributes meets the farmer requirements, then, there is an agreement on the rental price.

[3]A hat over a variable stands for farmers expectations. We use $\hat{x}_3$ to illustrate the effect of a given climate variable in our model, which can be seen as a fixed factor.

solving for x_1 and x_2, plugging them back into the first order condition and solving for $\hat{y}$, we obtain the optimal supply function:

$$\hat{y}^* = \left[\left(\frac{\hat{w}}{\alpha}\right)^\alpha \left(\frac{s}{\beta}\right)^\beta \frac{\hat{x}_3^{-\gamma}}{\hat{p}^{\alpha+\beta}}\right]^\Omega \tag{7}$$

From the optimal values of x_1^*, x_2^* and equation 7, we obtain the optimal income demand functions:

$$x_1^* = \left[\left(\frac{\hat{w}}{\alpha}\right)^{(\alpha\Omega-\beta)} \left(\frac{s}{\beta}\right)^{\beta(1+\Omega)} \frac{\hat{p}^{-(\alpha+\beta)\Omega}}{\hat{x}_3^{\gamma(1+\Omega)}}\right]^\sigma \tag{8}$$

$$x_2^* = \left[\left(\frac{\hat{w}}{\alpha}\right)^{\alpha(1+\Omega)} \left(\frac{s}{\beta}\right)^{(\beta\Omega-\alpha)} \frac{\hat{p}^{-(\alpha+\beta)\Omega}}{\hat{x}_3^{\gamma(1+\Omega)}}\right]^\sigma \tag{9}$$

substituting these last equations 7, 8, and 9 into the objective function, defining $A = \left[\frac{1}{\alpha^\alpha \beta^\beta}\right]^\Omega$, $B = \left[\frac{1}{\alpha^{\alpha\Omega-\beta} \beta^{\beta(1+\Omega)}}\right]^\sigma$, $C = \left[\frac{1}{\alpha^{\alpha(1+\Omega)} \beta^{\beta\Omega-\alpha}}\right]^\sigma$, and rearranging terms, we obtain the optimal profit function:

$$\hat{\pi}_{nl}^* = D\left[\frac{\hat{w}^\alpha s^\beta}{\hat{p}}\right]^\Omega \hat{x}_3^{-\gamma\Omega} - \delta\hat{x}_3 \tag{10}$$

where $D = A - B - C$. One can observe that the optimal "variable profit" in t_1 is a function of the expected output, labor, fixed factor and seeds prices and technical parameters as in Palmquist (1989), $\hat{\pi}_{nl}^* = f(\hat{p}, \hat{w}, s, \hat{x}_3, \alpha, \beta)$. Notice that, subtracting land rental costs, the expected profit is: $\hat{\pi}_{nl}^* - R = \hat{\pi}$. Thus, the farmer's bid for a specific parcel is given by the following equation:

$$\theta(\hat{p}, \hat{w}, s, \hat{x}_3, \alpha, \beta, \hat{\pi}) = \hat{\pi}_{nl} - \hat{\pi} = D\left[\frac{\hat{w}^\alpha s^\beta}{\hat{p}}\right]^\Omega \hat{x}_3^{-\gamma\Omega} - \delta\hat{x}_3 - \hat{\pi} \tag{11}$$

where θ is the *bid function* for a plot of land with the required attributes once the variable inputs are optimally chosen. So that, the *bid function* is the payment that a farmer is willing to make for using a parcel of land given a desired profit level. In equilibrium, some marginal conditions are necessary. If there is a marginal increase on a desirable land characteristic, it results in an increment of the farmer's bid, which is equal to the raise on the rental price of land attached to the change on that land attribute. Therefore, the farmer's bid has to be equal to the rental price of the parcel:

$$\theta(\hat{p}, \hat{w}, s, \hat{x}_3, \alpha, \beta, \hat{\pi}) = R = \hat{\pi}_{nl} - \hat{\pi} \tag{12}$$

thus, farmer's total bid results from the farmer's maximization problem (demand side). Regarding the *supply side*, Palmquist (1989) argues that land possesses different attributes, z, then, *the landlord maximizes profits from renting the plot of land* by choosing or altering $\tilde{z}$, given exogenoues attributes, $\hat{z}$. The landlord maximization problem is as follows:

$$\underset{\tilde{z}}{Max}\, \pi^s = R(\hat{z}, \tilde{z}) - C(\hat{z}, \tilde{z}, r, \Phi) \text{ subject to } \pi^s \geq 0 \tag{13}$$

where π^s represents the profits of the landowner, $R(\hat{z}, \tilde{z})$ is the rental price schedule, $C(\hat{z}, \tilde{z}, r, \Phi)$ is a common joint cost function, r is a vector of input prices and Φ a vector of technical parameters. The first order conditions indicate that the marginal cost of a $\tilde{z}$ characteristic has to be equal to its marginal price in the market. Then, the *offer function* is defined in the same manner as the bid function:

$$\phi(\hat{z}, \tilde{z}, \pi^{s*}, r, \Phi) = \pi^{s*} + C(\hat{z}, \tilde{z}, r, \Phi) \tag{14}$$

where π^{s*} is the desired profit subject to the land attributes that the landowner can alter. The *offer function* indicates unit prices the landowners are willing to accept on various

levels of the land attribute at a constant profit level when the amount of this attribute is optimally chosen. Optimality conditions, given that landowner maximizes profits, indicate that the marginal offer prices for the $\tilde{z}$ attributes have to be equal to their marginal characteristics prices in the market, and for $\hat{z}$, the characteristic price and his offer price would be completely demand-determined. Therefore, the landowners offer has to be equal to the rental price of the parcel:

$$\phi(\hat{z}, \tilde{z}, \pi^{s*}, r, \Phi) = R = \pi^{s*} + C(\hat{z}, \tilde{z}, r, \Phi) \tag{15}$$

and, in equilibrium:

$$\theta(\hat{p}, \hat{w}, s, \hat{x}_3, \alpha, \beta, \hat{\pi}) = \phi(\hat{z}, \tilde{z}, \pi^{s*}, r, \Phi) = R \tag{16}$$

Higher levels of z imply higher rental prices, if z is desirable. The reverse applies for non-desirable attributes. Accordingly, from equation 10 and the initial conditions, the rental price per unit of land in t_1 can be expressed as follows:

$$R = D\left[\frac{\hat{w}^\alpha s^\beta}{\hat{p}}\right]^\Omega \hat{x}_3^{-\gamma\Omega} - \delta\hat{x}_3 - \hat{\pi} \tag{17}$$

and the "variable profits" equation, which is observable in t_2, is given by:

$$\pi_{nl} = D\left[\frac{w^\alpha s^\beta}{p}\right]^\Omega x_3^{-\gamma\Omega} - \delta x_3 \tag{18}$$

According to Palmquist (1989) and (Diewert, 1974), equations 17 and 18 are differentiable with respect to a structural land attribute and/or a fixed factor, respectively:

$$\frac{\partial R}{\partial \hat{x}_3} = -\gamma\Omega D\left[\frac{\hat{w}^\alpha s^\beta}{\hat{p}}\right]^\Omega \hat{x}_3^{-\gamma\Omega-1} - \delta \tag{19}$$

and,

$$\frac{\partial \pi_{nl}}{\partial x_3} = -\gamma\Omega D\left[\frac{w^\alpha s^\beta}{p}\right]^\Omega x_3^{-\gamma\Omega-1} - \delta \tag{20}$$

For the purpose of this research, x_3 represents a climate variable (or land attribute, z) i.e. precipitation. Therefore, equations 19 and 20 represent the implicit prices or "shadow prices" from an ex-ante and an ex-post measure of land productivity. If these equations were observable in t_1, both implicit prices of x_3 were theoretically equivalent:

$$\frac{\partial \hat{\pi}_{nl}(\hat{p}, \hat{w}, s, \hat{x}_3)}{\partial \hat{x}_3} = \frac{\partial R(\hat{p}, \hat{w}, s, \hat{x}_3, \hat{\pi})}{\partial \hat{x}_3} \tag{21}$$

Notice that $\hat{\pi}$ is a constant once $\hat{\pi}_{nl}$ has been maximized. However, the actual values of the expected variables are observed in t_2. Assuming that the expected level of the fixed factor is equal to its actual value, $\hat{x}_3 = x_3$. Then, $\frac{\partial R}{\partial x_3}$ is observable in t_1 and reflects the MWTP for x_3 according to farmers' expectations on $\hat{p}, \hat{w}$ and $\hat{\pi}$ therefore equation 19 reflects the MWTP for x_3 in t_1. In contrast, $\frac{\partial \pi_{nl}}{\partial x_3}$ is observable in t_2 and reflects the implicit or imputed value of x_3 according to the actual prices, p and w, therefore equation 20 reflects the implicit value of x_3 in t_2. Accordingly, if $\hat{p} = p$ and $\hat{w} = w$, these equations are equivalent, $\frac{\partial R}{\partial x_3} = \frac{\partial \pi_{nl}}{\partial x_3}$. However, if $\hat{p} \neq p$ or $\hat{w} \neq w$, these values may be different, $\frac{\partial R}{\partial x_3} \neq \frac{\partial \pi_{nl}}{\partial x_3}$. Defining $\mu = \frac{\partial R}{\partial x_3}$, $\eta = \frac{\partial \pi_{nl}}{\partial x_3}$, τ as the difference between μ and η, assuming that the Cobb-Douglas production function exhibits constants returns to scale, $\alpha + \beta + \gamma = 1$, and $\alpha, \beta, \gamma > 0$, it yields:

$$\tau = \left[\frac{D}{s^{\left(\frac{\beta}{\gamma}\right)}}\right]\left[\left(\frac{\hat{p}}{\hat{w}^\alpha}\right)^{\frac{1}{\gamma}} - \left(\frac{p}{w^\alpha}\right)^{\frac{1}{\gamma}}\right] \tag{22}$$

