Spatial analysis of agricultural supply response in the Brazilian Center-West

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Abstract

A.M.R. Figueiredo, S.C.M. Bonjour, E.C. Teixeira, and S.M. Helfand. 2011. Spatial analysis of agricultural supply response in the Brazilian Center-West. This study investigates the importance of spatial dependence and inter-relations due to geographic localization over the supply response to agricultural prices, in the Brazilian Center-West. Specifically, we evaluated: the spatial error dependence in the input demand and output supply; and, the importance of input and output prices in farmers response. The contribution to the literature is to combine a translog profit share system of equations with spatial error dependence, cross-sectional and four agricultural censuses. There are econometric evidences of spatial dependencies in the residuals. There were high positive spatial autocorrelation in products. This demonstrates an influence of other factors not included in the model, modifying the residuals only due to localization. There are substitution relations mainly to rice price changes and some complementarities among others. Among factors, they were complements. The spatial effects in this study were very important, changing decisively the calculated elasticities, and showing that all analyzed products suffer from these effects.

Key words: Agriculture, Brazil, Spatial dependence, Shares, Profit.

INTRODUCTION

The Brazilian Center-West is a quite peculiar region, very heterogeneous across municipalities, with different types of land and climate. In fact, this region is a prominent agricultural producer of cash crops and animal products. In this environment, the influence of proximity from one farmer to another is seen as a spatial effect or dependence (Anselin, 1988), and our study questioned how important are these spatial effects to explain agricultural supply response in the Brazilian Center-West?

Some papers tried to understand agricultural supply response (Sckokai and Moro, 1996; Zaloshnja, 1997), using different methods regarding the functional form and types of data (cross-section, time series or pooled), but worried about input and output relationship, disregarding locational issues.

Lambert and Griffin (2004) used duality share equations with spatial components but their system was derived from a translog cost function. The translog functional form gives more flexibility in terms of variable elasticities of substitution among inputs and outputs (Greene, 2008).

The work of Fezzi and Bateman (2009) estimated a profit shares system for England's agriculture with spatial autocorrelation in the residuals, though there is little reference regarding the spatial contiguity matrix or the resulting spatial error dependence.

Chakir (2007) used a cross entropy analysis applied to the European Union agriculture to investigate land use determinants. One of his conclusions is that the model should incorporate spatial autocorrelation in order to be "more precise".

Other applications to agriculture include panel data techniques to evaluate the spatial dependence which required a time series and cross-sectional set of information. A recent discussion can be obtained at Kapoor *et al*. (2007), Baltagi *et al*. (2007). In our case, there are only four agricultural censuses which reduce the panel data techniques efficiency. Those papers mainly focused one single equation with time periods and regions, like Almeida (2005) and Delbecq *et al*. (2009).

This paper differs in such a way that we used a translog profit shares system incorporating the spatial error dependence, with county level census data and four censuses years. The dual system of profit shares helped analyzing a multi-output-multi-input model; and the spatial model corrects for spatial dependence in the errors. So, this paper differs conciliates duality theory in profit functions with spatial econometric theory.

The main goal of this paper is to investigate the importance of space over agricultural supply response to price changes in the Brazilian Center-West (CW). In this sense, we used four censuses data for the period 1975 to 1995, with a multiple output-multiple input model. Specifically, we evaluate: a) the spatial error dependence in the input demand and output supply; b) the importance of input and output prices in farmers response.

In Section 2, we review some duality characteristics of the profit function and the spatial econometric theory. The analytical model and data are presented in Section 3. The results are analyzed in Section 4 and the conclusions at the end.

MATERIALS AND METHODS

Profit theory

In this paper, we used the translog functional form presented by Christensen *et al*. (1973), which allows different degrees of substitutability. The maximization of the translog profit (π) function gives an indirect profit function and optimal solutions in terms of output and input prices:

(1) $$\pi = \beta_0 + \beta_1\, d + \tfrac{1}{2}\, d'\beta_2\, d$$

where *β's* are the parameters; and *d* is a vector [(*m* + *n* + *v*)*694 x 1] of *n* variable input prices (*w*), *m* output prices (*p*) and *v* fixed factors (*z*) (all variables in logs), for 694 municipalities in the four censuses. Using Hotelling´s Lemma (Mas-Colell *et al*., 1995) we have a profit shares (*S*) system as functions of *p*, *w* and *z* as follows:

(2) $$\frac{\partial \pi}{\partial p_i} \equiv \frac{p_i q_i^*}{\pi^*} \equiv S_i^* = \beta_i + \sum_{j=1}^{m} \beta_{ij}\, p_j + \sum_{h=1}^{n} \beta_{ih}\, w_h + \sum_{g=1}^{v} \beta_{ig}\, z_g \qquad \forall i = 1,\ldots,m$$

