Crop Rotation and the Impact of Biodiesel Mandates on Deforestation

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Abstract

In this paper, I evaluate the impact of Biodiesel mandates on land use and crop supply. Crop rotation is incorporated into a structural model of crop choice that allows for a dynamic complementarity in the production of soybeans and corn. As this production function ties the current crop choice to previous planting decisions, the farmer solves a dynamic program whith parameters that can be estimated using standard tools for dynamic games. I estimate the model using data from the 30 largest grain-producing municipalities in Brazil. Unlike static models of crop choice, the dynamic model produces positive long-run cross-price elasticities for the fraction of the land cultivated with each crop. I use a large positive permanent shock in the expected long-run price for soybeans to simulate the effects of Biodiesel policies. Farmers' response to an increase in biodiesel mandates involves reallocation of cropland area between crops that are dynamic complements, increasing corn supply indirectly in the long-run. Additionally, the dynamic model generates a response to the policy in terms of overall cultivated area that is 12 times smaller than the static model, predicting a much smaller environmental impact.

1 Introduction

Recently, many countries have implemented mandates that stipulate that a portion of the fuel supply comes from biofuels. In the US, a 5% of biodiesel per gallon was implemented in 2005 and was scheduled to increase incrementally to a maximum of 20% in 2015 and thereafter. For the gasoline, the legislature required a 10% of ethanol blends in 2003 after requiring a 7.7% blend between 1997 and 2003[1]. The European Union mandates on biofuels stipulate similar levels. Overall, in 2013, a total of 62 countries had targets for biofuels[2].

In Brazil, since January 1st 2010, all the diesel fuel that circulates in the country contains 5% of biodiesel. Biodiesel is a fuel produced using vegetable oils and animal fat and 80% of its production, in Brazil, has soybeans as its main primary feedstock. Also, since 2007, all gasoline fuel contains 25% of ethanol[3]. Ethanol can be produced using various crops and, in Brazil, it is entirely produced using sugar-cane[4]. Therefore, governmental resolutions regarding biofuels have a direct impact over crop demand and are usually accompanied by programs of subsidies to production. Thus, evaluating equilibrium effects generated by these resolutions or by any other policy whose final impact depends on crop supply responses requires estimation of land use responses as well. Changes in the cultivated area reveal important aspects of how the supply of agricultural products reacts to price changes. Hence, any question that depends on price elasticity of crop supply also depends on the effects that changes in relative prices have on land use and crop choice. Inversely, any policy affecting agricultural markets will have indirect land use and crop choice effects.

The main paper in the literature that evaluates the possible price effects of biofuels regulations is Roberts and Schlenker (2013). They present a framework to identify supply elasticities of storable commodities. With the resulting elasticities, they evaluate the impact of the 2009 Renewable Fuel Standard on commodity prices and quantities. Prices of four basic staples (corn, rice, soybeans ans wheat) increase by 20% if one-third of commodities used to produce ethanol are recycled as feedstock. At first sight, this seems like a huge effect. However, if we take into account that we are dealing with short-run price variations, the magnitude of this elasticity is rather reasonable because it is commensurate with the year-to-year variation of commodity prices. If we believe that the peaks of

[1]Source: US EPA, Environmental Protection Agency.

[2]Source: http://www.biofuelsdigest.com/bdigest/2016/01/03/biofuels-mandates-around-the-world-2016.

[3]This measure was attenuated to 20% in 2011, but was raised back to 25% in 2013.

[4]Source: ANP (The Brazilian National Oil Agency)

commodity prices in 2005 and 2008 were related to the United States ethanol policy then, these results should alarm us about this type of policy considering it directly affects food prices.

The goal of this paper is to account for the fact that such policies may not have homogeneous effects across different commodity markets. There are tight productive relationships between crops, notably between corn and soybeans. Both Livingston et al. (2008) and Ji et al. (2014) show with experimental data on crop fields in the US that there are productivity gains from cultivating soybeans and corn in sequence and that this affects famers' behavior. Because of this type of relationship, a policy that has a direct effect over one of these markets will have indirect effects over other crops as well. The catch is that the direction of the indirect effect over prices might be contrary to the direct effect. For example, a governmental policy that subsidizes the production of soybeans will also stimulate the production of corn in countries where farmers use rotation systems with these two crops, which is the case for both Brazil and the US. If the demand for the latter product is not increased, we should expect the opposite effect on its price.

There is a vast literature that acknowledges the importance of land use change to the evaluation of agricultural and environmental policies, as do Fezzi and Bateman (2011); Rodrigues (2012); Lubowski et al. (2006); Irwin (2002); Vance and Geoghegan (2002). Scott (2013) makes an important contribution to this literature by estimating land use elasticity with dynamic incentives in order to account for land use changes that may be induced by biofuel policies. He finds that static approaches tend to underestimate responses to long-run land use incentives. And, landowners are more likely to react to long-run changes rather than year-to-year variations in prices. By estimating a dynamic discrete choice model of land use for the US with forward-looking landowners, he finds a long-run elasticity of crop acreage with respect to crop prices ten times larger than the ones found in static models using the same data. This result implies in much smaller price effects of such policies. However, the approach limits itself to model the decision of whether to cultivate crops (of any kind), not considering the important nuances that may exist when we treat each type of crop separately. Besides, his assumption that dynamic incentives can be captured by intercepts in the profit function can be restrictive. This assumption means that the state variable associated with the field's relevant characteristics can affect switching costs but not switching benefits. That is, he allows there to be a cost of, for example, turning a pasture field into an agricultural land but no benefits that can come from switching from a culture to another. Although this restriction is directly imposed by the small size of his panel, it sacrifices important information.

The dissemination of the Direct Planting System (DPS) and the increasing role of rotation and succession systems in increasing productivity, notably in the grains sector, points out the relevance of switching benefits in the US as well as in Brazil. Furthermore, not only are switching benefits an important consideration in farmers' land use decision but, they are even more relevant in the decision of which crop to cultivate. In sum, Scott (2013) introduces land use changes in order to obtain long-run acreage-price elasticities but fails to account for crop choice, setting aside the fact that a reallocation of cropland between products might occur as a result of price changes. Hence, in the model presented in section 3, the field state variable provides relevant additional information when compared to Scott (2013)'s formulation. While is his framework the field state is defined by the number of years since any type of crop was last cultivated on that field, in this paper the field state provides additional information on which crops were previously cultivated as well. This information should help us infer the field's productivity, which is the ultimate unobserved endogenous state variable of interest.

Finally, adding switching benefits in a dynamic model provides insight about why the supply for some crops is inelastic in the short-run, by introducing a trade-off between short-run profit gains from cultivating crops that incurred temporary price increases and long-run productivity losses of deviating from the efficient crop rotation sequence. Most importantly, the model in this paper allows for interactions among the supply of different crops. Using this model, we can evaluate the effects on corn supply of an increase in the demand soybeans, due to biodiesel regulations. By way of illustration, the rapid increase in the production of soybeans in the past decades in Brazil was accompanied by a proportional increase of the winter harvest of corn. And, the results of this study support the argument that these two trends are connected by a relationship of dynamic interdependence between the productions of these crops.