From expression 22, the price of seeds, β, and γ are strictly positive, therefore $s^{(\frac{\beta}{\gamma})} > 0$. Recalling that $D = A - B - C$, then:

$$D = \left(\alpha^{\alpha}\beta^{\beta}\right)^{1/\gamma} - \left(\alpha^{\frac{\alpha+\beta-\alpha\beta-\beta^2}{\alpha+\beta}}\beta^{\beta}\right)^{1/\gamma} - \left(\alpha^{\alpha}\beta^{\frac{\alpha+\beta-\alpha^2-\alpha\beta}{\alpha+\beta}}\right)^{1/\gamma} \tag{23}$$

If $\alpha = \beta$, it implies that $\gamma = 1 - 2\alpha$ with constant returns, hence:

$$D = \left(\alpha^{2\alpha}\right)^{1/(1-2\alpha)} - 2\left(\alpha\right)^{1/(1-2\alpha)} \tag{24}$$

If $\alpha < 1/2$, $D > 0$. If $\alpha > 1/2$, $D < 0$, but it does not satisfy the constant returns to scale assumption because $\alpha + \beta > 1$. The previous equation is not defined if $\alpha = 1/2$, however, it implies that $\beta = 1/2$, which means $\gamma = 0$, which contradicts our initial condition. Therefore, for all values of $\alpha = \beta$ lower than $1/2$, D is well defined and positive. For all cases in which $\alpha > \beta$ and vice-versa, D is strictly positive. According to the equation 22 and $\hat{x}_3 = x_3$:

1. if $\hat{w} = w$ and $\hat{p} = p \Rightarrow \tau = 0 \Rightarrow \mu = \eta$
2. if $\hat{w} = w$ and $\hat{p} > p \Rightarrow \tau > 0 \Rightarrow \mu > \eta$
3. if $\hat{w} = w$ and $\hat{p} < p \Rightarrow \tau < 0 \Rightarrow \mu < \eta$
4. if $\hat{w} > w$ and $\hat{p} = p \Rightarrow \tau < 0 \Rightarrow \mu < \eta$
5. if $\hat{w} < w$ and $\hat{p} = p \Rightarrow \tau > 0 \Rightarrow \mu > \eta$

In this section we show that if farmers expectations are correct, both implicit values are equivalent. However, if the expected values of the fixed factor and wages are in line with their actual values at the end of the crop year, but the output price exceeds the initial expectation, the implicit value of x_3 from the profit equation is greater than the one obtained from the rental specification and vice versa when the expectation on the output price is higher than its actual level. Regarding the input price, w, fixing other variables in line with expectations, when it exceeds the initial expectation, the implicit price of x_3 from the rental price equation is greater than the value identified by the profit specification and vice-versa.

3 Methodology

The Ricardian Hedonic technique explores how farmland values vary across the space given different exogenous variables such as climate and soils, which farmers cannot control (Mendelsohn et al., 1994). This method uses a cross sectional analysis in order to identify how these sets of variables impact land values. Ricardo (1817) argues that land rents would reflect the net revenue of farmland under a competitive market. So, the present value of all these revenues are equal to the farmland value:

$$V = \int \pi_{nl}e^{-\varphi t}dt = \int [\Sigma_{m=1}^{M}p_m y_m(\mathbf{X}, \mathbf{F}, \mathbf{S}, \mathbf{H}) - \Sigma_{n=1}^{N}c_n x_n]e^{-\varphi t}dt \tag{25}$$

where, π_{nl} is the net revenue per hectare of land, p is the price of output, y_m is an output, $\mathbf{X}$ stands for non-land inputs, $\mathbf{F}$ represents a vector of climate variables, $\mathbf{S}$ and $\mathbf{H}$ are vectors of soils and control covariates, c_n represents the unit cost associated to input n, excluding land, t is the period of time, and φ is the discount rate.

As Palmquist (1989) states, farmers choose inputs and outputs in order to maximize net revenues given set of exogenous variables such as climate, adaptation is implicitly captured by the Ricardian model. Therefore, this process leads to a reduced form equation that relates farmland values to climate, soils, and economic variables[4]. According to Mendelsohn and Dinar (2009a), the Ricardian model is defined as follows:

$$V = \beta_0 + \Sigma_{g=1}^{G}\beta_{1g}F_g + \Sigma_{k=1}^{K}\beta_{2k}S_k + \Sigma_{l=1}^{L}\beta_{3l}H_l + u \tag{26}$$

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[4]Prices are assumed to be the same for all farmers.

where G, K and L are the total number of climate, soils and control variables, and u represents the disturbance term. The quadratic terms of climate variables are incorporated into the Ricardian equation for identifying non-linearities in the response of crops to them as agronomists and laboratory experiments suggest (Keating et al., 2003).There is a consensus on the existing literature indicating that temperature shows a hill-shaped relationship with land values. However, there is no agreement on how precipitation affects these values. Thus, differentiating equation 26 with respect to a climate variable gives us its marginal value:

$$\frac{\partial V}{\partial F_g} = \beta_{1g} + 2\beta_{1q}F_g \tag{27}$$

where $g \neq q^5$. Notice that 27 depends upon the value of F_g. Then, the literature suggests us to evaluate equation 27 at the sample mean of F_g, that yields, or, it should be computed for each observation and calculating the average of the distribution of marginal values.

The previous functional form assumes that the marginal value of F_g is independent of other climate variables. However, some land attributes cannot be sold separately (Palmquist, 1989). Accordingly, interactions between climate variables are commonly introduced into the Ricardian equation (Seo et al., 2009; Mendelsohn et al., 2010; Fezzi and Bateman, 2013; Gebreegziabher et al., 2013). In this case, the marginal value also depends upon other climate land attributes as the following expression states:

$$\frac{\partial V}{\partial F_g} = \beta_{1g} + 2\beta_{1q}F_g + \beta_{1r}F_r \tag{28}$$

which is also evaluated in the same fashion and $r \neq g \neq q^6$. The loglinear specification of the Ricardian equation represents an alternative functional form for identifying the marginal/implicit values of each land attribute, $\frac{\partial V}{\partial F_g}$ is now multiplicative and can be evaluated at the sample means:

$$\frac{\partial Ln(V)}{\partial F_g} = [\beta_{1g} + 2\beta_{1q}E[F_g] + \beta_{1r}E[F_r]] * E[V] \tag{29}$$

For applications in developing countries, the Ricardian method requires some adjustments due to reliable measures of farmland values are not commonly available because non-proper land market functioning (Timmins, 2006; Fleischer et al., 2008; Maddison et al., 2007; Wang et al., 2014), low densities of the meteorological stations network, output self-consumption, the presence of household labour and the correct accounting of livestock. Regarding the first issue, the existing literature suggests that annual revenue per unit of land should be utilized instead of farmland values (Mendelsohn and Dinar, 2009a). This annual indicator is defined as the difference between gross revenue and non-land costs, π_{nl}, as is stated in equation 25. There exist some shortcomings when researchers use net revenues within the RHM such as it comprises revenues from different crops and animals, farmers may allocate more than one plot to an specific crop or 2 cropping seasons as in Mexico, it is difficult to identify the specific cost of capital per parcel, the price that is considered for calculating the gross revenue may be distorted if intermediaries participate in the commercialization process, the accounting of self-consumption and household labour cost. Although all these elements may distort net revenues, it is essential to properly account for the annual cost of capital[7]. Taking these drawbacks on mind, this annual value is regressed onto the same set of explanatory variables as 26:

$$\pi_{nl} = \beta_0 + \Sigma_{g=1}^{G}\beta_{1g}F_g + \Sigma_{k=1}^{K}\beta_{2k}S_k + \Sigma_{l=1}^{L}\beta_{3l}H_l + u \tag{30}$$

Notwithstanding, this paper proposes an alternative specification for applications of the RHM in developing countries using annual rental prices instead of net revenues. These

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[5]β_{1g} comes fromt the linear term and β_{1q} from the quadratic term.
[6]β_{1r} comes from the interaction term between two climate variables.
[7]See annex 1 for variables description.

measures allow us to test for significant differences on the implicit prices of climate variables across models. These rental prices are determined as in Palmquist (1989). Thus, the rental price per hectare or unit of land can be regressed onto the same set of covariates[8]:

$$R = \beta_0 + \Sigma_{g=1}^{G}\beta_{1g}F_g + \Sigma_{k=1}^{K}\beta_{2k}S_k + \Sigma_{l=1}^{L}\beta_{3l}H_l + u \tag{31}$$

and, Additionally, we can also estimate Loglinear specifications of equations 30 and 31 and marginal values as in 29. For testing differences on land attributes implicit values we use a F-test. Pooling equations 30 and 31 into a general equation, we obtain[9]:

