Vitoria Rabello de Castro

The Dynamics of Crop Rotation in Brazil

DISSERTAÇÃO DE MESTRADO

DEPARTAMENTO DE ECONOMIA

Programa de Pós–graduação em Economia

Rio de Janeiro
Março de 2015

Pontifícia Universidade Católica
do Rio de Janeiro

Vitoria Rabello de Castro

The Dynamics of Crop Rotation in Brazil

Dissertação de Mestrado

Dissertação apresentada como requisito parcial para obtenção do grau de Mestre pelo Programa de Pós–graduação em Economia do Departamento de Economia da PUC–Rio

Orientador : Prof. Juliano Junqueira Assunção
Co–Orientador: Prof. Leonardo Bandeira Rezende

Rio de Janeiro
Março de 2015

Pontifícia Universidade Católica do Rio de Janeiro

Vitoria Rabello de Castro

The Dynamics of Crop Rotation in Brazil

Dissertação apresentada como requisito parcial para obtenção do grau de Mestre pelo Programa de Pós–graduação em Economia do Departamento de Economia do Centro de Ciências Sociais da PUC–Rio. Aprovada pela Comissão Examinadora abaixo assinada.

Prof. Juliano Junqueira Assunção
Orientador
Departamento de Economia — PUC–Rio

Prof. Leonardo Bandeira Rezende
Co–Orientador
Departamento de Economia — PUC–Rio

Prof. Gabriel Ulyssea
Departament of Economics — PUC–Rio

Prof. Arthur Amorim Bragança
CEDEPLAR/UFMG

Prof. Monica Herz
Coordenadora Setorial do Centro de Ciências Sociais – PUC–Rio

Coordenadora stetorial do Centro de Ciências Sociais da PUC-Rio

Rio de Janeiro, 19 de Março de 2015

Vitoria Rabello de Castro

Graduou–se em Ciências Econômicas pela PUC-Rio.

Ficha Catalográfica

Rabello de Castro, Vitoria

The Dynamics of Crop Rotation in Brazil / Vitoria Rabello de Castro; orientador: Juliano Junqueira Assunção; co–orientador: Leonardo Bandeira Rezende. — Rio de Janeiro : PUC–Rio, Departamento de Economia, 2015.

v., 46 f: il. ; 29,7 cm

1. Dissertação (mestrado) - Pontifícia Universidade Católica do Rio de Janeiro, Departamento de Economia.

Inclui referências bibliográficas.

1. Economia – Tese. 2. Estimação de oferta agrícola. 3. Escolha discreta dinâmica. 4. Uso da terra. 5. Políticas de biocombustíveis. 6. Desmatamento. 7. Rotação de culturas. I. Junqueira Assunção, Juliano. II. Bandeira Rezende, Leonardo. III. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Economia. IV. Título.

CDD: 330

Agradecimentos

Aos meus orientadores e professores Juliano e Leonardo pelos ensinamentos, simpatia de sempre e paciência para a realização deste trabalho.

A Capes, à PUC-Rio pelos auxílios concedidos, sem os quais este trabalho não poderia ter sido realizado.

Aos membros da banca, por aceitarem o convite e pelos comentários valiosos.

A todos os professores do departamento que me ensinaram ao longos dos últimos 6 anos.

Aos meus pais, por terem me inpirado pelo seu exemplo a buscar o saber. Ao meu querido Marcos, por seu apoio incondicional.

Resumo

Rabello de Castro, Vitoria; Junqueira Assunção, Juliano; Bandeira Rezende, Leonardo. **The Dynamics of Crop Rotation in Brazil**. Rio de Janeiro, 2015. 46p. Dissertação de Mestrado — Departamento de Economia, Pontifícia Universidade Católica do Rio de Janeiro.

A rotação de culturas é uma prática de manejo da terra usada nos maiores países produtores de grãos e pode ser um fator importante norteando a decisão de produtores quando há mudanças de incentivos a produzir. A existência de tal prática deve ser levada em consideração na avaliação de políticas que têm impacto sobre a decisão de plantio. Nesse artigo, estamos interessados no efeito de diferentes políticas sobre a área cultivada com soja e milho. A rotação de culturas é incorporada no nosso modelo ao considerarmos que obtém-se ganhos de produtividade no cultivo sequencial de soja e milho e, estimamos esses ganhos. Uma vez que a escolha do produto a ser cultivado está atrelada a decisões anteriores, o problema do agricultor é intrinsecamente dinâmico. Portanto, estimamos um modelo estrutural dinâmico que leva em consideração a interdependência dinâmica entre as funções de produtividade desses dois produtos, utilizando dados de área cultivada dos 30 maiores municípios produtores brasileiros. Usando essa estrutura, mostramos que uma política que estimule a produção de soja terá um efeito positivo indireto sobre a produção de milho. Essa abordagem permite uma análise mais rica de impactos diretos e indiretos de diferentes políticas sobre mercados interligados. Finalmente, esse resultado se diferencia daqueles obtidos através de modelos estáticos em termos da magnitude do efeito das políticas avaliadas sobre a oferta dos produtos avaliados. Também difere em sua previsão a respeito da magnitude do custo ambiental de políticas que promovam a produção de grão.

Palavras–chave

Estimação de oferta agrícola; Escolha discreta dinâmica; Uso da terra; Políticas de biocombustíveis; Desmatamento; Rotação de culturas;

Abstract

Rabello de Castro, Vitoria; Junqueira Assunção, Juliano; Bandeira Rezende, Leonardo. **The Dynamics of Crop Rotation in Brazil**. Rio de Janeiro, 2015. 46p. MSc. Dissertation — Departamento de Economia, Pontifícia Universidade Católica do Rio de Janeiro.

Crop rotation is a land management practice used in the world's largest grain producing countries that can deliver important insights on how landowners react to changes in incentives to produce crops. The existence of such practices should be taken into account in the evaluation of policies that have impact on crop choice and land use. In this paper, we are interested in the impact on cropland area of changes in incentives generated by different types of policies. We incorporate crop rotation into our model by considering that productivity gains are obtained by cultivating soybeans and corn in a particular sequence and estimate those gains. As the crop choice is tied to previous planting decisions, the farmer's problem is intrinsically dynamic. Therefore, we estimate a structural model that accounts for the dynamic interdependencies between productivity functions of these two crops, using data from 30 grain-producing municipalities in Brazil. Using this framework, we show that a policy that stimulates the production of soybeans has an indirect positive effect on corn production. This approach allows for a richer analysis of the impact of policies across markets affected directly and indirectly. Finally, the result differs from the ones reached by static and single-choice approaches in terms of the magnitude of the impact of such policies over crop supply. It also differs in its prediction of the magnitude of the environmental cost of policies that promote crop production.

Keywords

Agricultural supply estimation; dynamic continuous choice; Land use; Biofuels policy; Deforastation; Crop rotation;

Sumário

Lista de figuras

Lista de tabelas

1
Introduction

How landowners respond to changes in their incentive to produce crops is crucial to determine the impact of agricultural policies on the environment. A subsidy to crop production, for example, should make farmers willing to increase their cultivated area and transform pastures and forests into cropland, generating an indirect land use change (Arima et al. (2011); Richards (2012)). However, this land use problem is not the only important decision faced by farmers when there is a change in incentives to produce (Doole e Hertzler (2011)). How landowners chose which crop to produce is just as important to determine not only the impact of agricultural policies on different crops' supply but, to determine the overall environmental impact of these policies. More specifically, we show in this paper that, when farmers use crop rotation techniques, a policy that promotes the production of soybeans will also promote corn production because when these two crops are cultivated in sequence, there is a productivity gain for both harvests. Analogously, when there is a promotion of corn production, farmers cultivate more soybeans. This result enlighten us about the effects of energy policies such as biofuel mandates on crop supply.

Recently, many countries have been facing regulations including mandates that stipulate that a portion of the country's fuel supply should come from biofuels[1]. In Brazil, since the January 1st of 2010, all the diesel fuel that circulates in the country must contain 5% of biodiesel. The 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 the gasoline fuel sold in the country contains 25% of ethanol[2]. The ethanol can be produced through various primary sources and, in Brazil, it is entirely produced based on sugar-cane[3]. Governmental resolutions regarding biofuels have a direct impact over the demand for specific crops and are usually accompanied by programs of subsidies to production. As we will see later in this paper, even

[1] In the US, a 5% of biodiesel per gallon, scheduled to increase incrementally to a maximum of 20% in 2015 and thereafter, was initially implemented in 2005. As for the gasoline, the legislature required a 10% of ethanol blends statewide in 2003, after requiring a 7.7% blend between 1997 and 2003 (US EPA, Environmental Protection Agency). The EU mandates on biofuels stipulate similar levels. Overall, in 2013, a total of 62 countries have targets of mandates for biofuels (BiofuelDigest).