In this paper, I show that a policy that stimulates the demand for soybeans, like the biodiesel mandates, also stimulates the production of corn even if corn prices aren't as attractive. This result support the argument that, in order to have a comprehensive analysis of the implications of biofuel policies, it is necessary to properly measure the interdependencies that lie between the different crops' production functions.

2 Data and Reduced Form Analysis

2.1 Data

I use data on cultivated area between 2000 and 2012 provided by the PAM (Municipal Agricultural Research), an annual survey released by the IBGE (Brazilian Institute of Geography and Statistics). The sample is composed of the 30 largest grain producing municipalities in Brazil, all located in the *"Cerrado"* region. Together, these 30 municipalities accounted for 20% of Brazil's grain production in 2003, according to the PAM. For information on future prices, I use series from the *Chicago Board of Trade*. I use prices of future contracts for the months of August and January with closure in March and July, respectively. August and January are the two "decision" months: in August starts the summer harvest in Brazil and, in January starts the winter harvest. In March and July these two harvests end. Data on production costs per product/crop in each municipality are provided by the Conab (Brazilian National Company of Supply). Variation on this data is mostly conducted by seed prices. Data on weather is gathered from the INPE (Brazilian National Institute of Spatial Studies). I use information on precipitation value during the harvesting seasons and temperature measures as well. Excessive rainfall during the harvesting seasons may delay the following planting decisions and account for some of the variation in the cultivated areas.

2.2 Anecdotal Evidence

The time series for the fractions of the seasonal cropland cultivated with soybeans and corn, the two largest crop products in Brazil, present opposite patterns for Brazil as a whole (figure (1)) and Brazil's largest grain producing municipality, Lucas do Rio Verde (figure (2)). On the one hand, for the country as a whole, there is a steep growth trend of the fraction of soybeans cultivated relative to corn and other products. Over the years, the ratio of cropland cultivated with corn drops constantly as the area cultivated with soybeans grows. Soybeans become the largest crop production in Brazil around 1996. On the other hand, the municipalities that are mature in these productions present an opposite trend, during the same period. The fraction of the cropland area cultivated with soybeans is decreasing in Lucas do Rio verde and the fraction cultivated with corn is increasing over the same period. This local trend is driven by the the winter harvest. The winter harvest became a second official harvest in Brazil started during the 90's in the main producing states. The rapid growth of this second harvest was due to great technological improvements and to the implementation of DPS techniques.

This paper offers an explanation to this apparent contradiction between the relative success of the soybeans observed on the national data and the relative success of the corn observed in the largest grain producing municipalities. The beginning of the trend observed in the municipal data coincides with the start of the dissemination of the DPS techniques which are used to maximize the long-run productivity of the cropland. In the mature municipalities, the adoption of these techniques started years before the rest of the country and that is why there are different patterns on the data. Also, in these municipalities, the agricultural land has nearly reached its limits of expansion and therefore, a more efficient use of the land is necessary in order to increase production. Inversely, there are still many areas in Brazil that can be turned into agricultural land, outside of these traditional regions. In these new areas, the effect of the expansion of the agricultural frontier is lead by soybeans, which is the most profitable crop in most of the country. Therefore, Brazilian grain producers are increasing their output in two manners: expanding their cultivated area, which is the predominant effect in the national data, and improving their planting techniques, which is the predominant effect the municipal data from mature regions. In sum, in the regions where the expansion of the cultivated area is reaching its limit, we can see what the practices to increase productivity imply in terms of crop choices: a reduction of the gap between the fractions of soybeans and corn cultivated, reflecting crop rotation to reap productivity gains of cultivating these crops jointly.

As shown in figure **??**, the total area cultivated with non-perennial crops increases considerably from the beginning of our sample (1997) until the end (2012). Both the areas cultivated with soybeans and corn increase over time and the gap between the total area cultivated with each product reduces during this period. We can also notice that the sum of the areas of the two products is nearly equal to the total area cultivated with non-perennial crops, reinforcing the point that the choice of land use and the crop choice are tied. Therefore, I include in the model presented in the next section the size of the cropland as a choice variable, allowing it to vary over time.

2.3 Regression Analysis

The regressions presented in this section show correlation patterns between crop choices over time, justifying a model that could explain their meaning in terms of cultivation decisions. Tables (1) and (2) present the results of different regressions with panel data. The panel variable is the municipality and time is measured in years. I regress the fraction of the cropland area cultivated with soybeans on its lags and on the current and lagged values of the fraction of corn. I also include as explanatory variables the price of both crops in January and August (the months when crop choices are made). I do the same for the fraction of the cropland area cultivated with corn as the dependent variable.

For each of the dependent variable, the first lag of the fraction of land cultivated with the other crop is significantly positively correlated. In each of the regression models, a larger fraction of corn cultivated in the previous year imply a larger fraction of soybeans cultivated today. The same correlation pattern is found for corn as a dependent variable. In some of the regressions, I also find positive correlations between the dependent variable and the second or third lag of another product's fraction. Intuitively, all the regressions present a negative correlation between the fractions of each product cultivated on the same period. All the products compete during each period for cultivated area, showing no complementaries during the same period. However, the positive correlations found between each product and the lags of the other indicate that there might be dynamic complementarity in the production of these two products.

The model in the following section addresses explicitly the meaning of these correlations through a structural productivity equation that relates past and present crop choices to the productivity of each crop.

3 The Model

3.1 The Environment

In each period t, a landowner has an amount of cropland X_t that can be allocated between n different crops.

Definition *The available cropland X_t is a portion of the farmland, measured in hectares, that the landowner can allocate between different crops.*

Definition *An allocation δ_t is a vector of chosen shares of the cropland associated with each of the n available products in period t: $\delta_t \in [0, 1]^n$ such that*

$$\sum_i \delta_{it} = 1, \quad \forall \quad t. \tag{1}$$

Definition *A rotation system is a finite sequence of m years of cultivation. For the main harvest of each year, the rotation system designates a crop for each plot of land. The rotation system maximizes the land productivity in the long-run.*

In a give period t, the landowner may choose an allocation that differs from the one predicted by the rotation system followed. The timing of the model is the following: each period t is an instant of time in which there are planting decisions. In other words, a period represents a production-year. Thus, if a production-year begins on t then, it ends in $t + 1$ when another begins. A more detailed definition of time can be used, considering different harvests in the same production-year. The yield of a certain crop $i \in I$ during the period t is measured in *kg* and given by:

$$Y_{it} = \delta_{it} * X_t * \Omega_{it} \tag{2}$$

Where Ω_{it} is product i's productivity during t measured in *kg/ha* (kilograms gathered by cultivated hectare). If there exists a vector of shares that maximizes the long-run productivity of the cropland and if every landowner maximizes the discounted sum of profits, δ_t should float around this vector over time. And, deviations from this long-run equilibrium should be associated with short-run responses to price or cost incentives.