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\begin{aligned}
Y = {} & \Sigma_{g=1}^{G}\beta_{11g}(F_g * d_1) + \Sigma_{k=1}^{K}\beta_{21k}(S_k * d_1) + \Sigma_{l=1}^{L}\beta_{31l}(H_l * d_1) \\
& + \Sigma_{g=1}^{G}\beta_{12g}(F_g * d_2) + \Sigma_{k=1}^{K}\beta_{22k}(S_k * d_2) + \Sigma_{l=1}^{L}\beta_{32l}(H_l * d_2) \\
& + d_1 * (u_1) + d_2 * (u_2)
\end{aligned}
\tag{32}
$$

where Y represents the set of outcomes on the rental price and net revenue equations, d_1 equals one if the data comes from the former model and, 0 otherwise, d_2 equals one if the data comes from the net revenue data and, 0 otherwise. Given equation 32, we are able to estimate the marginal effects of each variable and test if the climate implicit values are statistically equivalent or not using individual, groups and global F-tests, where the null hypothesis is $H_0 : \frac{\partial R}{\partial F_g} = \frac{\partial \pi_{nl}}{\partial F_g}$, and the alternative $H_1 : \frac{\partial R}{\partial F_g} \neq \frac{\partial \pi_{nl}}{\partial F_g}$. From the theoretical section and given previous equations, we expect that implicit values from individual equations are not statistically equivalent when farmers' expectations deviate from actual prices and climate. We also expect non-linear effects of climate variables on rental prices and net revenues: a hill-shape relationship between temperature (Seo and Mendelsohn, 2008) or precipitation (Kabubo-Mariara and Karanja, 2007) or an U-shape relation with respect to rainfall (Ater and Aye, 2012) and land productivity. As agronomists suggest, not only the mean of temperature affects crops growth but also the range between the maximum and the minimum temperature, thus, the diurnal variable is introduced into the Ricardian model (Wheeler et al., 2000; Asseng et al., 2011; Mendelsohn and Dinar, 2003; Mendelsohn et al., 2010; Galindo and Reyes, 2015), suitable soil types increase land values and productivity, irrigation is relevant (Darwin, 1999; Mendelsohn and Nordhaus, 1999) and the more irrigated land the higher net revenues and rental prices, the land tenure regime is controversial because there is no consensus on the existing literature on how Ejidal[10] or private regimes affect land productivity (Johnson, 2001), the closer water bodies and markets, the higher rental prices and net revenue (Mendelsohn and Dinar, 2003), and repackaging is not costless for landowners and this diminishes farm values as in Maddison (2000).

Regarding our case study, Galindo and Reyes (2015) identify the potential damages of climate change on Mexican agriculture using a balanced panel model for the period 2003-2009. These authors use net revenues per hectare as an indicator of land productivity at the municipality level (2,431 municipalities). The main findings suggest that there is a hill-shaped relationship between net revenues and climate variables, all types of lands will suffer under a warmer and drier future, the greater the range of the diurnal temperature the greater the damage on agricultural revenues. The previous findings (implicit prices) relies on year-to-year estimations of the RHM, thus, Galindo and Reyes (2015) show that coefficients of the marginal effects of climate variables are unstable across time due to high degrees of uncertainty. Likewise, Mendelsohn et al. (2010) conduct a cross-sectional Ricardian analysis for 621 Mexican farms using survey data for the 2002 crop year. Thus, in

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[8]Loglinear specifications and marginal values calculations apply for both rental price and net revenue equations. However, the net revenues negative values require an adjustment. In order to estimate the net revenues Loglinear model, a constant could be added to all observations, which is equal to the minimum (negative) value plus one.

[9]We omit the constant term.

[10]It is the portion of land, forests or water that the government allocated to a peasants group in order to be harvested. The Agrarian Law establishes that if the Ejidal land is pretended to be sold, the "ejidatario" has to switch it from the social property right scheme to the private property regime.

that study, farmers self-reported land values reflect land productivity. The set of results suggests that a warmer and wetter environment would harm agriculture in Mexico.

4   Data

This section describes the data we use to fit models from equations 30 and 31 and 32. Land rental prices, output quantities and prices, costs, irrigated, Ejidal and total areas, and farms' location come from the National Agriculture Survey 2012 (Encuesta Nacional Agropecuaria 2012)[11]. This survey contains information on 2,524 farms that rented at least one parcel of land and harvested at least one of the main 33 crops or animals in the period between October 2011 and September 2012. The total number of plots is slightly greater than 32,000. These plots are distributed across Mexico: 25% located in Sinaloa, 15% in Sonora, 10% in Chihuahua, 8% in Jalisco, 7% in Guanajuato, and 35% on the remaining regions. So, the results of this study strictly rely on this sample. Rental prices and net revenues per hectare are reported at the farm level[12].

Climate variables come from two complementary sources. Temperature and precipitation data come from the 1km resolution rasters published by Hijmans et al. (2005)[13]. These authors create interpolated climate surfaces for the entire globe using the thin-plate smoothing spline algorithm considering latitude, longitude, and altitude. This estimation is based on a large number of sources: 1. the Global Historical Climate Network Dataset (GHCN), the WMO climatological normals (CLINO), FAOCLIM 2.0, and, the International Center for Tropical Agriculture (CIAT). Hijmans et al. (2005) conduct a data quality control dealing with uncertainty and provide a very high resolution on the surfaces they create. Hijmans et al. (2005) publish 48 global 30 arc s resolution rasters for monthly 1950-2000 normals of maximum, minimum temperature and precipitation. We extract climate values for each plot on our sample. In Mexico, farmers split the crop year into two main crop seasons: Spring-Summer and Autumn-Winter. Previous studies suggest that monthly normals are highly correlated, thus, seasonal normals better reflect climate on the Ricardian framework (Mendelsohn and Dinar, 2009b). We compute these seasonal variables by averaging the mean, minimum and maximum temperature and precipitation from December, January and February (Winter), March, April and May (Spring), June, July and August (Summer), September, October and November (Autumn). The difference between the maximum and minimum temperature yields the diurnal temperature[14].

The second set of climate variables considers the long term average of storm, hail and cloudy days in a specific season. The United Nations develops a climatological software operated by the National Meteorological Service (SMN) in Mexico, CLImate COMputing project (CLICOM). It reports daily data on storms, hail, and clouds from 5,459 meteorological stations distributed along Mexico. One can find data on different periods between 1920 and 2013. So, this database is temporarily compatible with Hijmans et al. (2005). We conduct quality controls over this information. First, we exclude stations with less than 10 years of continuous daily information and operated before 1950, thus, the remaining set comprises 3,388 stations. Second, by averaging the total number of storm, hail, and cloudy days per season and station, we interpolate these values applying the Thiessen method as some hydrological engineers suggest (Thiessen, 1911; Brassel and Reif, 1979; Tabios and Salas, 1985; Hartkamp et al., 1999). This technique creates a polygon for each point (station) containing all the closest areas to it. Thus, the spatial join tool in ARCGis allows us

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[11]The location of each plot of land is provided by the INEGI using the same Geo-referenced framework as the National Agriculture Census 2007, which uses control areas in order to identify the specific location.

[12]See Annex 1 for a detailed description about variables construction.

[13]Available on: http://www.worldclim.org

[14]As rental prices and net revenues report their values at the farm level, we weight climate variables by the proportion of each plot over the total area.

to extract these values for each plot of land[15].

Soils information comes from the *soils' profile* elaborated by the INEGI. This Institute publishes a soil classification based on the Soil Map of the World (FAO-UNESCO, 1974, 1997). It includes data on 4,418 soil profiles, chemical and physical analyses of 14,349 samples of land, and 1,901 photographs following the World Base Reference (WRB) and INEGI's adjustments. It also contains land morphological characteristics. However, using all these profiles could be cumbersome in terms of the purposes of this study, then, we use the more general classification, which group them into 21 broader categories. As the climate data, we obtain the soil type of each plot[16].

Dependent variables in our models also depend on a set of control variables such as the total area, altitude, distance to the nearest city, water body and river as measures of market access and water availability, irrigation, land tenure regime, and electricity. Thus, in order to incorporate those controls we combine data from the ENA 2012 and other Geo-referenced sources. The survey directly reports the total area per plot, so, we only add all rented and owned plots areas for each farm. Hijmans et al. (2005) also publish a 30 arc s resolution raster (1 km^2) reporting data on meters above the sea level (masl) for each grid. We extract the corresponding values for each plot of land[17]. Regarding, distances between each plot to the nearest city, the INEGI publishes a Shapefile of urban areas. Likewise, the same source provides information (polygons and lines Shapefiles) about water bodies and rivers along Mexico. For the purposes of this investigation, we use the Euclidean distance, which measures the straight line linking the center of each control area to these sources[18]. The ENA 2012 reports if a plot is irrigated or not and, if it is, the percentage over the total area. It also contains information about the land tenure regime of individual parcels.

Using all this information, we match Geo-referenced data with rental prices and net revenues using GIS tools. Table 3 in Appendix 2 shows the descriptive statistics from the two equations. The average rental price and net revenue per hectare are $6,096 and $5,301 Mexican pesos and they range from $77 to $41,630 and from -$131,677 to $143,075, respectively. From this sample, 863 farms observe negative values, which suggests that non-land costs exceed gross income.

In sum, we observe that irrigated and farms located in region 5 register the highest rental prices and net revenues in spite of the highest temperatures and the lowest volumes of precipitation and storm days. Most of the agricultural activities are concentrated on these lands. Ejidal lands and plots in those states are the closest to the water bodies, consequently, they report the highest percentage of irrigated over the total land. In contrast, rainfed and plots in region 2 observe the worst net revenues per hectare in spite of they are facing low temperatures. This may be caused because these farmers posses the furthest lands to the city and water body. Moreover, small farms in region 4 are the closest to cities and rivers, but, with high number of days with hail.

5 Results

This section presents the results from the estimated RHMs in equations 30 and 31[19] and the F-tests for the implicit prices from equation 32. An F-test for jointly significance of storm and cloudy days coefficients indicates that the null hypothesis, $H_0 : \beta_{1g} = 0$, cannot be rejected at the 5% level of significance, then, all these terms were excluded from the

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[15]As before, we weight these normals by the proportion between the plot and total farm land areas.

[16]These values are also weighted by the proportion of land.