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

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

though these policies only directly affect the demand for one specific crop, the supply for other crops is affected as well, due to the structure of crop choice. For example, biofuel mandates in Brazil, according to our results, should have an even greater positive impact on corn cultivation than on soybeans, due to dynamic interdependencies in the cultivation of these crops. Furthermore, we find that biofuel mandates can have very different overall crop supply impacts depending on the market that is directly impacted. Indeed, if an energy policy were to promote the demand for soybeans in Brazil, its overall impact on the cropland area would be about 12 times larger than if this policy were to promote the demand for corn. This difference is due to the fact that soybeans is the primary crop in Brazil's most productive areas, accounting for approximately two thirds of the cropland in these areas. In these highly productive regions, corn is an auxiliary crop used in a crop rotation around soybeans. Therefore, how landowners in these regions in Brazil chose their crop sequence is extremely relevant to determining the impact of policies that change incentives to cultivate one crop versus another. Thus, evaluating the equilibrium effects of policy resolutions that depend on crop supply responses requires us to include crop choice when modelling farmers' land use decisions.

Probably the main reference today when it comes to evaluating the possible price effects of biofuels regulations is Roberts e Schlenker (2013). The authors 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[4] increase by 20% if one-third of commodities used to produce ethanol are recycled as feedstock. That is a huge effect. Since we they are evaluating short-run price variations, the magnitude of this elasticity seems reasonable, once it is commensurate with the year-to-year variation of commodity prices. If we believe that the peaks of commodity prices in 2005 and 2008 were somewhat 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 a policy may not have an homogeneous effect across different commodity markets. As I will further elaborate in the following sections, there are tight productive relationships between crops, notably between corn and soybeans, that generate an important interdependency between both products' supplies. And, an important change in the incentives to produce crops can have unexpected indirect effects on seemingly unaffected markets. Both Livingston et al. (2008)

[4]Corn, rice, soybeans ans wheat.

and Ji et al. (2014) show, with experimental data on crop fields in the US, that there are productivity gains derived from cultivating soybeans and corn in sequence and that this, indeed, affects famers' behavior. Because of this type of relationship, a policy that has a direct effect over only one of these markets will have indirect effects over the other markets. Moreover, when we take this mechanism into account, the direction of the indirect effect on prices could end up being in the opposed direction to the direct effect. For example, suppose a governmental policy that subsidizes the production of soybeans. This measure will also stimulate the production of corn in countries where farmers use rotation systems involving these two crops, which is the case for Brazil and the US. If there is not an increased demand for the latter product, we should expect a decrease in its price. This type of relationship should invite us to question if the long run implications of the policies evaluated in Roberts e Schlenker (2013) might not be completely different than for the short run.

There is a vast literature that acknowledges the importance of land use change for the evaluation of agricultural and environmental policies, as do Fezzi e Bateman (2011); Rodrigues (2012); Lubowski et al. (2005); Irwin (2002); Vance e Geoghegan (2002). Aiming to account for land use changes that may be induced by biofuel policies and using a new and simple methodology, Scott (2013) makes an important contribution to the empirical literature regarding the estimation of land use elasticity by adding dynamic incentives to his approach. According to him, static approaches tend to underestimate responses to long-run land use incentives. Because landowners react more likely 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 found in static models using the same data. This result implies in much smaller[5] 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 seen as too 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

[5]About 10 times smaller, Scott (2013)

from switching from a culture to another. Although this restriction is directly imposed by the small size of his panel, it sacrifices important information. Indeed, the dissemination of the Direct Planting System (DPS) and the acknowledgement of the importance of the role of rotation and succession systems at 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 very important but, they become the more relevant when we consider the decision of which crop to cultivate in addition to the one of whether to cultivate crops or not. 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 in result of price changes. Hence, in the model presented in chapter 3, the field state variable provides relevant additional information when compared to Scott (2013)'s formulation. Whereas, in his framework, the field state is defined by the number of years since any type of crop was last cultivated on that field, in our framework, 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 unobservable endogenous state variable of interest.

Finally, adding switching benefits in a dynamic model provides insight about why some products' supplies are inelastic in the short-run, by introducing trade-offs between short-run profit gains that result from cultivating more of crops that have benefited from temporary price augmentation, and long-run profit and productivity losses that result from deviating from the efficient crop rotation[6] sequence. More importantly, if we decide to formulate the problem like in Scott (2013), as one that consist in a choice between cultivating any type of crop or having a non-agricultural use[7] of the land, we lose the interactions that may exist among the different products' supplies. For instance, we want to know what are the effects on corn cultivation if there is a demand increase for soybeans, due to biodiesel regulations. By way of illustration, in Brazil, the exponential increase in the production of soybeans in the past decades was accompanied by a commensurate increase of the winter harvest which is headed by corn production. 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 thesis, we show that a policy that increases the demand for soybeans, like the biodiesel mandates in Brazil, stimulates the production of corn, even

[6]Definition in chapter 3.1

[7]Scott defines the non-agricultural use of the land as a group of options composed mostly of forestry and pasture.

if corn prices aren't as attractive. We further illustrate, through a set of counterfactual examples, how taking crop rotation into account in a dynamic model can be relevant to determining the results of many types of agricultural policies. In sum, we argue that in order to have a more precise analysis of the implications of agricultural and environmental policies over crop choice and, by extension, over a set of crops' supplies, it is necessary to properly establish the interdependencies that lie between the different crops' production functions.

2
Crop Rotation in Brazil

2.1
Data

We use data on cultivated area between 1997 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, most located in the Brazilian *"Cerrado"*, as shown in figure 2.1. In light of the discussion in the previous section, we chose a set of municipalities that have been among the largest grains producers in the country since before the major methodological and technological changes associated with the spread of the DPS (Direct Planting System). In these municipalities, we observe a convergence between the shares of soybeans and corn cultivated (as in 2.3). The shares of soybeans decreases since before the 90's until approximately the year 2000 and the share of corn increases until the year 2000, when it stabilizes around one third of the cultivated area while the share of soybeans stabilizes around two thirds of the cultivated area. Hence, we will be working with a sample of municipalities where the crop rotation techniques have been used for more than two decades and where farmers have already adapted their crop choice mechanism to the innovations associated with DPS. These 30 municipalities accounted for 20% of Brazil's grain production in the beginning of our sample, according to the PAM. For information on future prices, we use series from the *Chicago Board of Trade*. We 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.

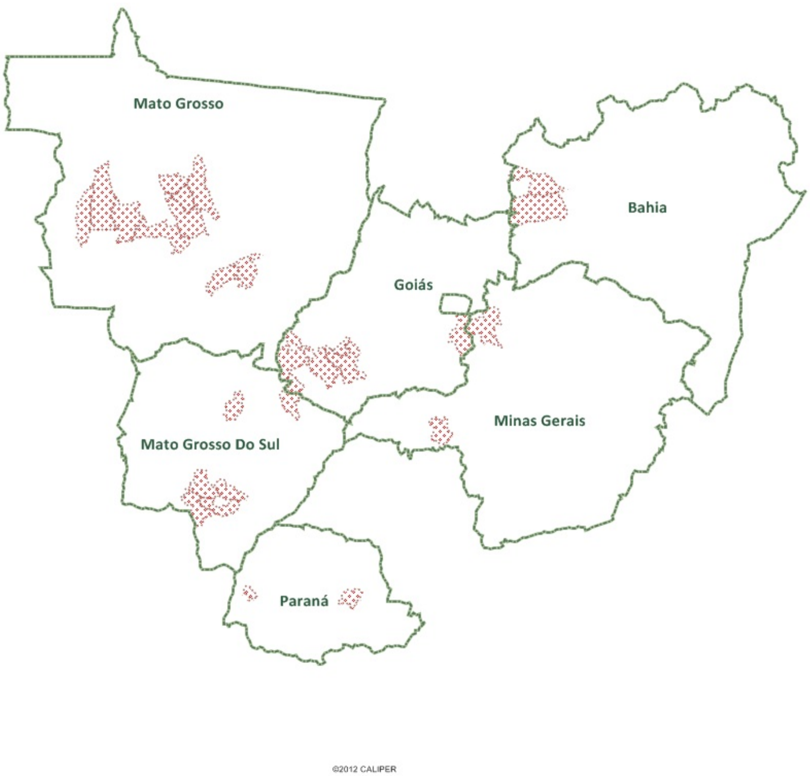


Figure 2.1: Largest Grain producing Municipalities in Brazil (2000)

2.2
Direct Planting System and Crop Rotation Background in Brazil

Comparing the historical series of shares of the seasonal cropland cultivated with soybeans and corn[1] we observe opposed patterns between the graphics of Brazil as a whole, in figure (2.2), and Brazil's largest grain producing municipality: Lucas do Rio Verde, in figure (2.3). On the one hand, for the country as a whole, there appears to be a steep trend of growth of the share of soybeans cultivated relatively to corn and other products. Over the years, the ratio of cropland cultivated with corn drops constantly as the area cultivated with soybeans grows. At this pace, soybeans become the largest crop production in Brazil around 1996. On the other hand, the municipalities that have cultivated grains for long present an opposed trend, during the same period[2]. The share of the cropland area cultivated with soybeans is decreasing in Lucas do Rio verde and the share cultivated with corn has an increasing trend[3], driven by the *"Safrinha Corn"* phenomenon[4].