3.1.1 State Variables

Productivity

The productivity of each crop evolves conditionally on the choices made by the landowner over time. So, in addition to soil management (fertilisation, manuring, etc.), the land's productivity depends on the present and the previous fractions of the cropland cultivated with each product.

$$\Omega_{it} = \overline{\Omega_i} + \alpha_i * t + \boldsymbol{\rho}_i * M_t + \sum_{i=1}^{n} \sum_{k=1}^{K} \gamma_{ik} * \delta_{it-k} + \varepsilon_{it} \tag{3}$$

α will capture linear time trend effects, including any exogenous technological progress that results in productivity gains. M_t is a vector of meteorological variables that can affect productivity. And, ε_{it} is a shock of zero mean associated with unforeseen weather effects and productivity shocks associated with pests and diseases infestations. Therefore, the landowner doesn't know the productivity of a given harvest when he makes his planting decision but, he can infer its expected value based on his present and past crop choices and the distribution of ϵ. We are interested in the values of the parameters in vector γ, which indicate the mutual productivity effects between soybeans and corn over time. More specifically, in (Equation 4), the coefficient $\gamma_{s'c}$ measures the effect on soybeans' current productivity of cultivating corn during the previous period. If this coefficient is positive then, we can say that corn is a dynamic complement to soybeans in production.

I estimate the coefficients in the following specification for each crop:

$$\Omega_{st} = \bar{\Omega}_s + \alpha_s * t + \gamma_{s's} * \delta_{st-1} + \gamma_{s'c} * \delta_{ct-1} + \gamma_{ss} * \delta_{st} + \gamma_{sc} * \delta_{ct} \tag{4}$$

$$\Omega_{ct} = \bar{\Omega}_c + \alpha_c * t + \gamma_{c'c} * \delta_{ct-1} + \gamma_{c's} * \delta_{st-1} + \gamma_{cc} * \delta_{ct} + \gamma_{cs} * \delta_{st} \tag{5}$$

Where s indexes soybeans and c indexes corn. $\gamma_{i'j}$ captures the effect on i's productivity of having cultivated j in the previous period. γ_{ii} captures the increasing (or decreasing) returns to scale in i's production. γ_{ij} captures the effect on i's productivity of also cultivating j in the current period.

Exogenous State Variables

I now define the exogenous state variables that are relevant to the landowner's decision at each harvest. This set of variables (S) is composed of price, cost and meteorological variables. The landowner decides the size of his cropland X_t and the fractions of the cropland to be cultivated with each product. Therefore, the policy function is:

$$\{X_t, \boldsymbol{\delta}_t\} = f(X_{t-1}, \boldsymbol{\delta}_{t-1}, ..., \boldsymbol{\delta}_{t-k}, S, \nu_{it}; \theta) \tag{6}$$

Where the regressions in section 2.2 suggest that $k = 1$. For simplicity and clarity purposes, I will present the rest of the model for two products, soybeans (s) and corn (c), and with $k = 1$.

Structural Shocks

Before choosing an action $\{X_t, \boldsymbol{\delta}_t\}$, each agent receives a private shock $\boldsymbol{\nu}_t$ for each action independently drawn across individuals and time from a distribution $G_i(.|\Omega_t, s_t)$ with support $\nu_i \in \Re^s$. Where s is the size of the choice set.

3.2 Farmer's Problem

Each agent's profit at a given period t depends on the state: crop choice and cropland size in the previous period and S as well as on the private shock. I assume that there is no strategic interaction and that agents do not have market-power separately. It is indeed reasonable to assume that farmers are "price takers" in agricultural markets given the concentration of production[5]. I denote a representative agent's profit by $\Pi(\boldsymbol{\delta}_t, \boldsymbol{\nu}_t)$.

I assume that agents have the same discount factor $\beta < 1$. For a given state in t, the agent's expected profit over the distribution of future shocks $\nu_\tau, \tau > t$ is:

$$\mathbb{E}[\sum_{\tau=t}^{\infty} \beta^{\tau-t} \Pi_j(\boldsymbol{\delta}_{j\tau}, \mathbf{s}_\tau, \boldsymbol{\nu}_{j\tau})] \tag{7}$$

[5] In Brazil, the largest firm producing soybeans in the country, which has several farms, produced, in 2011, less than 0.8% of soybeans harvest in the country. Sources: Embrapa and Good Future Group.

Finally, I write the farmer's policy function as transition probabilities such that a farmer's recursive problem will be:

$$V(\mathbf{s};\delta) = \Pi(\boldsymbol{\delta}, \mathbf{s}, \boldsymbol{\nu}) + \beta \mathbb{E}_{\nu} \int V(\mathbf{s}';\delta) dP(\delta'|\delta) \tag{8}$$

3.2.1 Profit Function

Consider the following profit function after the realizations of private shocks :

$$\begin{aligned}\Pi(\delta_t, \Omega_t, S, \nu_t) &= \sum_{i=1}^{n} (\delta_{it} * X_t * \Omega_{it} * p^f_{it+1} - c_{it} * \delta_{it} * X_t + \nu_{it}) \\ &= \tilde{\Pi}(\boldsymbol{\delta}, \Omega, \mathbf{S}) + \sum_{i=1}^{n} \nu_i(\delta_i) \end{aligned}\tag{9}$$

Where p^f_{it+1} is the price of a standard contract (for 1 kg) of product i in the futures market maturing in $t+1$ and c_{it} is a measure of cost of production per hectare cultivated of i. ν_{it} is a shock associated with alternative δ_i, available for the product i in t. Let's assume that shocks ν_{it} are distributed independently across products. We can rewrite the profit function specifying a transition function for the productivity:

$$\begin{aligned}\Pi(\delta_t, \delta_{t-1}, R_t, C_t, \nu_t) = \sum_{i} \delta_{it} * (R_{it} * (\overline{\Omega_i} + \alpha_i * t + \boldsymbol{\rho}_i * M_t + \sum_{i=1}^{2}\sum_{k=0}^{1} \gamma_{ik} * \delta_{it-k}) - C_{it}) \\ + \xi * (X_t - X_{t-1}) + \sum_{i=1}^{2} \nu_{it}(\delta_{it})\end{aligned}\tag{10}$$

Were I define:

$$R_{it} = p_{it} * X_t \tag{11}$$

$$C_{it} = c_{it} * X_t \tag{12}$$

$$\Omega_{it} = \overline{\Omega_i} + \alpha_i * t + \boldsymbol{\rho}_i * M_t + \sum_{i=1}^{2}\sum_{k=0}^{1} \gamma_{ik} * \delta_{it-k} \tag{13}$$

I allow in (13) that each product affects the productivity of the other in a singular form. That is, I allow effects of productive complementarity as well as negative effects of one product over another one's productivity. The parameters of interest are the γ_k' s , which represent the relationship of mutual benefit or penalty that may exist between productions over time. Based on this framework, we are able to define at least two types of dynamic relationships between corn and soybeans - positive or negative. With that, I hope to identify crossed-effects that may exist between supplies and prices of the two products. It is expected that myopic choices influenced by relative price ratios penalize future earnings by creating the need to make extra spendings to compensate for soil productivity penalized by those choices which increase the probability of negative productivity shocks [6].

With the following assumptions, we can estimate the parameters γ in the productivity function, using the two stage methodology in Bajari et al. (2007).