[17]We also weight each observation by the proportion of the plot over the total farmland area.

[18]As one farmer can hold more than one plot of land with different distances to these places, we compute the weighted average as before.

[19]Our set of estimations includes linear, Loglinear, unweighted, weighted, and groups of farmers RHMs, however, in this paper we only present the results from the linear specification because the adjustment to the negative values on the net revenues equation is significantly sensitive to the constant we choose. However, the main conclusions about implicit prices divergences do not change.

full-model.

Columns 2 and 6 in Table 1 show the results from the parsimonious rental price models[20]. All variables, climate and temperature-precipitation in the parsimonious model are statistically significant. Annual temperature holds a hill-shaped relation with respect to rental prices. Regarding precipitation, its annual value also reflects an inverted U-shaped relationship. Moreover, the joint effect of these variables is negative, which implies that warmer and wetter environments would be harmful, but, this effect is only significant in Summer. All seasonal diurnals are statistically significant. In Mexico, the 2 annual sowing seasons start in March-April and October-November, so, higher diurnals during the crop growing season negatively affect rental prices stressing animals and crops. However, more variability before the crop season, Spring and Autumn, benefits land productivity because it diminishes plagues populations. For the number of hail days, an additional day on Winter would harm rents, its effect in Spring is positive and significant, it is because hail contributes to soil moisture before the sowing activities for the second crop season and plagues numbers decline. Both equations show that the soil type is relevant for the rental price due to most of the associated coefficients are statistically significant. In the margin, one percent additional of the Vertisol, Xerosol and Feozem lands increases rents by $20-$23, $18-$22 and $11-$17 pesos, respectively. These findings imply that soil structural features do matter when the rental prices are negotiated. The linear and the square term of the total rented area reflect that repackaging of land is costly. Access to markets and distances to rivers are not relevant. In contrast, rental prices rise between $32 and $39 pesos per km. closer to the nearest water body. Additionally, we include the percentage of irrigated and Ejidal lands as plots attributes based on previous studies. Their estimated coefficients suggest that these lands observe higher rental prices with respect to private and rainfed farms, however, the effect of an Ejidal certificate is not significant. The positive effect of irrigation on the land price confirms that it is a desirable attribute, especially when rainfall is not enough or well distributed across the crop season. Similarly, the availability of electricity observes a positive value as expected, this also represents a desirable attribute due to it allows farmer can improve irrigation equipment or other machineries performances.

Columns 4 and 8 present the estimated coefficients from the net revenues equation. We adjusted the values of net revenues by adding an constant to each observation due to 863 farms observe negative values (non-land costs greater than gross income), otherwise, the Log-linear specification would be biased. Nonetheless, the results are highly sensitive to the value we select. Therefore, the linear model is preferred. Similar F-tests suggest that all, climate and temperature-precipitation coefficients are statistically significant. The annual temperature holds a hill-shaped relationship with respect to net revenues in the unweighted model, and an U-shape in the weighted regression, but, both linear and squared effects are not significant. It may suggest that long-term averages of temperature may not be affecting crops in that year, which in part corroborates our initial hypothesis. Regarding precipitation, one observe that annual rainfall maintains an inverted U-shaped effect on net revenues. In contrast to the temperature feedback, most of these terms are statistically significant. The joint effect of temperature and rainfall in Autumn is relevant, which indicates that higher volume of water and a warmer environment would lead to losses in that season. Analyzing diurnals, these covariates hold the same effects as in the rental price equation, but, they are significantly larger than the ones on the former model. It confirms that higher difference on diurnal temperature lead to losses during the growing phases and benefits from reductions on plagues populations in Spring and Autumn. Regarding hail days per season, an additional day during the growing seasons may harm crops while more hail before the sowing activities may be improving soil moisture and reducing plagues populations. Notice that these effects on net revenues are greater than the one on the rental prices equation as well. The net revenues model reveals that most of the soil types are

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[20]Each observation is weighted by the proportion of cropland in each municipality in order to better account for different prices mechanisms.

not statistically different from zero. It should be reflecting that, on the margin, yields do not depend on the soil type but they are sensitive to technological features (pesticides, herbicides, fertilizers, etc), which offset the soil features.

Table 1: Linear Ricardian Hedonic Models: rental prices and net revenues

VARIABLES	Rent per hectare Unweighted	se	Net Rev. per hectare Unweighted	se	Rent per hectare Weighted	se	Net Rev. per hectare Weighted	se
Temp. winter ºC	1,154.16***	(358.93)	2,209.07	(2,363.70)	1,338.38***	(429.46)	1,160.03	(3,044.36)
Temp. spring ºC	-1,365.25***	(289.86)	-2,750.50	(1,848.20)	-1,255.11***	(356.07)	-2,345.84	(2,332.97)
Temp. summer ºC	877.51**	(354.90)	174.12	(2,629.52)	1,107.72**	(444.79)	333.52	(3,190.61)
Temp. Autumn ºC	-719.19	(468.69)	-113.83	(3,259.28)	-1,060.08*	(576.74)	334.14	(3,942.63)
Temp. winter sq.	5.56	(25.08)	92.54	(149.88)	-5.53	(30.37)	165.26	(198.57)
Temp. spring sq.	7.38	(29.37)	-31.66	(188.35)	-13.80	(35.12)	-128.76	(219.27)
Temp. summer sq.	-19.52	(27.20)	-113.21	(157.75)	-72.76**	(34.01)	-29.55	(196.75)
Temp. Autumn sq.	-10.71	(36.72)	40.83	(209.17)	72.72	(53.47)	35.48	(287.32)
Prec. winter mm.	-174.40***	(34.71)	-775.26***	(237.81)	-159.59***	(45.40)	-889.84***	(290.34)
Prec. spring mm.	243.00***	(46.18)	769.32***	(275.28)	294.44***	(59.88)	959.22***	(332.67)
Prec. summer mm.	-20.11***	(7.72)	-89.67**	(43.61)	-18.96**	(9.01)	-56.55	(47.75)
Prec. Autumn mm.	28.98*	(15.81)	320.11***	(89.74)	37.71**	(19.07)	338.45***	(101.20)
Prec. winter sq.	1.71***	(0.65)	6.96*	(4.18)	1.36*	(0.76)	9.77**	(4.74)
Prec. spring sq.	-2.33***	(0.69)	-6.69*	(4.01)	-3.03***	(0.92)	-8.74*	(4.72)
Prec. summer sq.	0.05	(0.05)	0.50**	(0.23)	0.03	(0.06)	0.41*	(0.24)
Prec. Autumn sq.	-0.13	(0.13)	-1.62**	(0.69)	-0.12	(0.16)	-1.82**	(0.85)
Temp. Winter*Prec. winter	-3.84	(5.17)	27.11	(27.71)	-4.28	(7.93)	15.37	(34.45)
Temp. Spring*Prec. spring	-1.60	(4.60)	18.23	(28.58)	-3.88	(5.63)	36.25	(38.04)
Temp. Summer*Prec. summer	-1.40	(1.39)	7.52	(7.88)	-3.31*	(1.87)	4.70	(10.03)
Temp. Autumn*Prec. autumn	1.64	(2.54)	-42.78***	(14.14)	2.77	(3.47)	-38.22**	(17.42)
Diurnal winter ºC	-1,382.46***	(436.89)	-8,184.65***	(3,064.72)	-1,386.06**	(583.90)	-9,303.03**	(4,079.43)
Diurnal spring ºC	1,418.78***	(306.72)	6,023.73***	(2,015.52)	1,510.60***	(397.27)	7,980.31***	(2,573.92)
Diurnal summer ºC	-1,959.03***	(365.57)	-4,258.12*	(2,577.74)	-1,814.06***	(449.34)	-6,560.06**	(3,164.40)
Diurnal autumn ºC	1,686.98***	(483.27)	6,151.11*	(3,384.33)	1,617.92***	(614.31)	6,998.33	(4,458.17)
Hail winter (days)	-653.01***	(216.28)	-3,943.60***	(1,331.47)	-821.27***	(238.66)	-5,118.24***	(1,379.87)
Hail spring (days)	1,261.86***	(383.14)	2,493.50	(2,001.49)	1,418.40***	(422.04)	1,718.40	(1,914.72)
Hail summer (days)	3.98	(203.11)	-1,883.25	(1,450.16)	-74.49	(252.40)	-2,415.52	(1,601.58)
Hail autumn (days)	-430.74	(478.92)	8,138.50**	(3,286.65)	-346.21	(627.53)	10,048.49***	(3,769.76)
Soil acrisol	18.19**	(7.35)	13.07	(64.89)	14.60	(9.83)	40.52	(59.04)
Soil andosol	3.51	(18.23)	1.05	(105.80)	-5.41	(21.55)	25.47	(115.32)
Soil cambisol	29.35***	(7.06)	-13.38	(49.66)	29.72***	(10.15)	-3.47	(42.24)
Soil castanozem	26.84*	(14.91)	-36.44	(48.35)	23.29	(16.06)	6.67	(42.72)
Soil feozem	16.73***	(6.02)	-66.23	(50.92)	11.23	(8.94)	-67.31	(42.68)
Soil fluvisol	0.04	(7.94)	1.98	(68.31)	7.01	(10.81)	44.53	(68.58)
Soil litosol	29.63***	(9.77)	-168.19**	(70.24)	25.12*	(15.04)	-142.27	(123.90)
Soil luvisol	14.99	(10.01)	-73.95	(58.18)	10.90	(12.06)	-85.80	(57.59)
Soil planosol	18.77**	(8.51)	-52.29	(60.52)	13.40	(10.57)	-59.07	(57.72)
Soil regosol	25.40***	(6.50)	-55.36	(49.03)	21.91**	(9.45)	-9.27	(44.20)
Soil rendzina	23.69*	(12.12)	87.20	(95.29)	36.17*	(18.69)	320.00**	(133.24)
Soil solonchak	15.84**	(7.29)	-10.16	(52.55)	17.71*	(10.05)	26.15	(43.02)
Soil vertisol	22.99***	(5.62)	-19.50	(45.31)	20.20**	(8.26)	-4.53	(33.10)
Soil xerosol	22.00***	(6.11)	-43.85	(45.94)	18.43**	(8.92)	-53.77	(35.90)
Total area ha.	-4.93***	(0.92)	14.67***	(3.81)	-5.95***	(1.24)	20.67***	(5.10)
Total area sq.	0.00***	(0.00)	-0.00***	(0.00)	0.00***	(0.00)	-0.00***	(0.00)
Market access km.	16.02	(17.89)	46.39	(83.45)	0.13	(20.83)	21.00	(109.36)
Nearest river km.	-17.21	(26.01)	66.64	(112.08)	35.73	(37.21)	200.24	(124.26)
Nearest water km.	-32.14***	(9.04)	-0.00	(71.76)	-38.68***	(11.24)	44.21	(88.90)
Irrigated area %	37.96***	(3.16)	117.60***	(20.85)	37.54***	(3.68)	152.46***	(23.07)
Ejidal area %	1.01	(2.58)	5.43	(14.78)	2.38	(3.04)	3.40	(15.99)
Electricity grid (1=yes)	791.42***	(227.58)	-4,571.80***	(1,345.76)	975.51***	(280.19)	-4,599.25***	(1,449.28)
Constant	6,196.96***	(416.27)	9,257.94***	(2,271.31)	5,780.67***	(530.01)	7,418.45**	(2,983.78)
Observations	2,524		2,524		2,524		2,524	
R-squared	0.20		0.08		0.18		0.11	
Global F-test	21.43		4.74		17.00		5.25	
Prob>F	0.00		0.00		0.00		0.00	
Climate F-test	7.84		4.28		6.84		4.95	
Prob>F	0.00		0.00		0.00		0.00	
Temp-Prec F-test	4.42		3.07		4.38		2.93	
Prob>F	0.00		0.00		0.00		0.00	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This equation reflects that as land size increases, net revenues observe a hill-shaped relationship. In the margin, the larger the farmland the higher the net revenue per hectare. Surprisingly, the coefficients associated to the distance from each parcel to the nearest