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 on the graphics of 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 we observe 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 becomes 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 the soybeans, which is the most profitable product 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

[1]soybeans and corn are the two largest harvests in Brazil today. Source: PAM, IBGE

[2]We present the graph for Lucas do Rio Verde, located in the state of Mato Grosso but, this pattern is also found for the other largest grain producing municipalities in Brazil.

[3]Significance tests for time trends support this statement.

[4]The so called *"Safrinha Corn"* ("Little Harvest Corn") is the corn harvested during the winter. This phenomenon turned into a second official harvest in Brazil started during the 90's in the main producing states. The rapid growth of the "Safrinha" was due to great technological improvements and to the implementation of DPS techniques.

predominant effect in the more advanced municipalities. In sum, in the regions where the expansion of the cultivated area is reaching its limit, we can see what the productivity increasing practices imply in terms of crop choices: a reduction of the gap between the shares of soybeans and corn cultivated over the years, as crop rotation techniques are disseminated and evidences are built on the mutual productivity gains derived from cultivating both soybeans and corn jointly.

As we can see in figures 2.4 and 2.5, the total area cultivated with non-perennial crops increases considerably from the beginning of our sample (1997) until the end (2012) for the leading municipalities in the data[5]. 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. It certainly seems that the choice of whether to increase the cultivated area is just as important as the one of which crop to cultivate. Therefore, we include in the model presented in the next chapter the size of the cropland as a choice variable, allowing it to vary over time.

[5]The other 28 municipalities in the data follow a very similar pattern.

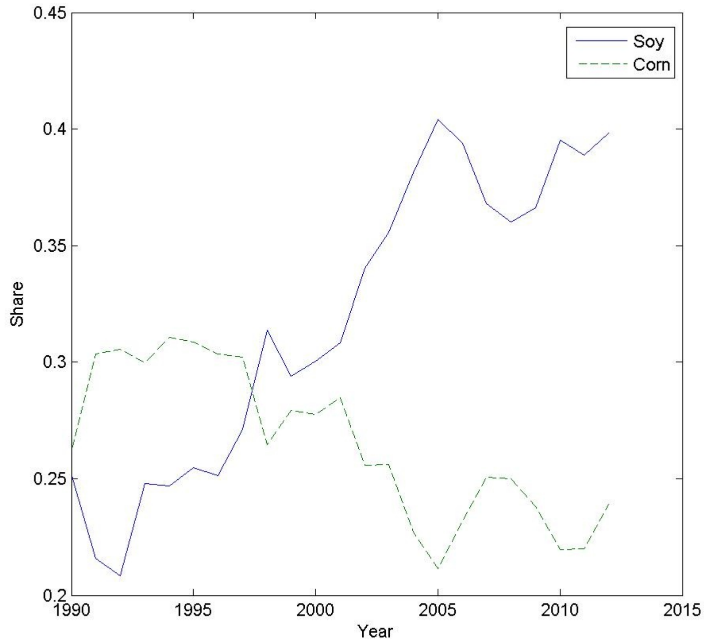


Figure 2.2: Share of seasonal cropland cultivated with soybeans and corn: Brazil

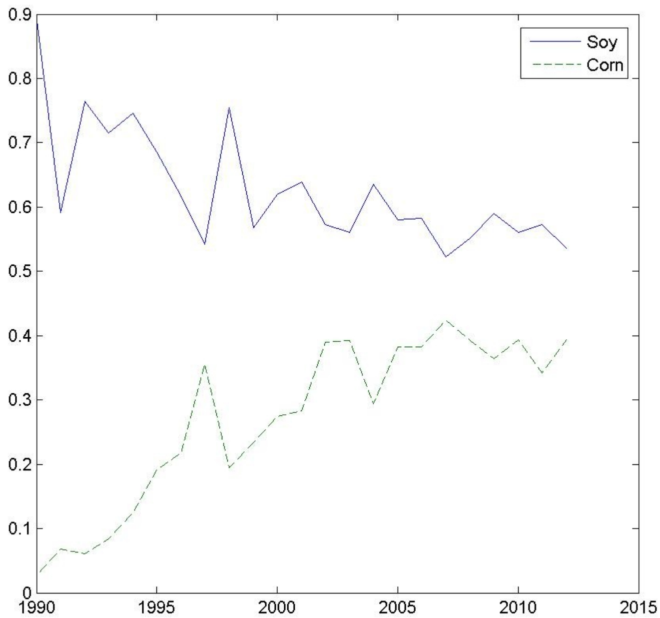


Figure 2.3: Share of seasonal cropland cultivated with soybeans and corn: Lucas do Rio Verde - MT

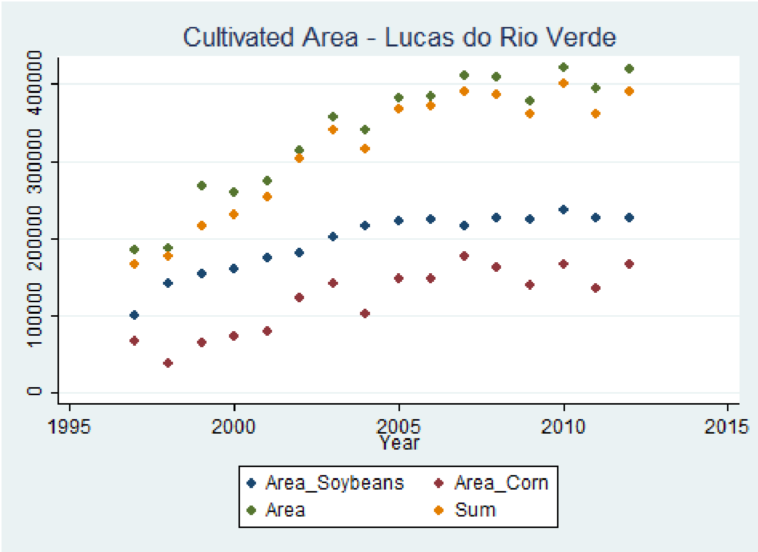


Figure 2.4: Cultivated Area in Municipality of Lucas do Rio Verde

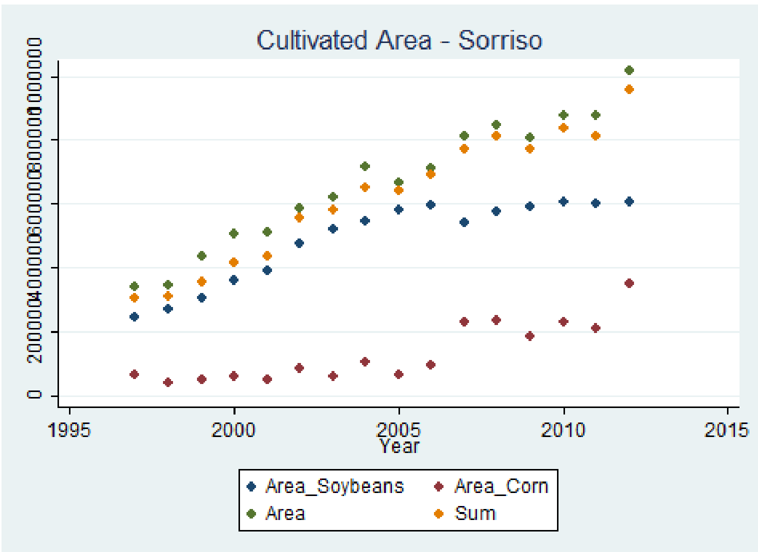


Figure 2.5: Cultivated Area in Municipality of Sorriso

2.3 Correlations

The regressions presented in this chapter show correlation patterns throughout time that indicate curious relationships between crop choices, justifying the construction of a model that could explain them. Tables (2.1) and (2.2) present the results of OLS, fixed effects and random effects estimations. We regress the share of the cropland area cultivated with soybeans on its lags, on the current and lagged values of the share of corn. We add prices of future contracts for the months of August and January with closure in March and July for soybeans and corn respectively. August and January are the months when farmers start to cultivate each of the two perennial seasons in Brazil and March and July are the months when each of these seasons ends. The variable $p\_aug_soybeans$ and $p\_jan\_soybeans$ stand for the price of a standardized contract for soybeans in August with closure in March and a standardized contract for soybeans in January with closure in July. The variables $p\_aug\_soybeans$ and $p\_jan\_soybeans$ stand for analogous prices for corn. The variable $year$ stands for a time trend. We do the same for the share of the cropland area cultivated with corn as the dependent variable.