3.3 Assumptions for Identification

Although the parameters I want to recover come from the landowner's problem, I only observe shares at the municipal level. We need to make sure that, with this data and model, we are able to identify the landowner's policy function and the correct parameters for the farm's productivity function. The following assumptions are necessary to warrant these objectives.

A.1 - Decision Separability:

The allocation problem in which the landowner decides the share of the cropland that will be cultivated with each product is independent of the area expansion problem in which the landowner decides whether to increase or decrease the size of his cropland. In other words, X_t is not a function of δ_t or any of its lags and vice versa.

A.2 - Absence of Externalities Between Farms:

For each product i and for all farms $k \neq j$, $\Omega_{ikt} \perp \{\delta_{jt}, \delta_{jt-1}, X_{jt}, X_{jt-1}\}$ and $X_{kt} \perp \{X_{jt}, X_{jt-1}, \delta_{jt}, \delta_{jt-1}\}$.

A.3 - Homogeneity of Rotation Regimes:

[6]"Monoculture or even continuous systems of succession such as wheat-soybeans or "safrinha corn" - soybeans, tend to cause physical degradation, chemical and biological and dropping crop yields. It also provides more favourable conditions for the development of diseases, pests and weeds. In regions of predominant monoculture of soybeans among annual crops, as in the Brazilian Cerrado, lies the need to introduce other species in the agricultural system, preferably grasses such as corn, grazing and others. " Embrapa - " Technologies for the Production of soybeans in central Brazil", 2004

I define a municipality M as a set of K farms. Then, for $\forall k \quad and \quad j \in M$, j and k use the same rotation system.

Adding **A.1** to **A.3**, we get that the function that maps the state variables and individual shocks into product shares and cropland area is the same for every farm in a given municipality. And, if $f_{\delta_k}(\boldsymbol{\delta}_{kt-1}, S, \boldsymbol{\nu}_k)$ is the same for every k then, $f_{\delta_k}(\boldsymbol{\delta}_{kt-1}, S, \boldsymbol{\nu}_k) = f_{\delta_m}(\boldsymbol{\delta}_{mt-1}, S, \boldsymbol{\nu}_m)$, where $\boldsymbol{\nu}_m = \sum_{i=1}^{K} \boldsymbol{\nu}_k$[7].

Finally, since I am opting for a continuous choice set for $\boldsymbol{\delta}_t$, the implementation of the estimation technique using (Bajari et al., 2007) requires the following assumption.

A.4 - Monotone Choice (MC) :

For each agent i and product j, Δ_{ij}, $\boldsymbol{\nu}_{ij} \subset \Re$ and $\pi_i(\boldsymbol{\delta}, \boldsymbol{\delta}_{t-1}, s, \nu)$ has increasing differences in (δ_i, ν_i).

4 Estimation

4.1 First Stage

The goal of the first stage of this method is to identify the probability distributions that best describes the law of motion of the state variable and of the policy function. Therefore, in this section I will briefly describe $Pr(S_{t+1}|S_t)$ and $f_{X,\delta}(X_{t-1}, \boldsymbol{\delta}_{t-1}, s, \nu)$.

There are numerous ways to fit the data into a policy function: I can choose both to leave the variables' spaces continuous or make them discrete. With a large number of state variables[8], both flexibility and discretization can curse the estimation with dimensionality problems. Hence, I opt for a continuous space of choices of two shares $\Delta \subset [0,1]^2$ - of soybeans and corn .

Conditional on the realizations of the state variables, the chosen fractions are approximately normal with similar variances. Therefore, we have that:

$$Pr(\boldsymbol{\delta}_{t+1}|\boldsymbol{\delta}_t = \mathbf{d}, s_t = s) \sim N(\mu_{ds}, \sigma) \tag{14}$$

[7]Details in the appendices.

[8]With more than two state variables, a non-parametric approach is usually considered to lack precision.

In figure 7, we have a comparison between the observed fractions of cropland area cultivated with soybeans and corn and the fractions simulated, based on equation 14. The cultivated area is simulated non-parametrically, conditional on X_{t-1} and crop prices.

Since I couldn't identify a known pattern for the frequencies of the state variables, I estimated their distributions non-parametrically with degree one of time-dependence.

$$P(p_{it}^f = p | p_{it-1}^f) = freq(p_{it}^f = p | p_{it-1}^f), \forall \quad t, i \tag{15}$$

$$P(c_{it} = c | c_{it-1}) = freq(c_{it} = c | c_{it-1}), \forall \quad t, i \tag{16}$$

4.2 Second Stage: Estimation and Results

With the estimated distributions described in the previous section, I simulate trajectories of share choices with different initial conditions. These simulated trajectories allow us to estimate the parameters in the profit function, using the method in (Bajari et al., 2007). The estimated parameters reveal the dynamic productive complementarity that exist between soybeans and corn. This strong interdependency that originates from land management choices, translates into interdependencies between supplies.

Using the first-stage estimate for the transition probabilities,I simulate the value function for any sequence of choices and parameter vector Θ. Then, I follow steps 1 to 4:

- Starting at state (Ω_0, S_0), I draw private shocks from the distribution of ν_i for all municipalities.
- Calculate the specified action δ_0 and corresponding profits.
- Draw a new state from the same distribution.
- Repeat Steps 1–3 for 1,000 periods.

The estimated parameters solve the minimization problem below, where k indexes inequalities generated by different combinations of $(i, S, \tilde{\delta})$ and n_d is the number of inequalities used.

$$\hat{\theta} = argmin_{\theta \in \Theta} \frac{1}{n_d} \sum_{k=1}^{n_d} [\min\{V(\Omega, \mathbf{s}; \delta) - V(\Omega, \mathbf{s}; \tilde{\delta}), 0\}]^2 \tag{17}$$

As we can see on table 3, we are able to capture on the soybeans' productivity function a positive effect of having cultivated corn in the previous period. Inversely, there is a negative effect associated with choosing to cultivate soybeans repeatedly, captured by the coefficient of δ_{st-1}. Analogously, there is a positive effect on the productivity of corn associated with cultivating soybeans in the previous period and a negative effect of having cultivated corn during the previous period (table 4). Because I am not using productivity data, only decision data, there is no information about the magnitudes of $\bar{\Omega}_s$ and $\bar{\Omega}_c$. So, I fixated these parameters at the different levels seen on tables 3 and 4, calibrated outside of the model. Then I solved the model for the remaining parameters. As we can see, the remaining parameters vary according to the level of $\{\bar{\Omega}_s;\bar{\Omega}_c\}$ but, their relative sizes remain the same. For the same reason, we cannot know the specific levels of α_s and α_m however, we are able to measure $\alpha_s - \alpha_m$, shown on tables 3 and 4. The measure ξ (in \$/ha) of the cost of expanding the cultivated area is also presented in both tables.

5 Counterfactual Analysis

Let's assume the absence of dynamic effects and of simultaneous productivity spillovers. Then, our counterfactual productivity function would be a static function that accounts only for increasing/decreasing returns to scale:

$$\Omega_{it} = \overline{\Omega_i} + \gamma_{i0} * \delta_{it} \tag{18}$$

In figures 6 and 7 we are able to compare both models' predictions about the effect of a long-run price shock (or subsidy) due to biodiesel mandates.