(3) $$\frac{\partial \pi}{\partial w_h} \equiv -\frac{w_h x_h^*}{\pi^*} \equiv -S_h^* = \beta_h + \sum_{j=1}^{m} \beta_{hj}\, p_j + \sum_{k=1}^{n} \beta_{hk}\, w_k + \sum_{g=1}^{v} \beta_{hg}\, z_g \qquad \forall h = 1,\ldots,n$$

Partial elasticities of substitution between the i[th] and j[th] product ($\hat{\eta}_{ij}$), or h[th] and k[th] input ($\hat{\eta}_{hk}$), can be expressed in terms of the estimated profit shares ($\hat{s}$):

(4) $$\hat{\eta}_{ij} = \frac{\hat{\beta}_{ij}}{\hat{S}_i} + \hat{S}_j \quad \text{and} \quad \hat{\eta}_{ii} = \frac{\hat{\beta}_{ii}}{\hat{S}_i} + \hat{S}_i - 1 \qquad \text{(Products)}$$

(5) $\hat{\eta}_{hk} = -\frac{\hat{\beta}_{hk}}{\hat{S}_h} - \hat{S}_k$ and $\hat{\eta}_{hh} = -\frac{\hat{\beta}_{hh}}{\hat{S}_h} - \hat{S}_h - 1$ (Inputs)

Once there is a share system of equations derived from a common profit function, the applied literature recommends the SUR (Seemingly unrelated regressions) estimator for the system of (2) and (3), constrained by the homogeneity and symmetry properties of the profit function (Greene, 2008). In this system, spatial dependence present in geographically disposed data is not specified as a particular function, but left as any non-specified covariance. This may result in non-spherical disturbances[1] due to spatial autocorrelation. The spatial econometrics avoids this limitation considering a spatial weighting matrix as described in the following.

The method and data

In this paper, the spatial effect is modeled with a weighting matrix, with one line and one column for each municipality, and the observation related to municipalities *r* and *s* will have a different weight if the municipality *r* is neighbor of *s*. It is common to have binary matrices with one for neighbors and zero otherwise.

Our model assumes that there are spatial effects due to non-specified variables in other municipalities (neighbors). These effects will show up in the residuals of the model as spatial autocorrelations. This regression model is called *spatial error dependent regression*.

Here, we adapt Anselin (1988a) SUR estimators for a system of equations adding a spatial error dependence component, called Spatial SUR (SSUR). The model SSUR implies a spatial autocorrelation, which differs from cross-section's heteroskedasticity and from time series autocorrelation as we have an explicit spatial weighting for neighbors.

[1]"*Disturbances that meet the twin assumptions of homoscedasticity and nonautocorrelation are sometimes called spherical disturbances*" (Greene, 2008).

The SSUR model is a system of *M* profit shares equations estimated with cross-section and time series data for *N* municipalities and four censuses, testing for spatially auto correlated errors. For *T* observations, the system can be expressed in the stacked form:

(6) $\mathrm{Y} = \mathrm{X}\beta + \varepsilon$ with $\varepsilon = \lambda \mathrm{W}\, \varepsilon + \mu$

where $Y \equiv [y_1' \, y_2' \ldots y_M']'$, whose elements are vectors T x 1 for each system equation; X is a block-diagonal matrix of explanatory variables; $\beta \equiv [\beta_0' \, \beta_1' \, \beta_2' \ldots \beta_M']'$ is the vector of parameters (β_0 is the intercept; β_M is the parameter vector of equation *M*); $\varepsilon \equiv [\varepsilon_1' \, \varepsilon_2' \ldots \varepsilon_M']'$ is a vector (*T.M* x 1) of non-spherical residuals, each element is a vector T x 1; l is a diagonal matrix (*M* x *M*) of spatial parameters, varying for each equation (outputs and inputs). The matrix W is the spatial weighting matrix for the whole set of observations, whose diagonal elements are blocks of the weighting matrix for each year, with dimensions N_c x N_c; N_c is the quantity of municipalities for census year c. Finally, m is a random vector of errors with variance-covariance matrix equal to E[μ . μ'] = Σ⊗ I.