For each of the dependent variables, the first lag of the share of the other product is significantly positively correlated. For example, in the OLS model, larger shares of corn cultivated in the immediately previous period are positively correlated with larger shares of soybeans cultivated currently. The same correlation pattern is found for corn as a dependent variable. In some of the models we also find positive correlations between the dependent variable and the second or third lag of another product's share. Intuitively, all the regressions present a negative correlation between the shares 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 some type of dynamic complementarity in the production of these two products.

The model that follows addresses explicitly the meaning of these correlations through a structural productivity equation that associates past and present crop choices to a productivity level.

Table 2.1: Regression of the share of the cropland cultivated with soybeans on shares of other products and on prices

VARIABLES	(1) Pooled OLS	(2) Fixed Effects	(3) Random Effects
year	0.00188	0.00331*	0.00190
	(0.00178)	(0.00173)	(0.00179)
L.Share_ Soybeans	0.785***	0.603***	0.781***
	(0.0491)	(0.0514)	(0.0491)
L2.Share_ Soybeans	0.0202	0.000421	0.0640
	(0.0609)	(0.0523)	(0.0529)
L3.Share_ Soybeans	0.113**	0.0256	0.0671*
	(0.0479)	(0.0370)	(0.0358)
Share_ Corn	-0.670***	-0.700***	-0.670***
	(0.0449)	(0.0457)	(0.0450)
L.Share_ Corn	0.550***	0.429***	0.558***
	(0.0662)	(0.0648)	(0.0661)
L2.Share_ Corn	-0.00430	0.0148	0.0580
	(0.0699)	(0.0562)	(0.0552)
L3.Share_ Corn	0.0777		
	(0.0537)		
p_ aug_ soybeans	0.0816	0.0413	0.0854
	(0.0705)	(0.0677)	(0.0705)
p_ aug_ corn	0.0907	0.127	0.0761
	(0.133)	(0.127)	(0.133)
p_ jan_ soybeans	-0.111	-0.105	-0.125*
	(0.0732)	(0.0692)	(0.0728)
p_ 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		0.700	
Number of municipio	30	30	30

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

Table 2.2: Regression of the share of the cropland cultivated with corn on shares of other products and on prices

VARIABLES	(1) Pooled OLS	(2) Fixed Effects	(3) Random Effects
year	0.00375**	0.00303*	0.00377**
	(0.00161)	(0.00156)	(0.00161)
L.Share_ Corn	0.842***	0.656***	0.845***
	(0.0491)	(0.0514)	(0.0489)
L2.Share_ Corn	0.0487	0.0109	0.0823*
	(0.0636)	(0.0509)	(0.0500)
L3.Share_ Corn	0.0419		
	(0.0489)		
Share_ Soybeans	-0.554***	-0.574***	-0.552***
	(0.0372)	(0.0375)	(0.0371)
L.Share_ Soybeans	0.483***	0.380***	0.480***
	(0.0522)	(0.0510)	(0.0520)
L2.Share_ Soybeans	0.0130	0.00258	0.0366
	(0.0554)	(0.0474)	(0.0481)
L3.Share_ Soybeans	0.0468	0.0372	0.0217
	(0.0438)	(0.0335)	(0.0327)
p_ aug_ soybeans	-0.0483	-0.0166	-0.0466
	(0.0642)	(0.0614)	(0.0641)
p_ aug_ corn	0.152	0.0995	0.144
	(0.121)	(0.115)	(0.120)
p_ jan_ soybeans	-0.226***	-0.211***	-0.233***
	(0.0658)	(0.0618)	(0.0652)
p_ 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	
Number of municipio		30	30

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

3
The Model

3.1
The Environment

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

Definição 3.1 *The available cropland, X_t, is a share of the farmland, measured in hectares, that the landowner can allocate between different crops.*

Definição 3.2 *An allocation δ_t is a vector of chosen shares of the cropland associated with each of the n available products, in a period t: $\delta_t \in [0,1]^n$ such that*

$$\sum_i \delta_{it} = 1, \quad \forall \quad t. \tag{3-1}$$

Definição 3.3 *A "rotation" system is a finite sequence of m years of cultivation. In the first harvest of each year of this sequence the rotation system indicates a crop for each plot of land within the same system. The sequence of crops is such that land productivity is maximized in the long-run.*

The landowner may choose, at a give period t, 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, in t, a production-year begins then, in $t+1$, the same production-year ends and another begins. To begin with, let's adopt the simpler time period above (production-year). However, more detailed time periods can be used, taking the different harvests of the same year as distinct periods.

The yield of a certain crop $i \in I$ during the period t is measured in *kg* gathered and given by:

$$Y_{it} = \delta_{it} * X_t * \Omega_{it} \tag{3-2}$$

Where Ω_{it} is the 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 wishes to maximize the discounted sum of his profits, one could think that $\boldsymbol{\delta}_t$ 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

Each crop's productivity evolves conditionally to the choices made by the landowner over time. So, in addition to soil management (fertilisation, manuring, etc.), productivity depends on the present and the previous shares of the cropland cultivated with each product. The productivity is penalized by deviations from the productivity-maximizing crop rotation system, discounting the expected future profit.

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

α will capture linear time trend effects. 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 $\boldsymbol{\gamma}$, which indicate the mutual productivity effects between soybeans and corn over time. More specifically, in (Equation 3-4), the coefficient $\gamma_{s'c}$ measures the effect on soybeans' productivity of cultivating corn during the previous period. If this coefficient is positive then, we can say that corn is dynamically complementary to soybeans cultivation.

We are going to estimate the coefficients in the following two equations:

$$\Omega_{st} = \bar{\Omega}_s + \alpha_s * t + \gamma_{s's} * \delta_{st-1} + \gamma_{s'c} * \delta_{ct-1} + \gamma_{ss} * \delta_{st} + \gamma_{sc} * \delta_{ct} \tag{3-4}$$

$$\Omega_{ct} = \bar{\Omega}_c + \alpha_c * t + \gamma_{c'c} * \delta_{ct-1} + \gamma_{c's} * \delta_{st-1} + \gamma_{cc} * \delta_{ct} + \gamma_{cs} * \delta_{st} \tag{3-5}$$

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.
γii captures the increasing/decreasing returns to scale in i's production.
γij captures the effect on i's productivity of also cultivating j in the current period.

Exogenous State Variables

We now define the exogenous state variables that are relevant to the landowner's decision at each harvest. This set of variables is basically composed of price, cost and meteorological variables. We will call this set S.
The landowner will then decide the size of his cropland X_t and the shares of the cropland to be cultivated with each product. Therefore, we can write the policy function as:

$$\{X_t, \boldsymbol{\delta}_t\} = f(X_{t-1}, \boldsymbol{\delta}_{t-1}, ..., \boldsymbol{\delta}_{t-k}, S, \nu_{it}; \theta) \quad (3\text{-}6)$$

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

Preference Shocks

Following Bajari et al. (2007), we assume that before choosing an action $\{X_t, \boldsymbol{\delta}_t\}$, each agent receives a private shock $\boldsymbol{\nu}_t$ independently drawn across individuals and time from a type II Extreme Value distribution $G_i(.|\Omega_t, s_t)$ with support $\nu_i \in \Re^2$. [1]

3.2 Setting the Agent'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) and on his private shock. We are assuming that there is no strategic interaction and that agents do not have market-power separately. It is indeed reasonable to assume that agents are " price takers " in agricultural markets, once we consider production concentration data[2]. We denote a representative agent's profit by $\Pi(\boldsymbol{\delta}_t, \boldsymbol{\Omega}_\mathbf{t}, \mathrm{s}_\mathbf{t}, \boldsymbol{\nu}_t)$, where $\boldsymbol{\Omega}_\mathbf{t} = (\Omega_{st}, \Omega_{ct})$ and $\boldsymbol{\nu}_t = (\nu_{st}, \nu_{ct})$.