Following Scott(2013), I compute a long-run elasticity with respect to prices as follows[9]:

$$\epsilon_{\delta,P_i} = [\delta^*(R_t)]^{-1}[\delta^*(R_{t'}) - \delta^*(R_t)]\frac{P_{it}}{P_{it'} - P_{it}} \tag{19}$$

[9] Scott (2013) computes long-run Acreage-price elasticities of a group of crops. I compute first the elasticities of the fraction of the cropland cultivated with each product in relation to the price of soybeans. In a second step, I compute the increase in the overall cropland area in order to get a net elasticity for each product.

$$\epsilon_{A,P_i} = [A^*(R_t)]^{-1}[A^*(R_{t'}) - A^*(R_t)]\frac{P_{it}}{P_{it'} - P_{it}} \tag{20}$$

Where,

$$R_t = \{\mathbf{P_t}, \Omega(\delta^*)\} \tag{21}$$

$$R_{t'} = \{\mathbf{P'_t}, \Omega(\delta^*)\} \tag{22}$$

$$A_t = X_t * \delta_t \tag{23}$$

In table 7, I present the elasticity of the area cultivated with each product and the elasticity of the share of each product, both with respect to soybeans' prices. In columns (1) and (2), we have the effect of an increase in soybeans' prices on the shares and, in columns (3) and (4), we have the effect on the overall area cultivated with each product for each type of model.

These simulations show that farmers reallocate cropland area between two or more products when there is an expected permanent change in prices[10]. In a model where there are positive productivity spill-overs between soybeans and corn, an increase in the price of soybeans will generate an incentive to increase the productivity of this product in order to increase production. Because cultivating corn in the previous period has a positive impact on soybeans productivity, such a positive shock in the price of soybeans generates an incentive to increase the fraction of the cropland cultivated with corn. When we do not account for this type of mechanism, as in figure **??**, we get that the crop choice is exclusively driven by price incentives and that farmers will reduce the fraction of the cropland cultivated with corn and augment the fraction of soybeans. In addition to reallocating the existing cropland between products, farmers will also decide whether to increase their overall cultivated area in response to a price shock, as suggested in Scott (2013). In figure 8 we can see that, although the fraction of soybeans cultivated will decrease in response to the price shock, the total area cultivated with soybeans will rise due to an increase in the overall cropland area. Figure 8 shows that, not only will the area cultivated with corn increase but, it will more than for soybeans.

These results are not directly comparable to Scott (2013) once he computes elasticities with respect to a long run increase in prices of all products in a set. Here, I evaluate

[10]Both simulations start with prices and costs set at their average levels in the data. between periods 1 and 14, the graphics show each models' predictions about the equilibrium size of the cropland (X^*) and fractions of each product cultivated (δ^*). In period 15, soybeans' prices increase by 30% and, between periods 15 and 60, the graphics display the new equilibrium reached by each model

how two products that have a dynamic complementarity in production will respond to a shock in only one of those products' price. Indeed, it is unlikely that a biofuel policy will increase the demand for all crops. What we actually observe are policies that directly affect a specific market, like biodiesel does for soybeans and ethanol does for corn (in the US) or sugar-cane (in Brazil). And, although only one market is directly affected by such policies, this generates changes in incentives to produce specific crops, affecting other markets indirectly. For instance, if we chose to evaluate biofuel policies by interpreting it as a long-run positive price shock on all crops' prices and not as a shock only on soybeans' prices then, we would get a positive effect over cropland acreage which would correspond, in our two product world, to the sum of the jumps in figure 8. We wouldn't be able to see that, although soybeans' prices increase in the long-run, this products' fraction of the cropland area is actually reduced. In fact, if we compute the long-run cropland acreage[11] elasticity with respect to the average price increase[12], we arrive at a result similar to Scott (2013)'s (table 7).

6 Conclusion

This work contributes to the debate about the implications of biofuel policy over food prices and its environmental cost. By adding the crop choice dynamics into the farmer's problem, I am able to separate short-run variations from long-run variations in cropland area for each product. Therefore, I can compute the effects of a long-run price change in soybeans price on each crop's cultivated area resulting from biodiesel policies. This model generates important differences in the magnitude of the long-run price elasticity when compared with static models. The estimated elasticities for the overall cultivated area in the dynamic model are 12 times smaller than in the static model. It is crucial to get the magnitude of these supply responses correctly in order to predict the environmental impact of policies that stimulate crop production. Indeed, as previously discussed, there are strong reasons to think that the short-run and the long-run price elasticities of cultivated area are different. While cropland acreage can be very inelastic in the short-run, we might observe a very different pattern in the long-run, especially when we take into account cross-price elasticities between crops' cultivated areas. It may be the case that, even in the long-run, the elasticity of a crop's acreage with respect to its own price is small. However, the response to variations in its own price combined with variations in other

[11] Here, the total cropland area corresponds to the sum of the areas cultivated with corn and soybeans.

[12] If soybeans' prices increase by $[(p_s' - p_s)/p_s] * 100\%$ and corn prices are not affected, the average price increase is $\Delta_p = \delta_s * (p_s' - p_s)/p_s$

crops' prices may present very different results due to dynamic interdependencies. For example, the response of the corn acreage in the long-run to simultaneous increases in its own price and in the soybeans' price is, in this context, expected to be larger than if there were negative or no variations in the price of soybeans. Indeed, the dynamic model with productive interdependencies generates a positive long-run price elasticity of the fraction of corn in the cultivated area with respect to soybean prices. Inversely, in the short-run, increases in the price of soybeans result in negative responses in terms of corn acreage.

7 Tables and Figures

Figure 1: Proportions of the seasonal cropland cultivated with soybeans and corn: Brazil

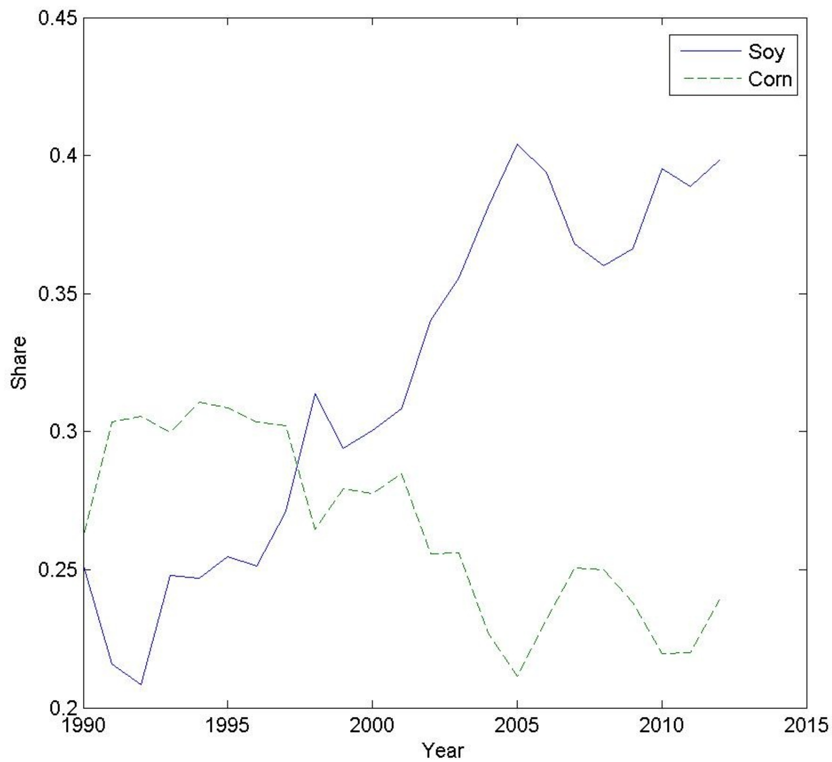


Figure 2: Proportions of the seasonal cropland cultivated with soybeans and corn: Lucas do Rio Verde - MT