market, river[21] and water body show positive effects, which means, the further away the market and water the higher net revenues. But, any of these measures is significant. Irrigation holds a positive and significant effect as expected, but its marginal effect is 4 times greater than the one on the rent equation. Land tenure regime does not matter, which is in line with our previous findings. In this case, the availability of electricity shows a negative coefficient because it also represents a cost. In order to test and answer the main question of this research, we conduct individual and accumulated F-test for the estimated marginal effects. Table 2 provides implicit prices for each climate variable evaluated at the sample means. Columns 2 and 3 show these prices from the unweighted regressions while columns 7 and 8 present the weighted results. From the rental price equation, columns 2 and 7 shows that if there exists an increment of 1 °C on the current levels of temperature, it would lead to the following seasonal impacts. Higher temperature and lower precipitation in Winter would lead to positive impacts, a possible explanation is because the current temperature is low regarding the crops and animals harvested and the fact that this season highly depends on irrigation. In Spring and Autumn, colder environments and larger volumes of water are desirable, which reflects that precipitation is essential before sowing activities and due to the nature of main crops in Mexico higher temperature would be harmful in the initial crops growing phase. The largest negative effect is observed in Spring due to most of the droughts take place in April. Moreover, warmer and drier contexts are desired in Summer because the current level of rainfall may exceed the optimal value. The total annual implicit price of 1 °C would be around $-56-$131 pesos (-0.87-2.03% of the average rental price per hectare). Similarly, an increment of 1 mm. on the current level of precipitation would lead to an annual effect around $77-$154 pesos (1.27-2.38%). Moreover, an extra °C on the annual diurnal temperature diminishes rents by $-236-$-72 (-3.87%-(-)1.11%). Columns 3 and 8 in table 2 also shows the estimated marginal effects from the net revenue specification. It confirms that warmer and drier environments are preferred in Winter and Summer while a colder and wetter future is desired in Spring. The annual effects of 1 °C and 1 mm. of rainfall lead to a reduction on the net revenue per unit of land between -$481 and -$518 pesos (-9.08% and -8.89%) and $225 and $351 pesos (4.24% and 6.03%), respectively. Similarly, an extra °C in the diurnal temperature may cause damages around $-268-$-884 pesos (-5.05-(-)15.17%). The annual positive and negative effects of precipitation and diurnal temperature are consistent across all specifications. However, benefits from a warmer environment arise from the weighted rental price equation.

In order to formally test our main hypothesis, $H_0 : \frac{\partial R}{\partial F_g} = \frac{\partial \pi_{nl}}{\partial F_g}$ and the alternative $H_1 : \frac{\partial R}{\partial F_g} \neq \frac{\partial \pi_{nl}}{\partial F_g}$, columns 4-6 and 9-11 present the individual, groups (annual) and global F-tests for each climate implicit price. For all estimated margins, the alternative cannot be rejected at the 1% level of significance. So that, our hypothesis hold in the sense that, globally, the implicit values from these models within the RHM are statistically different, $F = 4.68$ and $F = 5.43$, respectively. Tests for annual effects indicate that the implicit prices of a °C from both equations are statistically equivalent. The null hypothesis cannot be rejected. Although individual values from the rental price equation are statistically relevant, the joint effect is not, while all seasonal effects of temperature on net revenues are not significant. Thus, we argue that rental prices reflect long term seasonal implicit prices of temperature while annual weather may be affecting net revenues. We cannot conclude that the implicit values are the same, zero, because the ones on the net revenues model are not correctly identified when researchers regress annual net revenues on long-term normals. Notice that the effects from the net revenues models are generally larger than the impacts from the rental price RHM i.e. the implicit price of a °C in Spring, which is in line with previous findings in Mexico (Mendelsohn et al., 2010). Our results from the rental price model are more comparable with those on Galindo and Reyes (2015), which use a panel data model.

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[21]Some lands close to rivers are under a flood risk, and, if the flood occurs, agriculture activities suffer a negative impact.

Table 2: Test of marginal effects: rental prices and net revenues

VARIABLES	Rent per hectare Unweighted d(Rent)/d(x)	Net Rev. per hectare d(Net R.)/d(x)	Individual F-test [Prob>F]	Groups F-test [Prob>F]	Cummulative F-test [Prob>F]	Rent per hectare Weighted d(Rent)/d(x)	Net Rev. per hectare d(Net R.)/d(x)	Individual F-test [Prob>F]	Groups F-test [Prob>F]	Cummulative F-test [Prob>F]
Temp. winter °C	1,154.16*** (358.93)	2,209.07 (2,363.70)	0.19 [0.66]	0.19 [0.66]	0.19 [0.66]	1,338.38*** (429.46)	1,160.03 (3,044.36)	0.00 [0.95]	0.00 [0.95]	0.00 [0.95]
Temp. spring °C	-1,365.25*** (289.86)	-2,750.50 (1,848.20)	0.55 [0.46]	0.30 [0.74]	0.30 [0.74]	-1,255.11*** (356.07)	-2,345.84 (2,332.97)	0.21 [0.64]	0.39 [0.68]	0.39 [0.68]
Temp. summer °C	877.51** (354.90)	174.12 (2,629.52)	0.07 [0.79]	1.02 [0.38]	1.02 [0.38]	1,107.72** (444.57)	333.52 (3,190.61)	0.06 [0.81]	0.31 [0.82]	0.31 [0.82]
Temp. Autumn °C	-719.19 (468.69)	-113.83 (3,259.28)	0.03 [0.84]	0.82 [0.51]	0.82 [0.51]	-1,060.08* (576.74)	334.14 (3,942.63)	0.12 [0.73]	0.26 [0.90]	0.26 [0.90]
Prec. winter mm.	-174.40*** (34.71)	-775.26*** (237.81)	6.25*** [0.01]	6.25*** [0.01]	1.89* [0.09]	-159.59*** (45.40)	-889.84*** (290.34)	6.18*** [0.01]	6.18*** [0.01]	1.30 [0.26]
Prec. spring mm.	243.00*** (46.18)	769.32*** (275.28)	3.56* [0.06]	3.75** [0.02]	1.70 [0.12]	294.44*** (59.88)	959.22*** (332.67)	3.87** [0.05]	3.50** [0.03]	1.39 [0.22]
Prec. summer mm.	-20.11*** (7.72)	-89.67** (43.61)	2.47 [0.12]	3.65*** [0.01]	1.67 [0.11]	-18.96** (9.01)	-56.55 (47.75)	0.60 [0.44]	2.53* [0.06]	1.24 [0.28]
Prec. Autumn mm.	28.98* (15.81)	320.11*** (89.74)	10.21*** [0.00]	4.69*** [0.00]	2.64*** [0.01]	37.71** (19.07)	338.45*** (101.20)	8.53*** [0.00]	3.56*** [0.01]	2.09** [0.03]
Diurnal winter °C	-1,382.46*** (436.89)	-8,184.65*** (3,064.72)	4.83*** [0.03]	4.83*** [0.03]	2.43*** [0.01]	-1,386.06** (583.90)	-9,303.03** (4,079.43)	3.69** [0.05]	3.69** [0.05]	2.04*** [0.03]
Diurnal spring °C	1,418.78*** (306.72)	6,023.73*** (2,015.52)	5.10** [0.02]	2.60* [0.07]	2.70*** [0.00]	1,510.60*** (397.27)	7,980.31*** (2,573.92)	6.17*** [0.01]	3.60** [0.03]	2.64*** [0.00]
Diurnal summer °C	-1,959.03*** (365.57)	-4,258.12* (2,577.74)	0.78 [0.38]	2.54** [0.05]	2.61*** [0.00]	-1,814.06*** (449.34)	-6,560.06** (3,164.40)	2.20 [0.14]	2.41* [0.07]	2.43*** [0.01]
Diurnal autumn °C	1,686.98*** (483.27)	6,151.11* (3,384.33)	1.71 [0.20]	1.99* [0.09]	2.66*** [0.00]	1,617.92*** (614.31)	6,998.33 (4,458.17)	1.43 [0.23]	1.85 [0.12]	2.95*** [0.00]
Hail winter (days)	-653.01*** (216.28)	-3,943.60*** (1,331.47)	5.95*** [0.01]	5.95*** [0.01]	3.15*** [0.00]	-821.27*** (238.66)	-5,118.24*** (1,379.87)	9.42*** [0.00]	9.42*** [0.00]	3.52*** [0.00]
Hail spring (days)	1,261.86*** (383.14)	2,493.50 (2,001.49)	0.37 [0.55]	3.20** [0.04]	3.01*** [0.00]	1,418.40*** (422.04)	1,718.40 (1,914.72)	0.02 [0.88]	6.22*** [0.00]	3.67*** [0.00]
Hail summer (days)	3.98 (203.11)	-1,883.25 (1,450.16)	1.66 [0.20]	2.22* [0.08]	2.81*** [0.00]	-74.49 (252.40)	-2,415.52 (1,601.58)	2.08 [0.15]	4.26*** [0.01]	3.43*** [0.00]
Hail autumn (days)	-430.74 (478.92)	8,138.50** (3,286.65)	6.66*** [0.01]	7.48*** [0.00]	4.68*** [0.00]	-346.21 (627.53)	10,048.49*** (3,769.76)	7.40*** [0.01]	8.87*** [0.00]	5.43*** [0.00]
Observations	2,524	2,524				2,524	2,524			