[1] Where 2 is the number of products in the set of crop choices.
[2] 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.

Assuming that agents have the same discount factor $\beta < 1$, for a given the state realization in t, the agent's expected profit, before the realization of shocks ν and ε is :

$$\mathbb{E}[\sum_{\tau=t}^{\infty} \beta^{\tau-t}\Pi_j(\boldsymbol{\delta}_{j\tau}, \boldsymbol{\Omega}_{j\tau}, \mathbf{s}_\tau, \boldsymbol{\nu}_{j\tau})] \tag{3-7}$$

We finally assume that the state at $t+1, \{\boldsymbol{\Omega}_{\mathbf{t+1}}, \mathbf{s}_{\mathbf{t+1}}\}$, is drawn from a probability distribution $P(\boldsymbol{\Omega}_{\mathbf{t+1}}, \mathbf{s}_{\mathbf{t+1}}|\boldsymbol{\delta}_t, \boldsymbol{\Omega}_{\mathbf{t}}, \mathbf{s}_{\mathbf{t}})$.

Writing a representative farmer's profit recursively, we have:

$$\begin{aligned} V \quad & (\boldsymbol{\Omega}, \mathbf{s}; \delta) = \mathbb{E}_\nu[\Pi(\delta(\boldsymbol{\delta}_{t-1}, \mathbf{s}, \boldsymbol{\nu}), \boldsymbol{\Omega}, \mathbf{s}, \boldsymbol{\nu}) + \\ + \quad & \beta \int V(\boldsymbol{\Omega}', \mathbf{s}'; \delta) dP(\boldsymbol{\Omega}', \mathbf{s}'|\delta(\boldsymbol{\delta}_{t-1}, \mathbf{s}, \nu), \boldsymbol{\Omega}, \mathbf{s})|\boldsymbol{\delta}_{t-1}, \mathbf{s})] \end{aligned} \tag{3-8}$$

3.2.1 Profit Function

We consider that there is only one harvest per year[3]. Consider the following profit function after the realizations of shocks :

$$\begin{aligned} \Pi(\delta_t, \Omega_t, S, \nu_t) &= \sum_{i=1}^{n} (\delta_{it} * X_t * \Omega_{it} * p^f_{it+1} - c_{it} * \delta_{it} * X_t + \nu_{it}) + \xi * (X_t - X_{t-1}) \\ &= \tilde{\Pi}(\boldsymbol{\delta}, \boldsymbol{\Omega}, S) + \sum_{i=1}^{n} \nu_i(\delta_i) \end{aligned} \tag{3-9}$$

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. ξ is a measure for the cost associated with increasing the cultivated area[4]. 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:

[3]We ignore the existence of double-cropping, in this paper

[4]We could include a measure for a potential benefit of decreasing the cultivated area and selling or renting that portion of land. However, we do not observe reductions in cultivated area in the yearly data.

$$\Pi(\delta_t, \delta_{t-1}, R_t, C_t, \nu_t) = \sum_i \delta_{it} * (R_{it} * (\overline{\Omega_i} + \alpha_i * t + \boldsymbol{\rho}_i * M_t + \sum_{i=1}^{2}\sum_{k=0}^{1} \gamma_{ik} * \delta_{it-k} + \varepsilon_{it}) - C_{it}) + \xi * (X_t - X_{t-1}) + \sum_{i=1}^{2} \nu_{it}(\delta_{it}) \quad (3\text{-}10)$$

Were we define:

$$R_{it} = p_{it} * X_t \quad (3\text{-}11)$$

$$C_{it} = c_{it} * X_t \quad (3\text{-}12)$$

$$\Omega_{it} = \overline{\Omega_i} + \alpha_i * t + \boldsymbol{\rho}_i * M_t + \sum_{i=1}^{2}\sum_{k=0}^{1} \gamma_{ik} * \delta_{it-k} + \varepsilon_{it} \quad (3\text{-}13)$$

We allow in (3-13) that each product affects the productivity of the other in a singular form. That is, we 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, we hope to identify crossed-effects that may exist between cultivated area 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 [5].

With the following assumptions, we can estimate the parameters $\boldsymbol{\gamma}$ in the productivity function, using the two stage methodology in Bajari et al. (2007).

3.3 Assumptions for Identification

Although the parameters we want to recover come from the landowner's problem, we only observe shares at the municipal level. We need to make sure

[5] "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

that, with this data and our 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 $\boldsymbol{\delta}_t$ or any of its lags and vice versa.

A.2 - Absence of Externalities Between Farms:

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

A.3 - Homogeneity of Rotation Regimes:

We define a municipality M as a set of K farms. Then, for $\forall k$ and $j \in M$, 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 $\boldsymbol{\nu}_m = \sum_{i=1}^{K} \boldsymbol{\nu}_k$[6].

Finally, since we are opting for a continuous choice set for $\boldsymbol{\delta}_t$, the Bajari et al. (2007) method requires us to make 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).

[6]Details in the appendices.

4
BBL: Estimation in Two Stages

In order to estimate the parameters in the productivity function, we wil follow the methodology in Bajari et al. (2007). This estimation method is divided in two parts: approximation of the distributions of the policy function and state variables (First Stage), followed by an error minimization process (Second Stage).

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 chapter we will briefly describe $Pr(S_{t+1}|S_t)$ and $f_{X,\boldsymbol{\delta}}(X_{t-1}, \boldsymbol{\delta}_{t-1}, s, \nu)$.

There are numerous ways to fit the data into a policy function: We can choose both to leave the variables' spaces continuous or make them discrete. With a large number of state variables[1], both flexibility and discretization can curse the estimation with dimensionality problems. Hence, we 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 shares are approximately normal with similar variances. Therefore, we have that:

$$Pr(\boldsymbol{\delta}_{t+1}|\boldsymbol{\delta}_t = \mathbf{d}, s_t = s) \sim N(\mu_{ds}, \sigma) \quad (4\text{-}1)$$

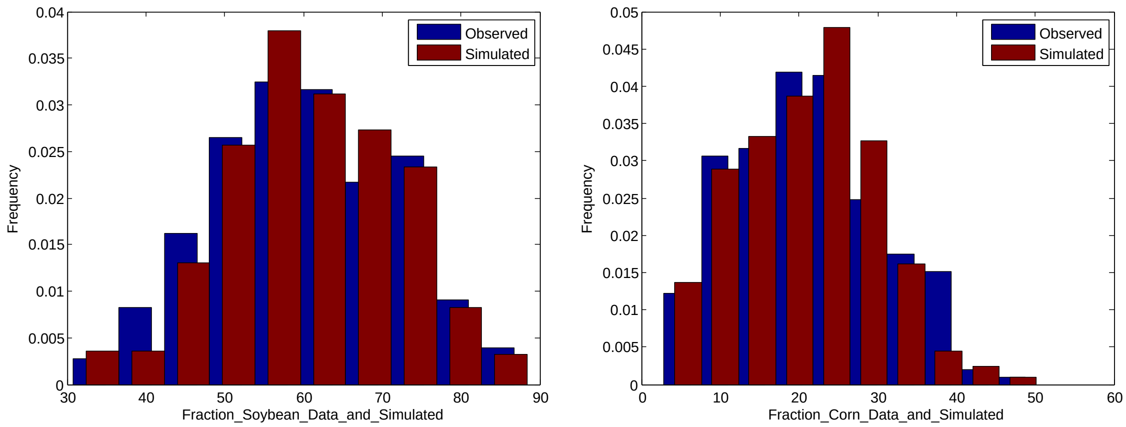
In figure 4.1, we have a comparison between the observed shares of cropland area cultivated with soybeans and corn and the shares simulated, based on equation 4-1.

Since we couldn't identify a known pattern for the frequencies of the state variables and for X_t, we estimated their distributions non-parametrically with degree one of time-dependence[2].

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

[2] We made the space for these variables discrete and limited by the minimum and maximum value observed for each variable in the data.