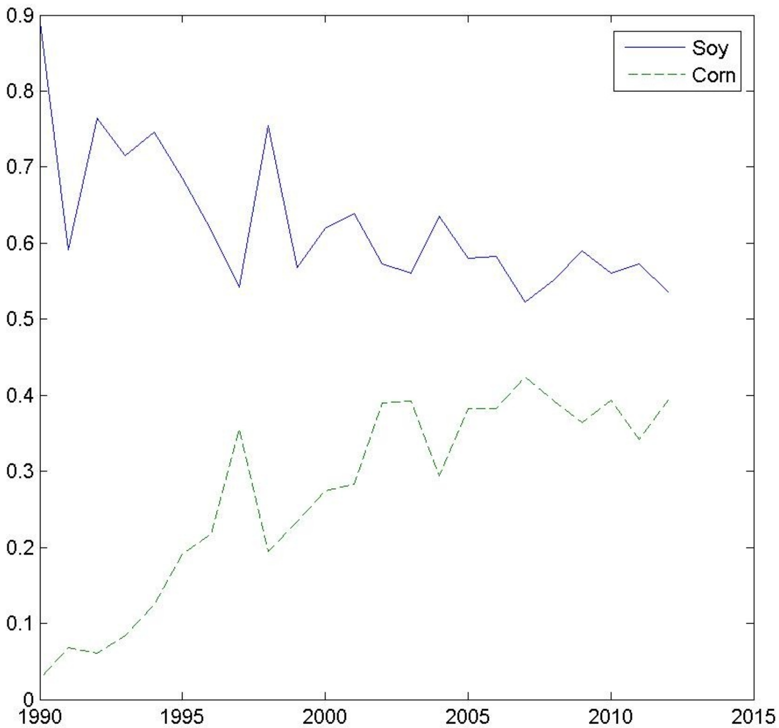


Figure 3: Lucas do Rio Verde

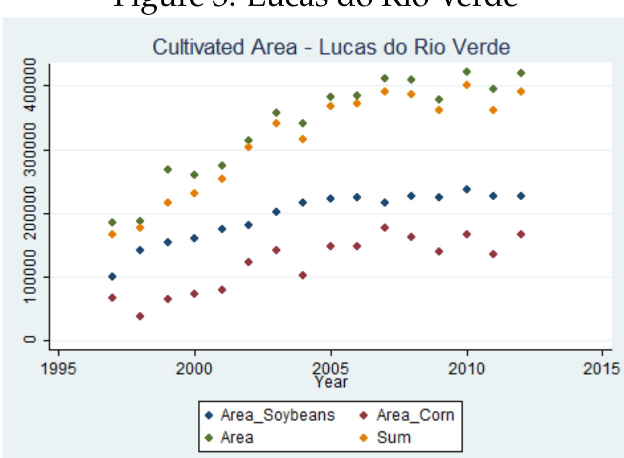


Figure 4: Sorriso

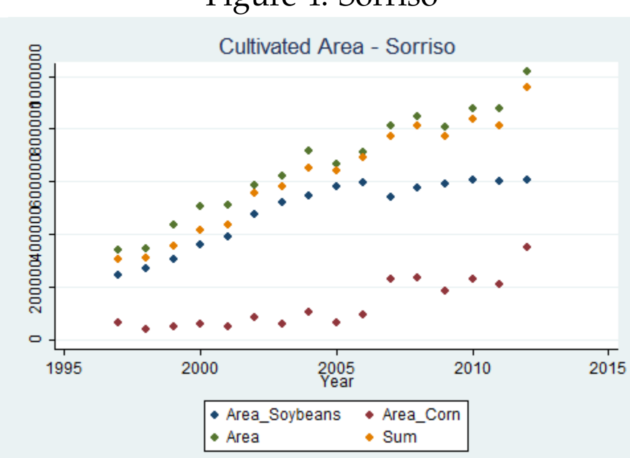


Table 1: Fraction of the cropland cultivated with soybeans

VARIABLES	(1) Pooled OLS	(2) Fixed Effects	(3) Random Effects
year	0.00188	0.00331*	0.00190
	(0.00178)	(0.00173)	(0.00179)
L.soybeans	0.785***	0.603***	0.781***
	(0.0491)	(0.0514)	(0.0491)
L2.soybeans	0.0202	0.000421	0.0640
	(0.0609)	(0.0523)	(0.0529)
L3.soybeans	0.113**	0.0256	0.0671*
	(0.0479)	(0.0370)	(0.0358)
corn	-0.670***	-0.700***	-0.670***
	(0.0449)	(0.0457)	(0.0450)
L.corn	0.550***	0.429***	0.558***
	(0.0662)	(0.0648)	(0.0661)
L2.corn	-0.00430	0.0148	0.0580
	(0.0699)	(0.0562)	(0.0552)
L3.corn	0.0777		
	(0.0537)		
price_Aug_soy	0.0816	0.0413	0.0854
	(0.0705)	(0.0677)	(0.0705)
price_Aug_corn	0.0907	0.127	0.0761
	(0.133)	(0.127)	(0.133)
price_Jan_soy	-0.111	-0.105	-0.125*
	(0.0732)	(0.0692)	(0.0728)
price_Jan_corn	-0.275	-0.333**	-0.252
	(0.169)	(0.164)	(0.169)
Constant	-3.670	-6.312*	-3.703
	(3.560)	(3.443)	(3.565)
Observations	390	390	390
R-squared	0.679	0.700	0.676
Number of municipalities	30	30	30

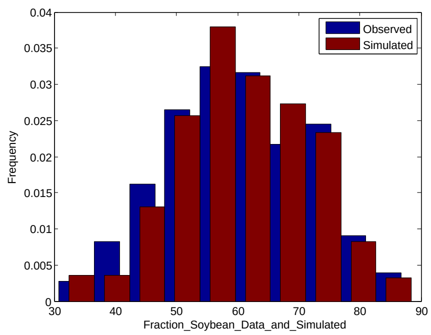
Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2: Fraction of the cropland cultivated with corn