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Regarding precipitation, seasonal implicit prices differ, except in Summer. We highlight that individual implicit prices of one mm. of water from the net revenues model considerably exceeds the marginal effect from the rents specification. Moreover, the annual effect of 1 mm. of rainfall statistically differ across both specifications, $F = 4.69$ and $F = 8.53$. As we stated in section 2, from these 2 models $\tau_{prec} = \$ - 147$, which implies that the actual output price was greater than its expected value or the actual prices of variable inputs were lower than the original expectations. The annual implicit prices of an extra °C in the current diurnal temperature are statistically non-equivalent in the unweighted model, $F = 1.99$ and it is on the limit in the weighted specification, $F = 1.85$. However, individual values in Winter and Spring are significantly different. These findings suggests that implicit prices from both equations differ and it may be because actual values of climate, inputs and output prices were not in line with the farmers original expectations or there would also be an issue on how the net revenues are computed, specifically, the annual cost of capital, or the farmers in the survey misreported revenues and expenses.

6 Conclusions and further research

This paper combines rental prices and net revenues per unit of land on 2,524 Mexican farms with climate, soils and a set of control variables within a RHM. The main contribution of this research is that it tests for significant differences on the implicit values estimated from two alternative RHM specifications using ex-ante and ex-post annual measures of land productivity. Our hypothesis is that these values are statistically different when farmers' expectations about inputs-outputs prices and climate formed at the beginning of the crop year deviate from their actual values observed at the end of the cycle. Regarding the former model, land rental prices are sensitive to long term temperature, precipitation, difference between maximum and minimum diurnal temperature, extreme events, soil types, farmland area, access to water, land tenure regime, irrigation and the availability of electricity. The annual implicit values of an extra °C is approximately 2.03% of the average rental price; 2.38% for an additional mm. of rainfall; and, -1.11% if the temperature variance

increases by 1 °C. We also find that land repackaging is costly, the distance to the nearest water body determines land prices, and irrigation and electricity increases land productivity. However, according to the results from the second specification, net revenues seem to be not sensitive to long-term temperature and soils structural features. An extra °C reduces annual net revenues by -8.89%, but this effect is not statistically significant; one mm. of rainfall in the whole year rises this indicator by 6.03%; a marginal increase on the diurnal temperature would harm net revenues by -15.17%. This model also suggests that the larger the farm and irrigated areas the higher net revenues. We formally test divergences on these values using individual, annual and global F-tests to the results from unweighted and weighted regressions. Estimations from these models indicate that the implicit values of land attributes are globally different across equations.The alternative hypothesis, that implicit values differ across equations, cannot be rejected at the 1% level of significance. According to our simple model, these marginal effects may differ because farmers expectations about input and output prices and climate deviate from their actual values. We believe that rental prices are negotiated taking into account structural land attributes such as temperature and precipitation values from the previous years (normals) while net revenues are subject to crop year conditions such as market shocks that affect prices. Moreover, the output is too sensitive to negative climate shocks or extreme events. Another explanation for these divergences relies on the net revenues calculation method, especially, the annual cost of capital. The next steps of this research involve: investigate if short term weather better fits the net revenue equation; extrapolate the estimated marginal effects in order to identify potential damages and/or benefits of climate change on agriculture Geo-statistical areas in Mexico; conduct a regional analysis; and, estimate a farmers' choice model (alternative-specific conditional logit, mixed logit and nested logit) to analyze how the farmers are choosing/would choose/be choosing crops and animals under the current/future climate conditions.

References

Asseng, S., Foster, I., and Turner, N. C. (2011). The impact of temperature variability on wheat yields. *Global Change Biology*, 17(2):997–1012.

Ater, P. and Aye, G. (2012). Economic impact of climate change on nigerian maize sector: a ricardian analysis. *Environmental Impact*, 162:231.

Brassel, K. E. and Reif, D. (1979). A procedure to generate thiessen polygons. *Geographical Analysis*, 11(3):289–303.

Darwin, R. (1999). The impact of global warming on agriculture: A ricardian analysis: Comment. *The American Economic Review*, 89(4):pp. 1049–1052.

Diewert, W. E. (1974). *Applications of duality theory*. Stanford Institute for Mathematical Studies in the Social Sciences.

FAO-UNESCO (1974). Soil map of the world. Technical report, FAO-UNESCO.

FAO-UNESCO (1997). Soil map of the world. Technical report, FAO-UNESCO.

Fezzi, C. and Bateman, I. (2013). The Impact of Climate Change on Agriculture: Nonlinear Effects and Aggregation Bias in Ricardian Models of Farm Land Values. Working Papers 2013.94, Fondazione Eni Enrico Mattei.

Fleischer, A., Lichtman, I., and Mendelsohn, R. (2007). Climate change, irrigation, and Israeli agriculture : will warming be harmful ? Policy Research Working Paper Series 4135, The World Bank.

Fleischer, A., Lichtman, I., and Mendelsohn, R. (2008). Climate change, irrigation, and israeli agriculture: Will warming be harmful? *Ecological Economics*, 65(3):508 – 515.

Galindo, L. M. and Reyes, O. (2015). Climate change, irrigation and agricultural activities in mexico: A ricardian analysis with panel data. *Journal of Development and Agricultural Economics*, 7(7):261–272.

Gebreegziabher, Z., Mekonnen, A., Deribe, R., Abera, S., and Kassahun, M. M. (2013). Crop-livestock inter-linkages and climate change implications for ethiopia's agriculture: A ricardian approach. Technical report.

Hartkamp, A. D., De Beurs, K., Stein, A., and White, J. W. (1999). Interpolation techniques for climate variables.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., Jarvis, A., et al. (2005). Very high resolution interpolated climate surfaces for global land areas. *International journal of climatology*, 25(15):1965–1978.

Johnson, N. L. (2001). Tierra y libertad: Will Tenure Reform Improve Productivity in Mexico's Ejido Agriculture? *Economic Development and Cultural Change*, 49(2):291–309.

Kabubo-Mariara, J. and Karanja, F. K. (2007). The economic impact of climate change on kenyan crop agriculture: A ricardian approach. *Global and Planetary Change*, 57(3):319–330.

Keating, B. A., Carberry, P. S., Hammer, G. L., Probert, M. E., Robertson, M. J., Holzworth, D., Huth, N. I., Hargreaves, J. N., Meinke, H., Hochman, Z., et al. (2003). An overview of apsim, a model designed for farming systems simulation. *European Journal of Agronomy*, 18(3):267–288.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Deressa, T., Diop, M., Eid, H. M., Fosu, K. Y., Gbetibouo, G., Jain, S., Mahamadou, A., and Renneth (2006). Will African Agriculture Survive Climate Change? *World Bank Economic Review*, 20(3):367–388.

Maddison, D. (2000). A hedonic analysis of agricultural land prices in England and Wales. *European Review of Agricultural Economics*, 27(4):519–532.

Maddison, D., Manley, M., and Kurukulasuriya, P. (2007). The impact of climate change on African agriculture : a ricardian approach. Policy Research Working Paper Series 4306, The World Bank.

Mendelsohn, R., Arellano-Gonzalez, J., and Christensen, P. (2010). A Ricardian analysis of Mexican farms. *Environment and Development Economics*, 15(02):153–171.

Mendelsohn, R. and Dinar, A. (2003). Climate, water, and agriculture. *Land Economics*, 79(3):pp. 328–341.