Figure 4.1: Observational and Simulated δ of Soybeans and Corn



$$P(p^f_{it} = p|p^f_{it-1}) = freq(p^f_{it} = p|p^f_{it-1}), \forall \quad t, i \tag{4-2}$$

$$P(c_{it} = c|c_{it-1}) = freq(c_{it} = c|c_{it-1}), \forall \quad t, i \tag{4-3}$$

$$P(X_t = c|X_{t-1}) = freq(X_t = x|X_{t-1}), \forall \quad t \tag{4-4}$$

To simulate the data, we start we an initial state $\{S_0 = s, X_0 = x, \boldsymbol{\delta}_0 = \delta\}$, we draw initial private shocks ν_0. We calculate the specified choice $\{X_1, \boldsymbol{\delta}_1\} = f(X_0, \boldsymbol{\delta}_0, S_0, \nu_0; \theta)$ and the resulting profits. Then, we draw a new state using the estimated transition probabilities for prices and production costs, as specified above. Finally, we repeat these steps for 100 periods and for 100 different initial states.

4.2
Second Stage

With the estimated distributions described in the previous chapter, we were able to simulate trajectories of 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). We compute the difference between the value function evaluated at the chosen sets of $\{X_t, \boldsymbol{\delta}_t\}$ and all the alternative sets of choices, for each period and each initial condition. The set of estimated parameters must minimize the quadratic mean of these differences.

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.

As we can see on table 4.1, 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 4.2). Because we are not using productivity data, only decision data, there is no information about the magnitudes of $\bar{\Omega}_s$ and $\bar{\Omega}_c$. So, we fixated these parameters at the different levels seen on tables 4.1 and 4.2, estimated outside of the model, and 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 4.1 and 4.2. Our measure ξ (in \$/ha) of the cost of expanding the cultivated area is also presented in both tables.

Table 4.1: BBL Coefficients in Soybeans' Productivity Equation and Expansion Cost

$$\Omega_{st} = \bar{\Omega}_s + \alpha_s * t + \gamma_{s's} * \delta_{st-1} + \gamma_{s'c} * \delta_{ct-1} + \gamma_{ss} * \delta_{st} + \gamma_{sc} * \delta_{ct} \quad (4\text{-}5)$$

$\beta = 0.9$

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

$$\Omega_{ct} = \bar{\Omega}_c + \alpha_c * t + \gamma_{c'c} * \delta_{ct-1} + \gamma_{c's} * \delta_{st-1} + \gamma_{cc} * \delta_{ct} + \gamma_{cs} * \delta_{st} \quad (4\text{-}6)$$

$\beta = 0.9$

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)

5
Elasticities and Discussion

Following Scott(2013), we compute a long-run elasticity with respect to prices as follows[1]:

$$\epsilon_{\delta,P_i} = [\delta^*(R_t)]^{-1}[\delta^*(R_{t'}) - \delta^*(R_t)]\frac{P_{it}}{P_{it'} - P_{it}} \tag{5-1}$$

$$\epsilon_{A,P_i} = [A^*(R_t)]^{-1}[A^*(R_{t'}) - A^*(R_t)]\frac{P_{it}}{P_{it'} - P_{it}} \tag{5-2}$$

Where,

$$R_t = \{\mathbf{P_t}, \Omega(\boldsymbol{\delta}^*)\} \tag{5-3}$$

$$R_{t'} = \{\mathbf{P'_t}, \Omega(\boldsymbol{\delta}^*)\} \tag{5-4}$$

$$A_t = X_t * \delta_t \tag{5-5}$$

[1] Scott (2013) computes long-run Acreage-price elasticities of a group of crops.

The results we present in this section are computed in order to provide a comparison with Scott (2013). However, the shock we use to compute our elasticities is not the same, as our goal is to show that the source of the price shock matters. Scott (2013) computes elasticities with respect to a long-run increase in prices of all products in a set whereas, we compute elasticities with respect to a long-run increase in the average price received by a landowner that cultivates a positive share of both soybeans and corn[2], generated by a shock in only one of the two prices. We evaluate two cases: one where the change in the average price is induced by a shock in the price for soybeans and another where it is induced by a shock in the price for corn. Note that our long-run total cropland acreage[3] elasticity with respect to the average price increase[4] provides a very similar result compared to Scott (2013)'s (table 5) when the price increase originates in the soybeans market (Acreage-Price Elasticity (1)). However, if the price shock originates in the corn market (2), the effect on the total cultivated area is much smaller. Therefore, if we only evaluate the effect of a shock impacting all crop prices homogeneously, we can't see that the source of the price shock matters. In both calculations the average price increase for the soybeans and corn producing landowner is the same but, as relative prices between crops change, the incentive to increase cropland area also changes and, we can't capture this nuance with a homogeneous price shock. Additionally, if we limit ourselves to this aggregated analysis, we are not able to see that important nuances may occur in the distribution of cropland area between crops. In the next section we will show that the effects of a single price increase can generate more complex results than an overall increase in crop production. Changes in relative prices or relative productivity between crops produce interesting results when we account for dynamic interdependencies in productivity. Cropland area is reallocated between different crops in order to increase productivity and benefit further from the price changes and this cropland reallocation is crucial to understanding consequences at the level of each specific market.

Therefore, we chose to evaluate 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

[2]We use the mean values of each share.

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

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

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.

Table 5.1: Comparison Between Long-Run Acreage Elasticities with Respect to Average Price

	Acreage-Price Elasticities		Acreage-Price Elasticities (Scott (2013)[5])
	Dynamic Model	Static Model	Dynamic Model
Acreage-Price Elasticity (1)	0,396	0,735	0,379
Acreage-Price Elasticity (2)	0,033	0,000	0,379

6 Counterfactual Analysis

6.1 Context

We want to know how the supply of agricultural products responds to shocks with precision and, there are different types of shock we may be interested in. For example, we might want to know the impact of biofuel policies over food prices. As discussed in section 1, there is a recent debate about the magnitude of the impact of such policies on crop supply and, by extension, on deforestation and food prices. This debate in composed of different perspectives on how to measure supply elasticities. In the following subsection, we argue that it is extremely important that we also consider cross-price elasticities when analysing this type of policy.

There are many ways that we can justify our interest in a more precise estimation of the supply of specific crops. One of which is the booming demand for soybeans, unlike for any other crop, lead by consumption in China (see figure 6.1). This is another factor that can justify an expectation of sustained pressure on soybeans' prices.

In the next subsection we also analyse the effects of productivity shocks. This is particularly relevant in Brazil, as corn productivity is notably lower than in the US. A productivity shock driven, for example, by an improvement of transportation logistics could change incentives to produce corn versus other products. As we will see in the following subsection, even an increase in productivity of equal magnitude for corn and soybeans, could benefit corn production, if large enough. This type of counterfactual is useful to predict the effects of the construction of the road BR-163, connecting Brazil's largest producing states to its northern and southern harbours. This project is expected to increase productivity of Brazilian agriculture and affect corn exports most[1].

[1]Source: Conab - *"Corredores de Escoamento da Produção Agrícola"*

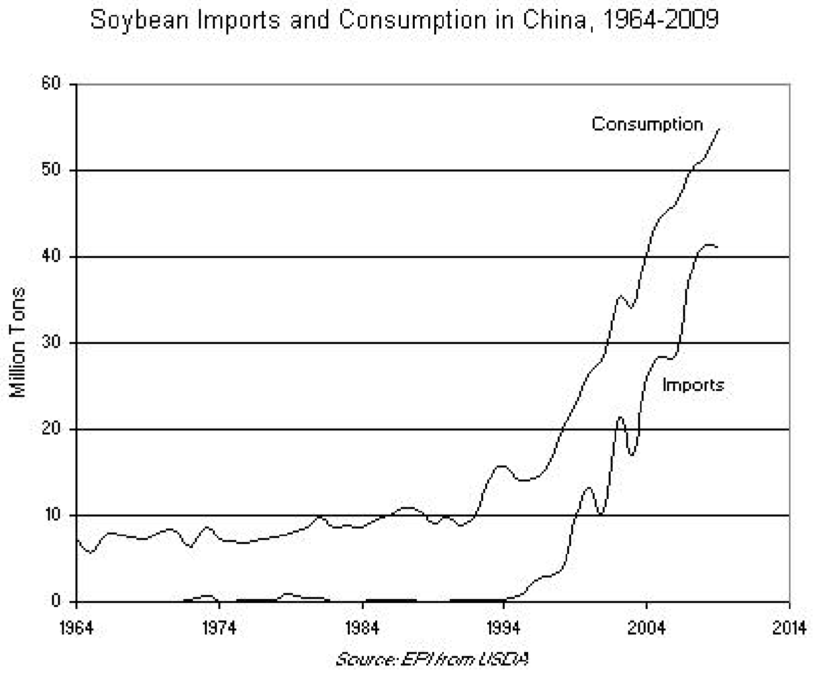


Figure 6.1: Chinese Soybeans Imports and Consumption

6.2 Results

In this section, we compare each model's predictions about cropland shares and area in an illustrative manner. In figures 6.2 and 6.3 we present both models' predictions about the effect of a long-run price shock due to an increased demand for soybeans, simulating the effect of biodiesel mandates. For the static model, we assume the absence of dynamic effects and of simultaneous productivity spillovers. Then, our static model's productivity function would be one that accounts only for increasing or decreasing returns to scale:

$$\Omega_{it} = \overline{\Omega_i} + \gamma_{i0} * \delta_{it} + \varepsilon_{it} \tag{6-1}$$