VARIABLES	(1) Pooled OLS	(2) Fixed Effects	(3) Random Effects
year	0.00375**	0.00303*	0.00377**
	(0.00161)	(0.00156)	(0.00161)
L.corn	0.842***	0.656***	0.845***
	(0.0491)	(0.0514)	(0.0489)
L2.corn	0.0487	0.0109	0.0823*
	(0.0636)	(0.0509)	(0.0500)
L3.corn	0.0419		
	(0.0489)		
soybeans	-0.554***	-0.574***	-0.552***
	(0.0372)	(0.0375)	(0.0371)
L.soybeans	0.483***	0.380***	0.480***
	(0.0522)	(0.0510)	(0.0520)
L2.soybeans	0.0130	0.00258	0.0366
	(0.0554)	(0.0474)	(0.0481)
L3.soybeans	0.0468	0.0372	0.0217
	(0.0438)	(0.0335)	(0.0327)
price_Aug_soy	-0.0483	-0.0166	-0.0466
	(0.0642)	(0.0614)	(0.0641)
price_Aug_corn	0.152	0.0995	0.144
	(0.121)	(0.115)	(0.120)
price_Jan_soy	-0.226***	-0.211***	-0.233***
	(0.0658)	(0.0618)	(0.0652)
price_Jan_corn	0.192	0.232	0.206
	(0.154)	(0.149)	(0.153)
Constant	-7.467**	-5.886*	-7.488**
	(3.220)	(3.117)	(3.218)
Observations	390	390	390
R-squared	0.859	0.724	0.707
Number of municipalities	30	30	30

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure 5: Observational and Simulated δ of Soybeans and Corn



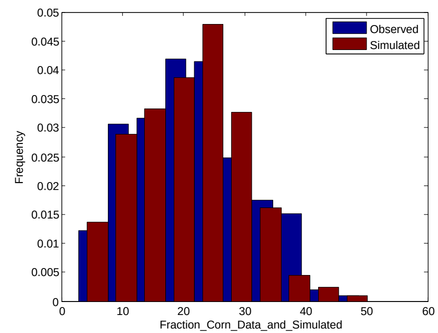


Figure 6: Dynamic Model with Spillovers

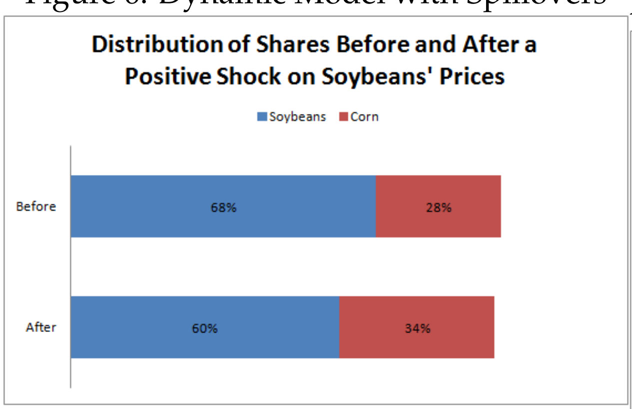


Figure 7: Static Model with Decreasing Returns

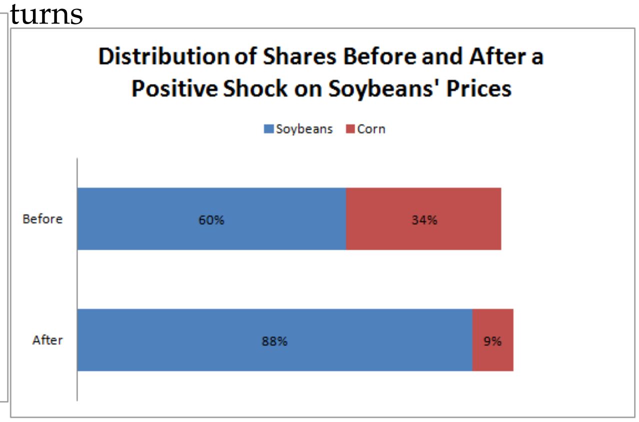


Table 3: BBL Coefficients in Soybeans' Productivity Equation and Expansion Cost

$$\Omega_{st} = \bar{\Omega}_s + \alpha_s * t + \gamma_{s's} * \delta_{st-1} + \gamma_{s'c} * \delta_{ct-1} + \gamma_{ss} * \delta_{st} + \gamma_{sc} * \delta_{ct}$$

$\beta = 0.9$

Variables $\bar{\Omega}_s$	δ_{st-1}	δ_{ct-1}	δ_{st}	δ_{ct}	$\alpha_s - \alpha_m$	ξ
1000	-45,16 ***	164,70 ***	-35,08 ***	84,18	-2218,83***	58,64***
	(10,87)	(43,95)	(5,39)	(265,48)	(191,64)	(13,46)
1400	-62,68***	236,71***	-46,72***	134,98	-2950,63***	84,24***
	(16,54)	(53,94)	(8,14)	(380,74)	(311,87)	(15,86)
2000	-96,10***	365,56***	-67,47***	49,45	-3942,22***	133,59***
	(28,86)	(108,19)	(10,61)	(432,20)	(441,81)	(21,21)
2200	-100,48***	355,20***	-77,83***	257,50	-4625,41***	132,44***
	(28,96)	(92,58)	(13,59)	(580,88)	(515,88)	(28,97)

Table 4: BBL Coefficients in Corn's Productivity Equation and Expansion Cost

$$\Omega_{ct} = \bar{\Omega}_c + \alpha_c * t + \gamma_{c'c} * \delta_{ct-1} + \gamma_{c's} * \delta_{st-1} + \gamma_{cc} * \delta_{ct} + \gamma_{cs} * \delta_{st}$$

$\beta = 0.9$

Variables $\bar{\Omega}_c$	δ_{ct}	δ_{st}	δ_{st-1}	δ_{ct-1}	$\alpha_s - \alpha_m$	ξ
1000	-200,09***	192,84	296,35***	-339,46***	-2218,83***	58,64***
	(49,69)	(543,76)	(87,05)	(87,81)	(191,64)	(13,46)
1700	-358,26***	257,14	452,63***	-543,15***	-2950,63***	84,24***
	(58,35)	(782,86)	(118,18)	(114,00)	(311,87)	(15,86)
2800	-551,09***	323,60	744,97***	-927,25***	-4625,41***	132,44***
	(145,49)	(1189,31)	(182,95)	(222,85)	(515,88)	(28,97)
3000	-587,80***	595,82	704,27***	-960,87***	-3942,22***	133,59***
	(128,23)	(902,84)	(159,21)	(294,68)	(441,81)	(21,21)