Mendelsohn, R. and Dinar, A. (2009a). Climate change and agriculture an economic analysis of global impacts, adaptation and distributional effects. *Environment and Development Economics*.

Mendelsohn, R. and Nordhaus, W. (1999). The impact of global warming on agriculture: A ricardian analysis: Reply. *The American Economic Review*, 89(4):pp. 1053–1055.

Mendelsohn, R., Nordhaus, W. D., and Shaw, D. (1994). The Impact of Global Warming on Agriculture: A Ricardian Analysis. *American Economic Review*, 84(4):753–71.

Mendelsohn, R. O. and Dinar, A. (2009b). *Climate change and agriculture: an economic analysis of global impacts, adaptation and distributional effects*. Edward Elgar Publishing.

Molua, E. L. and Lambi, C. M. (2007). The economic impact of climate change on agriculture in Cameroon. Policy Research Working Paper Series 4364, The World Bank.

Palmquist, R. B. (1989). Land as a Differentiated Factor of Production: A Hedonic Model and Its Implications for Welfare Measurement. *Land Economics*, 65(1):23–28.

Ricardo, D. (1817). *Principles of political economy and taxation*. G. Bell and sons.

Seo, S., Mendelsohn, R., Dinar, A., Hassan, R., and Kurukulasuriya, P. (2009). A ricardian analysis of the distribution of climate change impacts on agriculture across agroecological zones in africa. *Environmental and Resource Economics*, 43(3):313–332.

Seo, S. N. and Mendelsohn, R. (2008). Climate change impacts on Latin American farmland values: the role of farm type. *Revista de Economia e Agronegocio / Brazilian Review of Economics and Agribusiness*, 6(2).

Tabios, G. Q. and Salas, J. D. (1985). A comparative analysis of techniques for spatial interpolation of precipitation1. *JAWRA Journal of the American Water Resources Association*, 21(3):365–380.

Thiessen, A. H. (1911). Precipitation averages for large areas. *Monthly weather review*, 39(7):1082–1089.

Timmins, C. (2006). Endogenous land use and the ricardian valuation of climate change. *Environmental and Resource Economics*, 33(1):119–142.

Wang, J., Huang, J., Zhang, L., and Li, Y. (2014). Impacts of climate change on net crop revenue in North and South China. *China Agricultural Economic Review*, 6(3):358–378.

Wheeler, T. R., Craufurd, P. Q., Ellis, R. H., Porter, J. R., and Prasad, P. V. (2000). Temperature variability and the yield of annual crops. *Agriculture, Ecosystems & Environment*, 82(1):159–167.

7 Appendix 1: Variables construction

The rental price per hectare of farm i is defined as follows:

$$R_i \cong ln\left(\frac{TR_i}{A_i}\right) \tag{33}$$

R_i: Natural logarithm of the rental price per hectare in farm i
TR_i: Total rental payment of farm i
A_i: Total area of farm i

The net revenue per hectare is defined as follows:

$$\pi_i \cong ln\left(\frac{\Pi_i}{A_i}\right) \tag{34}$$

π_i: Natural logarithm of the net revenue per hectare in farm i
Π_i: Total net revenue of farm i

The total net revenue of farm i is defined as follows:

$$\Pi_i = \Sigma_m^M p_{im} x_{im} - \Sigma_n^N c_{in} x_{in} \tag{35}$$

p_{im}: output prices for farm i
x_{im}: output in farm i
c_{in}: non-land input costs for farm i
x_{in}: non-land inputs in farm i
M: Total number of outputs in farm i
N: Total number of non-land input cost in farm i

$\Sigma_m^M p_{im} x_{im} =$ price per ton (maize) $*$ volume of production in tons (maize)
$\qquad +$ price per ton (beans) $*$ volume of production in tons (beans)
$\qquad + \ldots$
$\qquad +$ price per ton (pumpkins) $*$ volume of production in tons (pumpkins)
$\qquad +$ price per cattle head (< 1 year) $*$ number of sold cattle (< 1 year)
$\qquad +$ price per cattle head ($1 \leq x_m \leq 2$ y.) $*$ number of sold cattle ($1 \leq x_m \leq 2$ y.)
$\qquad +$ price per cattle head ($2 < x_m \leq 3$ y.) $*$ number of sold cattle ($2 < x_m \leq 3$ y.)
$\qquad +$ price per cattle head (> 3 years) $*$ number of sold cattle (> 3 years)
$\qquad +$ price per kg of carcass meat (cattle) $*$ kg of sold carcass meat (cattle)
$\qquad +$ price per kg of unpacked meat (cattle) $*$ kg of sold unpacked meat (cattle)
$\qquad +$ price per kg of packed meat (cattle) $*$ kg of sold packed meat (cattle)
$\qquad +$ price per stallion (pigs) $*$ number of sold stallions (pigs)
$\qquad +$ price per breeding sow (pigs) $*$ number of sold breeding sows (pigs)
$\qquad +$ price per pig (< 8 weeks) $*$ number of sold pigs (< 8 weeks)
$\qquad +$ price per pig (fattening pigs) $*$ number of sold pigs (fattening pigs)
$\qquad +$ price per pig (old pigs) $*$ number of sold pigs (old pigs)
$\qquad +$ price per rooster $*$ number of sold roosters
$\qquad +$ price per chicken $*$ number of sold chicken
$\qquad +$ price per broiler chicken $*$ number of sold broiler chicken
$\qquad +$ price per chicken (growing phase) $*$ number of sold chicken (growing phase)
$\qquad +$ price per chick $*$ number of sold chicks

$$\tag{36}$$

$\Sigma_n^N c_{in} x_{in}$ = total costs of seeds and plants

$+$ total costs of natural and artificial fertilizers, insecticides and herbicides

$+$ total costs of tillage activities $+$ total costs of harvesting activities

$+$ total costs of irrigation (right fee) $+$ total costs of resowing activities

$+$ total costs of animals' food $+$ total costs of medicines, vaccines and vet

$+$ total costs of animals' replacement $+$ total costs of animals rents

$+$ total costs of fuel, diesel, oils, etc.

$+$ total costs of machinery, equipment and facilities (annual rents)

$+$ total costs of genetic improvements $+$ total costs of technical support

$+$ total costs of electricity $+$ total costs of transport

$+$ total costs of taxes and interests $+$ total costs of labour

$+$ total costs of "maquila" $+$ total costs of new technology

$+$ other costs $+$ total costs of capital

$$(37)$$

$$\text{total costs of capital} = \left(\frac{\text{updated price of tractor (2012)}}{15 \text{ years}}\right) * \text{number of tractors in farm } i$$

$$+ \left(\frac{\text{updated price of combine harvester (2012)}}{15 \text{ years}}\right) * \text{number of combine harvesters in farm } i$$

$$+ \left(\frac{\text{updated price of harvester (2012)}}{15 \text{ years}}\right) * \text{number of harvesters in farm } i$$

$$+ \left(\frac{\text{updated price of mower (2012)}}{15 \text{ years}}\right) * \text{number of mowers in farm } i$$

$$+ \left(\frac{\text{updated price of packaging machine (2012)}}{15 \text{ years}}\right) * \text{number of packaging machines in farm } i$$

$$+ \left(\frac{\text{updated price of sprinkler (2012)}}{15 \text{ years}}\right) * \text{number of sprinklers in farm } i$$

$$+ \left(\frac{\text{updated price of manure spreader (2012)}}{15 \text{ years}}\right) * \text{number of manure spreaders in farm } i$$

$$+ \left(\frac{\text{updated price of harrow (2012)}}{15 \text{ years}}\right) * \text{number of harrows in farm } i$$

$$+ \left(\frac{\text{updated price of sowing machine (2012)}}{15 \text{ years}}\right) * \text{number of sowing machines in farm } i$$

$$+ \left(\frac{\text{updated price of self-loading wagons (2012)}}{15 \text{ years}}\right) * \text{number of self-loading wagons in farm } i$$

$$(38)$$

These prices represent the mean of each machine in 2015 published by the Ministry of Agricultural, Livestock, Rural Development, Food and Fishery of Mexico (SAGARPA). Then we update this information using an Index price for each machine or equipment. The prices list is available on:

http://www.sagarpa.gob.mx/agricultura/Precios/Paginas/PreciosdeMaquinariaAgricola.aspx.

The normal of seasonal temperature per farm is defined as follows:

$$T_{is} = \Sigma_{j=1}^{J} \frac{T_{ijs} A_{ij}}{A_i} \tag{39}$$

T_{is}: The s mean temperature normal in farm i

s: Season $s = [winter, spring, summer, autumn]$

T_{ijs}: The s mean temperature normal in plot j of farm i
J: Total number of plots in farm i
A_{ij}: Area of plot j in farm i

The normal of seasonal precipitation per farm is defined as follows:

$$P_{is} = \Sigma_{j=1}^{J} \frac{P_{ijs} A_{ij}}{A_i} \tag{40}$$

P_{is}: The s cummulated precipitation normal in farm i
P_{ijs}: The s cummulated precipitation normal in plot j of farm i

The normal of seasonal diurnal temperature per farm is defined as follows:

$$D_{is} = Tmax_{is} - Tmin_{is} \tag{41}$$

D_{is}: Diurnal temperature of season s in farm i
$Tmax_{is}$: The s maximum temperature normal in farm i
$Tmin_{is}$: The s minimum temperature normal in farm i