These simulations show that farmers reallocate cropland area between two or more products when there is an expected permanent change in prices[2]. 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

[2]Both simulations start with prices and costs set at their average levels in the data. Graphics show each models' predictions about the equilibrium size of the cropland (X^*) and shares of each product cultivated ($\boldsymbol{\delta}^*$) after a price increase of 30% for each crop.

an incentive to increase the share of the cropland cultivated with corn. When we do not account for this type of mechanism, as in figure 6.3, we get that the crop choice is exclusively driven by price incentives and that farmers will reduce the share of the cropland cultivated with corn and augment the share 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 6.4 we can see that, although the share 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 6.4 shows that, not only will the area cultivated with corn increase but, it will do so more than for soybeans.

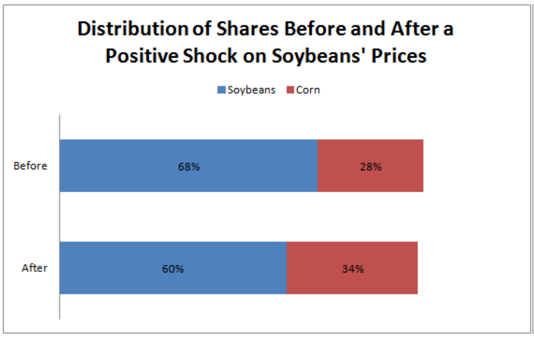


Figure 6.2: Dynamic Model

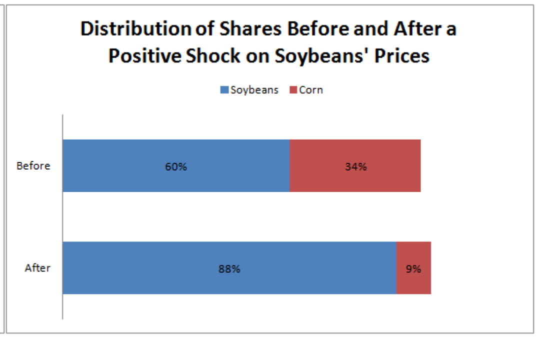


Figure 6.3: Static Model

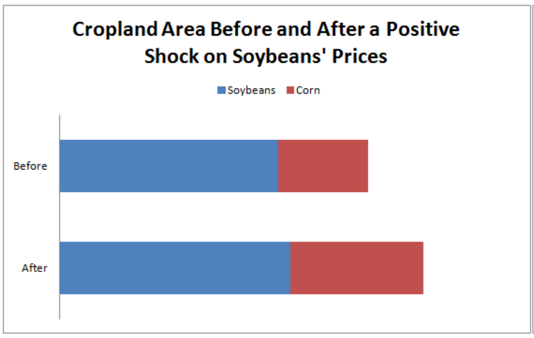


Figure 6.4: Dynamic Model

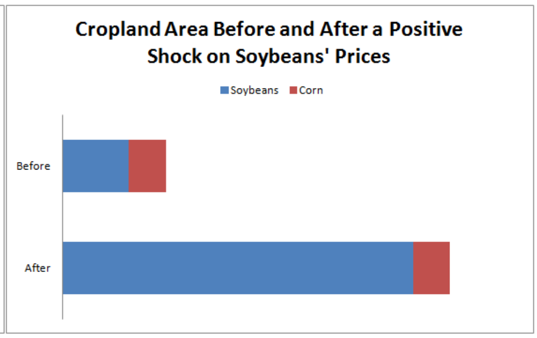


Figure 6.5: Static Model

In sum, an increase in one of the crops' price creates an incentive to cultivate a smaller share of that crop and larger share of the other crop, as we can see that the share-price elasticities are negative and the cross-price elasticities of shares are positive for both products. This is a direct consequence of the dynamic interdependencies in the productivity functions shown in the previous section. The second important observation about these results is that they are not perfectly symmetric. Although share elasticities with respect to each price change have nearly opposite effects, area elasticities do not. That happens because an increase in soybeans' prices does not generate the same incentive to increase cropland area as an increase in corn prices. That is a consequence of the relative importance of each crop in production, soybeans being the main product and corn being the secondary product. In sum, it absolutely matters where the price shock is coming from, when evaluating policy impacts. Scott (2013) computes elasticities with respect to an average price change in crop prices, assuming that prices would increase homogeneously. However, it is more likely that policies will not directly affect markets homogeneously and, as we saw on table 6.1, the source of the price shock matters not only to the magnitude of the total effect on cultivated area but, to specific market effects.

Unlike a positive price shock, a positive productivity shock on corn production has a positive effect on corn share and a negative effect o soybeans' share which corroborates with the expected effect of the BR-163 project. However, this project would actually benefit both crops' productivity equally, once they are transported in the same manner for exportation. So, in the last two columns of tables 6.1 and 6.2, we compute the elasticities with respect to an equal productivity increase for both products. As we can see on each table, the effect is discontinuous: if the productivity shock is small, it will benefit soybeans' production whereas, if it is large[3], it will benefit corn production. This makes sense when we take into account the fact that soybeans are more lucrative than corn in Brazil. Therefore, the corn productivity increase would only be fruitful to corn production if it were large enough for productivity to reach a certain threshold.

Lastly, the dynamic and static models systematically differ in their prediction of the impact of price and productivity shocks on the landowner's decision to increase the cultivated area. As figures 6.4 and 6.5 show, a positive shock on soybeans' price has a much larger impact on X^*, the equilibrium cropland area, if we consider the static model to be the correct one. This choice of model is extremely important if we are trying to predict environmental impacts of such policies. If we assume that cropland area expansion is done by turning forests into agricultural land then, our dynamic model has a far more optimistic prediction about the impact of biodiesel mandates on deforestation when compared to our static model. Crop rotation creates a trade-off between price-driven profit and productivity-driven profit. In the absence of crop rotation, farmers have no other choice but to increase cultivated area to increase profits, assuming they are already exploring their best alternatives a far as

[3]The "small" shock corresponds to an increase of up to 3 times the values of $\bar{\Omega}_s$ and $\bar{\Omega}_c$. The "large" shock corresponds to an increase of more than 3 times the values of $\bar{\Omega}_s$ and $\bar{\Omega}_c$.

pesticides and fertilizers to maximize productivity. Crop rotation provides an alternative to increasing cropland area by introducing the possibility of profit gains through a more efficient allocation of cropland are between cultivated products. As expanding the agricultural land comes at a cost, crop rotation reduces the incentive to deforest and the potential environmental cost policies that stimulate the demand for crops.

Table 6.1: Elasticities of Share and Area for Dynamic Model

		Type of Shock					
		Price of			Productivity of		
		Soybeans	Corn		Corn	Both_<3fold	Both_>3fold
Share	Soybeans	-0,403	0,079	x	-0,045	0,012	-0,046
	Corn	0,811	-0,177	x	0,091	-0,026	0,065
Area	Soybeans	0,178	0,191	x	0,020	0,029	0,018
	Corn	1,632	-0,073	x	0,184	-0,011	0,163

Table 6.2: Elasticities of Share and Area for Static Model

		Type of Shock					
		Price of			Productivity of		
		Soybeans	Corn		Corn	Both_<3fold	Both_>3fold
Share	Soybeans	0,188	0	x	-0,134	-0,101	0,063
	Corn	-0,294	0	x	0,409	0,186	0,132
Area	Soybeans	1,732	0	x	1,109	4,961	7,276
	Corn	-0,017	0	x	1,316	8,885	9,875

7
Conclusion

This work contributes to the debate around the implications of agricultural and environmental policies on crop supply and deforestation. By adding the crop choice dynamics into the farmer's problem, we are able to separate short-run variations from long-run variations in cropland area for each product as well as in the overall cultivated area. Therefore, we are able simulate the effects of long-run price shocks as well as productivity shocks to predict the effects of known policies, for the municipalities in the data. The counterfactual results reveal that there are important interdependencies between crop markets and that indirect effects are crucial to predict a policy results with accuracy. Our model generates important differences in the magnitude of the long-run acreage equilibrium effects estimated in agricultural markets when compared with static models. Indeed, as previously elaborated, there are strong reasons to think that the short-run and the long-run price elasticities of cultivated area are very 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. While we do find effects for an average increase in crop prices similar to the existing literature, as we decompose those effects, we discover that indirect effects can be even more important than direct effects and identifying which crop receives the initial shock matters. Indeed, we found that cross-price effects can supplant own-price effects and that these effects are not symmetric between soybeans and corn markets. As our counterfactual results show, an equal price shock applied to soybeans' price will not reach the same results as one applied to corn price. Not only is the total effect on cultivated area of different magnitudes but, the reallocation of the area between crops follows different patterns. Therefore, it is essential, when evaluating agricultural policies, to identify the directly affected market and the indirectly affected ones even if we are only interested in the total impact on cultivated area and chose to ignore consequences in specific markets. Finally, we have shown that our dynamic model has an optimistic prediction about the impact of biofuel mandates on the environment. Indeed, crop rotation must be taken into account when measuring the potential impacts of agricultural and energy policies on deforestation as it directly affects farmers' incentive to expand the agricultural land.