Anselin (1988a) shows the estimators for a system of cross-section and time series for a single equation model, from a loglikelihood maximatization like.

$$L = -\tfrac{T}{2} \ln \Sigma + \sum_i \ln I - \lambda_i W - \tfrac{1}{2}(Y - X\beta)' [I - (\Lambda \otimes W')][\Sigma^{-1} \otimes I][I - (\Lambda \otimes W)](Y - X\beta)$$

The estimated parameters will be as expression (7):

(7) $$\hat{\beta} = \{X'[I - (\Lambda \otimes W')][\Sigma^{-1} \otimes I][I - (\Lambda \otimes W)]X\}^{-1} X'[I - (\Lambda \otimes W')][\Sigma^{-1} \otimes I][I - (\Lambda \otimes W)]Y$$

and $\Sigma = \frac{1}{N} Z'Z$ where *Z* is a matriz of spatially transformed residuals of dimensions T x M, $Z = [z_1, z_2, \ldots, z_M]$, where $z_M = (l - \lambda_M W)e_M = e_M - \lambda_M W e_M$; $e_M = y_M - X_M b_M$; M is the product or input share equation.

In order to test the presence of spatial dependence, Anselin (1988b) presented a Lagrange Multiplier (LM) test where the null hypothesis is H_0: $\lambda = 0$, λ is the spatial error parameter vector (M x 1) of all different λ_M. The test statistic for the error dependence across equations is

$$(8) \quad LM_{SUR} = \iota'\left(\Sigma^{-1} * U'WU\right)\left[T_2.I + T_1 * \Sigma^{-1} * \Sigma\right]^{-1}\left(\Sigma^{-1} * U'WU\right)'\iota$$

where i is a vector (M-1) x 1 of ones; U is a T x (M-1) matrix of residuals; T_2 is a diagonal matrix (M-1) x (M-1) whose elements are trace of W^2; T_1 is a symmetric matrix (M-1) x (M-1) whose elements are trace of ($W'W$); and * corresponds to the Hadamard product. The LM_{SUR} statistic will follow a χ^2 distribution with (M-1) degrees of freedom. The test is conducted with the SUR residuals without spatial error dependence in order to verify or not the spatial dependence[2].

The share system of (2) and (3) is applied to six products (rice, edible beans, corn, soybeans, bovine cattle and milk), four variable inputs (rented land; hired labor; fuel; and fertilizers) and four fixed factors (family labor, disposable owned land, tractors and livestock). The multi-equation (i^{th} product and h^{th} input shares) spatial system is:

$$(9) \qquad S_i = \beta_i + \sum_{j=1}^{m} \beta_j \tilde{p}_j + \sum_{h=1}^{n} \beta_h \tilde{w}_h + \sum_{g=1}^{v} \beta_g \tilde{z}_g + \varepsilon_i$$

$$(10) \qquad -S_h = \beta_h + \sum_{j=1}^{m} \beta_h \tilde{p}_j + \sum_{k=1}^{n} \beta_k \tilde{w}_k + \sum_{g=1}^{v} \beta_g \tilde{z}_g + \varepsilon_h$$

[2] As all variables are distributed in time, we omitted the time subscript (t). We also tested for spatial lag and the spatial Durbin dependence, the results indicated for just spatial error dependence, which is conducted in the paper.

$$(11) \qquad \begin{bmatrix} \varepsilon_i \\ \varepsilon_h \end{bmatrix} = \begin{bmatrix} \lambda_i W \varepsilon_i + \mu_i \\ \lambda_h W \varepsilon_h + \mu_h \end{bmatrix} \qquad \begin{matrix} \forall i = 1,\ldots,m \\ \forall h = 1,\ldots,n \end{matrix}$$

where l's are the spatial error parameters ((m + n - 1) x 1), one to each output and input equation, but contemporaneouslly constant among observations; μ_i and μ_h are gaussian residuals; ε_i and ε_h are disturbances capturing the spatial dependence. The role model has 169 parameters (99 were estimated and the others are obtained through simmetry and homogeneity imposed assumptions). The spatial weighting matrix (W) is constant across equations, with dimensions 694 x 694 with a diagonal of zeros and off-diagonal elements are ones for common-border counties and zero otherwise. The W matrix rows were normalized to sum one. To satisfy the translog profit function properties, we imposed homogeneity in prices.

The Iterative Spatial SUR (SSUR) model was estimated with nine share equations after imposing symmetry and homogeneity in the parameters. The fertilizer's equation parameters were obtained residually from homogeneity and symmetry profit function's conditions.

The Spatial SUR estimation followed Anselin (1988a) and Elhorst (2003) with an iterative procedure between equation parameter and variance-covariance estimates, on one hand, and the spatial parameter estimates, on the other, until convergence. Oberhoffer and Kmenta (1974) cited by Anselin (1988a) showed that this Iterative Generalized Least Squares converge to a local maximum and that these estimators will be the same as from Maximum Likelihood methods.