The normal of seasonal maximum temperature per farm is defined as follows:

$$Tmax_{is} = \Sigma_{j=1}^{J} \frac{Tmax_{ijs} A_{ij}}{A_i} \tag{42}$$

$Tmax_{ijs}$: The s maximum temperature normal in plot j of farm i

The normal of seasonal minimum temperature per farm is defined as follows:

$$Tmin_{is} = \Sigma_{j=1}^{J} \frac{Tmin_{ijs} A_{ij}}{A_i} \tag{43}$$

$Tmin_{ijs}$: The s minimum temperature normal in plot j of farm i

The normal of seasonal storm days per farm is defined as follows:

$$SD_{is} = \Sigma_{j=1}^{J} \frac{SD_{ijs} A_{ij}}{A_i} \tag{44}$$

SD_{is}: The s storm days normal in farm i
SD_{ijs}: The s storm days normal in plot j of farm i

The normal of seasonal cloudy days per farm is defined as follows:

$$CD_{is} = \Sigma_{j=1}^{J} \frac{CD_{ijs} A_{ij}}{A_i} \tag{45}$$

CD_{is}: The s cloudy days normal in farm i
CD_{ijs}: The s cloudy days normal in plot j of farm i

The proportion of k soil type per farm is defined as follows:

$$S_{ik} = \Sigma_{j=1}^{J} \frac{S_{ijk} A_{ij}}{A_i} \tag{46}$$

S_{ik}: The total proportion of soil k in farm k
k: Soil type k =[acrisol, andosol, cambisol, castanozem, chernozem, feozem, gleysol, fluvisol, litosol, luvisol, planosol, regosol, rendzina, solonchak, vertisol, xerosol, yermosol]

The proportion of irigated area in farm i is defined as follows:

$$I_i = \Sigma_{j=1}^{J} \frac{I_{ij}}{A_i} \tag{47}$$

I_i: The proportion of irrigated area in farm i
I_{ij}: Irrigated area in plot j and farm i

The proportion of ejidal area in farm i is defined as follows:

$$E_i = \Sigma_{j=1}^{J} \frac{E_{ij}}{A_i} \tag{48}$$

E_i: The proportion of ejidal area in farm i
E_{ij}: Ejidal area in plot j and farm i

The weighted distance from the farm/plots to the nearest city is defined as follows:

$$DC_i = \Sigma_{j=1}^{J} \frac{DC_{ij} A_{ij}}{A_i} \tag{49}$$

DC_i: Distance from the farm i to the nearest city
DC_{ij}: Distance from the plot j of farm i to the nearest city

The weighted distance from the farm/plots to the nearest river is defined as follows:

$$DR_i = \Sigma_{j=1}^{J} \frac{DR_{ij} A_{ij}}{A_i} \tag{50}$$

DR_i: Distance from the farm i to the nearest river
DR_{ij}: Distance from the plot j of farm i to the nearest river

The weighted distance from the farm/plots to the nearest water body is defined as follows:

$$DW_i = \Sigma_{j=1}^{J} \frac{DW_{ij} A_{ij}}{A_i} \tag{51}$$

DW_i: Distance from the farm i to the nearest water body
DW_{ij}: Distance from the plot j of farm i to the nearest water body

The electricity grid availability of farm i is defined as follows:

$$EL_i = \frac{TEL_i}{J} \tag{52}$$

EL_i: The proportion of plots in farm i which have an electricity grid
TEL_i: The total number of plots that have an electricity grid in farm i

The weighted altitude of farm i is defined as follows:

$$AL_i = \Sigma_{j=1}^{J} \frac{AL_{ij} A_{ij}}{A_i} \tag{53}$$

AL_i: The weighted altitude of farm i
AL_{ij}: Meters above the sea level of plot j in farm i

8 Appendix 2: Descriptive statistics

Table 3: Descriptive statistics

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max	(6) N	(7) mean	(8) sd	(9) min	(10) max
Rental price ($/ha)	**2,524**	**6,096**	**5,328**	**77**	**41,630**					
Net revenue ($/ha)						**2,524**	**5,301**	**27,939**	**-131,677**	**143,075**
Temperature winter (°C)	2,524	16.68	4.20	4.67	27.44	2,524	16.66	4.19	4.36	27.43
Temperature spring (°C)	2,524	21.83	3.17	11.43	31.23	2,524	21.81	3.17	11.03	31.13
Temperature summer (°C)	2,524	26.74	4.44	11.63	32.47	2,524	26.72	4.45	11.63	32.47
Temperature autumn (°C)	2,524	23.02	4.47	10.43	28.83	2,524	23.01	4.47	10.43	28.83
Precipitation winter mm.	2,524	14.03	7.32	1.67	136.00	2,524	14.05	7.37	1.89	136.00
Precipitation spring mm.	2,524	10.14	12.44	0.67	107.00	2,524	10.17	12.49	0.67	107.00
Precipitation summer mm.	2,524	102.25	70.79	0.67	423.00	2,524	102.32	70.81	0.67	420.33
Precipitation autumn mm.	2,524	56.90	35.90	5.33	349.00	2,524	56.94	35.97	5.33	349.00
Diurnal winter (°C)	2,524	16.96	1.99	9.47	21.93	2,524	16.96	1.98	9.47	21.90
Diurnal spring (°C)	2,524	18.21	2.28	8.91	22.43	2,524	18.21	2.28	8.53	22.43
Diurnal summer (°C)	2,524	13.50	2.16	8.03	21.61	2,524	13.50	2.16	7.89	21.61
Diurnal autumn (°C)	2,524	14.75	2.13	8.57	20.16	2,524	14.75	2.13	8.54	20.16
Storm winter (days)	2,524	0.35	0.88	0.00	12.46	2,524	0.35	0.87	0.00	12.46
Storm spring (days)	2,524	0.52	1.23	0.00	12.54	2,524	0.52	1.21	0.00	12.54
Storm summer (days)	2,524	3.39	5.77	0.00	47.93	2,524	3.39	5.64	0.00	47.93
Storm autumn (days)	2,524	1.46	2.64	0.00	23.50	2,524	1.46	2.57	0.00	23.50
Hail winter (days)	2,524	0.24	0.64	0.00	4.57	2,524	0.24	0.64	0.00	4.73
Hail spring (days)	2,524	0.22	0.57	0.00	5.63	2,524	0.22	0.56	0.00	5.63
Hail summer (days)	2,524	0.48	1.76	0.00	20.25	2,524	0.48	1.72	0.00	20.25
Hail autumn (days)	2,524	0.22	0.73	0.00	8.33	2,524	0.22	0.73	0.00	8.33
Cloudy winter (days)	2,524	2.47	4.36	0.00	51.77	2,524	2.49	4.35	0.00	51.77
Cloudy spring (days)	2,524	1.75	3.62	0.00	49.77	2,524	1.76	3.61	0.00	49.77
Cloudy summer (days)	2,524	1.94	5.08	0.00	53.37	2,524	1.96	5.07	0.00	53.37
Cloudy autumn (days)	2,524	2.34	5.09	0.00	55.15	2,524	2.36	5.10	0.00	55.15
Soil acrisol (%)	2,524	0.37	5.78	0.00	100.00	2,524	0.30	5.10	0.00	100.00
Soil andosol (%)	2,524	0.61	7.71	0.00	100.00	2,524	0.62	7.61	0.00	100.00
Soil cambisol (%)	2,524	7.46	25.15	0.00	100.00	2,524	7.34	24.34	0.00	100.00
Soil castanozem (%)	2,524	1.26	10.81	0.00	100.00	2,524	1.13	9.92	0.00	100.00
Soil feozem (%)	2,524	10.29	29.41	0.00	100.00	2,524	10.04	28.15	0.00	100.00
Soil fluvisol (%)	2,524	0.36	5.57	0.00	100.00	2,524	0.44	5.76	0.00	100.00
Soil litosol (%)	2,524	1.23	10.44	0.00	100.00	2,524	1.27	9.98	0.00	100.00
Soil luvisol (%)	2,524	2.27	14.31	0.00	100.00	2,524	2.22	13.70	0.00	100.00
Soil planosol (%)	2,524	3.68	18.55	0.00	100.00	2,524	3.72	17.94	0.00	100.00
Soil regosol (%)	2,524	9.27	28.29	0.00	100.00	2,524	9.55	28.21	0.00	100.00
Soil rendzina (%)	2,524	0.59	7.28	0.00	100.00	2,524	0.59	7.07	0.00	100.00
Soil solonchak (%)	2,524	3.19	15.82	0.00	100.00	2,524	3.26	15.32	0.00	100.00
Soil vertisol (%)	2,524	36.64	46.71	0.00	100.00	2,524	36.73	45.98	0.00	100.00
Soil xerosol (%)	2,524	21.39	39.88	0.00	100.00	2,524	21.39	39.36	0.00	100.00
Soil yermosol (%)	2,524	1.40	11.33	0.00	100.00	2,524	1.39	11.05	0.00	100.00
Total area (has)						2,524	138.52	298.81	0.63	6,136.29
Total rented area (has)	2,524	80.94	185.05	0.40	4,006.62					
Altitude (masl)	2,524	697.83	847.73	1.00	3,217.00	2,524	700.97	848.12	1.00	3,217.00
Nearest city (km)	2,524	7.19	8.00	0.00	67.88	2,524	7.29	7.95	0.00	67.88
Nearest river (km)	2,524	4.79	4.43	0.01	44.09	2,524	4.84	4.38	0.01	43.80
Nearest water body (km)	2,524	15.86	11.83	0.00	81.15	2,524	15.89	11.79	0.00	81.15
Irrigated area (%)	2,524	76.98	40.24	0.00	100.00	2,524	75.40	39.15	0.00	100.00
Ejidal area (%)	2,524	62.95	44.96	0.00	100.00	2,524	59.69	43.37	0.00	100.00
Electricity grid (1=yes)	2,524	0.38	0.48	0.00	1.00	2,524	0.38	0.48	0.00	1.00

Source: See the text