A
Appendices

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

$$\boldsymbol{\delta}_m = \sum_{i=1}^{K} \delta_k * \sigma_k \tag{A-1}$$

for each municipality m containing K farms with relative size:

$$\sigma_k = \frac{X_k}{\sum_{i=1}^{K} X_m} \tag{A-2}$$

First of all, we 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:

$$\begin{aligned}
\Pi_t^{cp} &= \delta_{mst} * X_m(\bar{\Omega}_s + \gamma_{s's} * \delta_{mst-1} + \gamma_{s'mc} * \delta_{mct-1} + \gamma_{ss} * \delta_{mst} + \gamma_{sm} * \delta_{mct}) + \\
&+ \delta_{mct} * X_c(\bar{\Omega}_c + \gamma_{c'c} * \delta_{mct-1} + \gamma_{c's} * \delta_{mst-1} + \gamma_{cc} * \delta_{mct} + \gamma_{cs} * \delta_{mst}) - \\
&- \delta_{mst} * X_m * C_{st} - \delta_{mct} * X_c * C_{mt}
\end{aligned} \tag{A-3}$$

Substituting equation (A-1) in (A-3):

$$\begin{aligned}
\Pi_t^{cp} &= \sum_k \delta_{kst} * \sigma_k * X_m(\bar{\Omega}_s + \gamma_{s's} * (\sum_k \delta_{kst-1} * \sigma_k) + \gamma_{s'm} * (\sum_k \delta_{kct-1} * \sigma_k) \\
&+ \gamma_{ss} * (\sum_k \delta_{kst} * \sigma_k) + \gamma_{sc} * (\sum_k \delta_{kct} * \sigma_k) + \sum_k \delta_{kct} * \sigma_k * X_c(\bar{\Omega}_c + \\
&+ \gamma_{c'c} * (\sum_k \delta_{kct-1} * \sigma_k) + \gamma_{c's} * (\sum_k \delta_{kst-1} * \sigma_k) + \gamma_{cc} * (\sum_k \delta_{kct} * \sigma_k) + \\
&+ \gamma_{cs} * (\sum_k \delta_{kst} * \sigma_k) - \sum_k \delta_{kst} * \sigma_k * X_m * C_{st} - \sum_k \delta_{kct} * \sigma_k * X_c * C_{mt}
\end{aligned} \tag{A-4}$$

$$
\begin{aligned}
\Pi_t^{cp} &= \bar{\Omega}_s * X_m * \sum_k \delta_{kst}\sigma_k + \gamma s's * X_m(\sum_k [\delta_{kst} * \delta_{kst-1} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jst-1}\sigma_i\sigma_j + \\
&+ \sum_j \sum_i \delta_{jst}\delta_{ist-1}\sigma_i\sigma_j) + \gamma s'c * X_m(\sum_k [\delta_{kst} * \delta_{kct-1} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jct-1}\sigma_i\sigma_j + \\
&+ \sum_j \sum_i \delta_{jst}\delta_{ict-1}\sigma_i\sigma_j) + \gamma ss * X_m(\sum_k [\delta_{kst} * \delta_{kst} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jst}\sigma_i\sigma_j + \\
&+ \sum_j \sum_i \delta_{jst}\delta_{ist}\sigma_i\sigma_j) + \gamma sc * X_m(\sum_k [\delta_{kst} * \delta_{kct} * \sigma_k^2] + \sum_i \sum_j \delta_{ist}\delta_{jct}\sigma_i\sigma_j + \\
&+ \sum_j \sum_i \delta_{jst}\delta_{ict}\sigma_i\sigma_j) + \bar{\Omega}_c * X_m * \sum_k \delta_{kct}\sigma_k + \gamma c'c * X_m(\sum_k [\delta_{kct} * \delta_{kct-1} * \sigma_k^2] + \\
&+ \sum_i \sum_j \delta_{ict}\delta_{jct-1}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ict-1}\sigma_i\sigma_j) + \gamma c's * X_m(\sum_k [\delta_{kct} * \delta_{kst-1} * \sigma_k^2] + \\
&+ \sum_i \sum_j \delta_{ict}\delta_{jst-1}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ist-1}\sigma_i\sigma_j) + \gamma cc * X_m(\sum_k [\delta_{kct} * \delta_{kct} * \sigma_k^2] + \\
&+ \sum_i \sum_j \delta_{ict}\delta_{jct}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ict}\sigma_i\sigma_j) + \gamma cs * X_m(\sum_k [\delta_{kct} * \delta_{kst} * \sigma_k^2] + \\
&+ \sum_i \sum_j \delta_{ict}\delta_{jst}\sigma_i\sigma_j + \sum_j \sum_i \delta_{jct}\delta_{ist}\sigma_i\sigma_j) \qquad \text{(A-5)}
\end{aligned}
$$

If Assumption A.1 is valid then, the terms with double sums in equation (A-5) 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 shares and vice versa (A.3).

Bibliography

ARIMA, E.; RICHARDS, P.; WALKER, R. ; CALDAS, M.. **Statistical confirmation of indirect land use change in the brazilian amazon**. *Environmental Research Letters*, 6(2), 2011.

BAJARI, P.; BENKARD, C. L. ; LEVIN, J.. **Estimating dynamic models of imperfect competition**. *Econometrica*, 75(5):1331–1370, 09 2007.

DOOLE, G. J.; HERTZLER, G.. **Optimal Dynamic Management of Agricultural Land-Uses: An Application of Regime Switching**. *Journal of Agricultural and Applied Economics*, 43(01), February 2011.

FEZZI, C.; BATEMAN, I. J.. **Structural Agricultural Land Use Modeling for Spatial Agro-Environmental Policy Analysis**. *American Journal of Agricultural Economics*, 93(4):1168–1188, 2011.

IRWIN, E. G.. **Interacting agents, spatial externalities and the evolution of residential land use patterns**. *Journal of Economic Geography*, 2(1):31–54, January 2002.

LUBOWSKI, R. N.; PLANTINGA, A. J. ; STAVINS, R. N.. **Land-Use Change and Carbon Sinks: Econometric Estimation of the Carbon Sequestration Supply Function**. Working paper 225, Regulation2point0, Jan. 2005.

RICHARDS, P. D.. **Food, fuel, and the hidden margins of capital**. *Journal of Land Use Science*, 7(3):289–310, 2012.

ROBERTS, M. J.; SCHLENKER, W.. **Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate**. *American Economic Review*, 103(6):2265–95, October 2013.

LIVINGSTON, M.; ROBERTS, M. J. ; RUST, J. P.. **Optimal corn and soybean rotations**. 2008 Annual Meeting, July 27-29, 2008, Orlando, Florida 6213, American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association), 2008.

SCOTT, P. T.. **Dynamic discrete choice estimation of agricultural land use**. *Working Paper.*, 12 2013.

JI, Y.; RABOTYAGOV, S. ; KLING, C. L.. **Crop Choice and Rotational Effects: A Dynamic Model of Land Use in Iowa in Recent Years**. Technical report, 2014.

RODRIGUES, E. D. S.. **Demand for deforestation in the amazon**. *Working Paper.*, 2012.

VANCE, C.; GEOGHEGAN, J.. **Temporal and spatial modelling of tropical deforestation: a survival analysis linking satellite and household survey data**. *Agricultural Economics*, 27(3):317–332, November 2002.