Figure 8: Dynamic Model with Spillovers

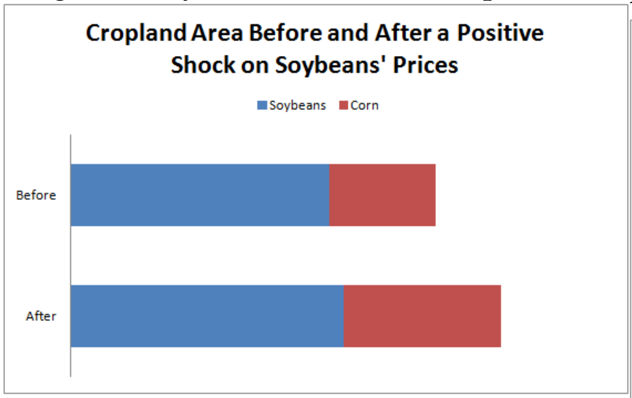


Figure 9: Static Model with Decreasing Returns

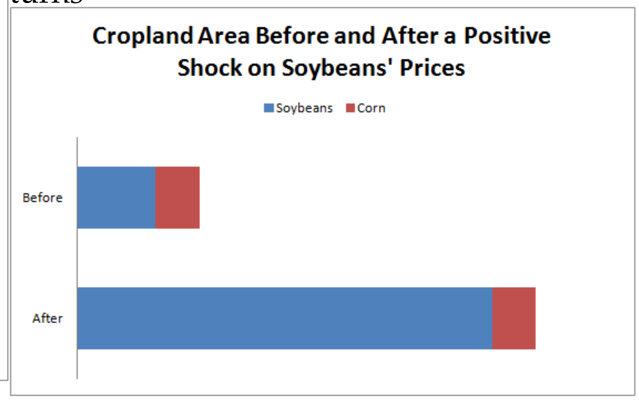


Table 5: Long-Run Acreage/ Fraction-Price Elasticities

	Fraction-Price Elasticities		Acreage-Price Elasticities	
	Dynamic Model	Static Model	Dynamic Model	Static Model
soybeans	-0,403	0,188	0,178	1,732
Corn	0,811	-0,294	1,632	-0,017

Table 6: Comparison Between Long-Run Acreage-Price Elasticities

	Acreage-Price Elasticities		Acreage-Price Elasticities (Scott (2013)[13])
	Dynamic Model	Static Model	Dynamic Model
Acreage Elasticity	0,396	0,735	0,379

Appendices

I want to recover the parameters γ of the productivity function in the farm's problem. However, I do not observe each farm's decision. I do observe shares and cropland areas at the level of each municipality and, we have that:

$$\delta_m = \sum_{i=1}^{K} \delta_k * \sigma_k \tag{24}$$

for each municipality m containing K farms with relative size:

$$\sigma_k = \frac{X_k}{\sum_{i=1}^{K} X_m} \tag{25}$$

First of all, I will show, thanks to Assumption A.2, that the observed solution to each municipality's problem is also the solution to the central planner's problem for each municipality.

A central planner maximizes the sum of the farms' profits:

$$\begin{aligned}\Pi_t^{cp} &= \delta_{mst} * X_m(\bar{\Omega}_s + \gamma_{s's} * \delta_{mst-1} + \gamma_{s'mc} * \delta_{mct-1} + \gamma_{ss} * \delta_{mst} + \gamma_{sm} * \delta_{mct}) + \\ &+ \delta_{mct} * X_c(\bar{\Omega}_c + \gamma_{c'c} * \delta_{mct-1} + \gamma_{c's} * \delta_{mst-1} + \gamma_{cc} * \delta_{mct} + \gamma_{cs} * \delta_{mst}) - \\ &- \delta_{mst} * X_m * C_{st} - \delta_{mct} * X_c * C_{mt}\end{aligned} \tag{26}$$

Substituting equation (24) in (26):

$$\begin{aligned}\Pi_t^{cp} &= \sum_k \delta_{kst} * \sigma_k * X_m(\bar{\Omega}_s + \gamma_{s's} * (\sum_k \delta_{kst-1} * \sigma_k) + \gamma_{s'm} * (\sum_k \delta_{kct-1} * \sigma_k) + \gamma_{ss} * (\sum_k \delta_{kst} * \sigma_k) + \\ &+ \gamma_{sc} * (\sum_k \delta_{kct} * \sigma_k) + \sum_k \delta_{kct} * \sigma_k * X_c(\bar{\Omega}_c + \gamma_{c'c} * (\sum_k \delta_{kct-1} * \sigma_k) + \gamma_{c's} * (\sum_k \delta_{kst-1} * \sigma_k) + \\ &+ \gamma_{cc} * (\sum_k \delta_{kct} * \sigma_k) + \gamma_{cs} * (\sum_k \delta_{kst} * \sigma_k) - \sum_k \delta_{kst} * \sigma_k * X_m * C_{st} - \sum_k \delta_{kct} * \sigma_k * X_c * C_{mt}\end{aligned} \tag{27}$$

$$
\begin{aligned}
\Pi_t^{cp} = {} & \bar{\Omega}_s * X_m * \sum_k \delta_{kst}\sigma_k + \gamma s's * X_m(\sum_k [\delta_{kst} * \delta_{kst-1} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jst-1}\sigma_i\sigma_j + \\
& + \sum_j \sum_i \delta_{jst}\delta_{ist-1}\sigma_i\sigma_j) + \gamma s'c * X_m(\sum_k [\delta_{kst} * \delta_{kct-1} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jct-1}\sigma_i\sigma_j + \\
& + \sum_j \sum_i \delta_{jst}\delta_{ict-1}\sigma_i\sigma_j) + \gamma ss * X_m(\sum_k [\delta_{kst} * \delta_{kst} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jst}\sigma_i\sigma_j + \\
& + \sum_j \sum_i \delta_{jst}\delta_{ist}\sigma_i\sigma_j) + \gamma sc * X_m(\sum_k [\delta_{kst} * \delta_{kct} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jct}\sigma_i\sigma_j + \\
& + \sum_j \sum_i \delta_{jst}\delta_{ict}\sigma_i\sigma_j) + \bar{\Omega}_c * X_m * \sum_k \delta_{kct}\sigma_k + \gamma c'c * X_m(\sum_k [\delta_{kct} * \delta_{kct-1} * \sigma_k^2] + \\
& + \sum_i \sum_j \delta_{ict}\delta_{jct-1}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ict-1}\sigma_i\sigma_j) + \gamma c's * X_m(\sum_k [\delta_{kct} * \delta_{kst-1} * \sigma_k^2] + \\
& + \sum_i \sum_j \delta_{ict}\delta_{jst-1}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ist-1}\sigma_i\sigma_j) + \\
& + \gamma cc * X_m(\sum_k [\delta_{kct} * \delta_{kct} * \sigma_k^2] + \sum_i \sum_j \delta_{ict}\delta_{jct}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ict}\sigma_i\sigma_j) + \\
& + \gamma cs * X_m(\sum_k [\delta_{kct} * \delta_{kst} * \sigma_k^2] + \sum_i \sum_j \delta_{ict}\delta_{jst}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ist}\sigma_i\sigma_j) \qquad (28)
\end{aligned}
$$

If Assumption A.1 is valid then, the terms with double sums in equation (28) will be equal to zero. Hence, the profit function in the Central Planner's Problem will be equal to municipality's problem with observable data. And, solving the muncipality's problem will lead to recovering the original parameters in the farm's problem if every farm within the same municipality has the same set of parameters and if we can properly identify the farms' policy function in the estimation's first stage.

In order to identify the farms' policy function we don't need to observe each farm's choices and neither need those choices be the same for all farms in a given municipality. The choices between farms may vary due to differences in idiosyncratic shocks received but, the function that maps state variables and shocks into choices must be the same. In order to have that, it must also be true that the farm's size does not influence the choice of crop fractions and vice versa (A.3).

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