Data characteristics

We used four agricultural censuses data from the Brazilian Institute of Geography and Economy, IBGE, aggregated in Comparable Areas (CA) for 1975, 1980, 1985 and 1995. We used municipal data for the three states in the Center-West of Brazil: South Mato Grosso (MS), Mato Grosso (MT) and Goias (GO).

Prices were obtained from value of production and quantities for each product and for each CA. Hired labor prices were calculated from wages expenditures divided by the number of permanent and temporary hired labor. Rented land prices were calculated similarly to the labor prices, as rented land expenditures divided by respective areas. Fuel prices proxies were obtained dividing fuel expenditures by quantity of diesel used. For fertilizers, we used state prices from Getulio Vargas Foundation (FGV).

The quantities of family labor were weighted to compensate for adult and child labor similarly to Zaloshnja (1997) and Sckokai and Moro (1996). The disposable owned land is the disposable land stock, excluding unusable land, but including non-utilized areas. The number of tractors was obtained as an aggregation of different horsepower (HP) tracts, using the average HP to obtain the number of tractors in HP units. For livestock, different aged animals are aggregated in animal units (450 kg each animal unit). Profit shares were obtained from production and expenditures censuses reported values, with positive shares for products and negative for inputs.

All values were real values of December 2000, converted using FGV's general price index (IGP-DI). The sample had 694 useful observations (157 for 1975, 179 for 1980, 214 for 1985 and 144 for 1995). An additive trend variable was used to investigate time effects.

RESULTS AND DISCUSSION

The spatial dependence test was conducted using residuals (*e*) from a SUR estimation without spatial error dependence, and the spatial weighting matrix. We built a weighting matrix for each year and then used these matrices as the diagonal of a 694-dimension spatial weighting matrix (*W*). The spatial error dependence test in the SUR model was done with the LM statistic of (8), equal to $LM = 352.31$, distributed as a qui-squared, nine degrees of freedom, significant at 1% (p-value=0.000) meaning we could not accept the hypothesis that the spatial parameters were jointly zero (H0: $\lambda_i = 0$ for all i).

The SSUR results for prices are in Table 1 and for fixed factors in Table 2. Setting aside the intercept and trend, the estimates are in general (59%) statistically significant[3]. The fixed factors parameters were mostly (72%) statistically significant showing fixed factors' importance in supply response.

As noted by Tomek (1973), this type of estimation cannot use traditional R^2 measures and its adequacy should be based on the parameters' significance and the confirmation of monotonicity and convexity properties of the profit function. Monotonicity was observed with estimated shares (positive for products and negative for factors), while convexity was checked in the positive semidefinite Hessian matrix. They were violated only locally for rice and soybeans on average, though for only one year for soybeans. This is a common result on translog functions and we looked for average and median estimates (Table 2).

The spatial parameters (λ) were mostly high and close to unity, indicating positive and almost perfect spatial autocorrelation, as observed in Table 3. Delbecq *et al*. (2009) cited Lowenberg-DeBoer *et al.* (2006) and argued that in agriculture "*it is not uncommon to observe levels of spatial autocorrelation as high as 0.8 or even*

[3] In all cases we searched for at least 90% of confidence level. The reader may look the reported p-values directly in the presented tables.

Table 1. Profit Shares system parameters estimated using the SSUR Method, Brazil, Center-West, 1975-1995.

Equation	intercept	Par	Pfe	Pmi	Pso	Pbv	Ple	Pmc	Pte	Pds	Pfr	Trend
Rice	-0.003**	0.140	-0.020	-0.042	-0.013	-0.113	0.003	0.020	0.021	0.019	-0.016	1.974
	(-0.494)	(2.969)$^{+}$	(-1.611)	(-1.771)$^{+}$	(-0.601)	(-3.621)$^{+}$	(0.137)	(1.655)$^{+}$	(3.405)$^{+}$	(1.515)		(0.038)
	[0,621]	[0,003]	[0,108]	[0,077]	[0,548]	[0,000]	[0,891]	[0,099]	[0,001]	[0,130]		[0,970]
Edible Beans	0.002		0.018	-0.004	0.008	-0.006	-0.010	-0.003	0.006	0.008	0.003	-0.325
	(0.806)		(2.480)$^{+}$	(-0.405)	(1.116)	(-0.607)	(-1.070)	(-0.666)	(2.945)$^{+}$	(1.180)		(0.286)
	[0,421]		[0,013]	[0,685]	[0,265]	[0,544]	[0,285]	[0,505]	[0,003]	[0,239]		[0,775]
Corn	0.007			0.090	-0.029	-0.022	0.042	-0.005	0.000	-0.019	-0.012	-0.138
	(0.639)			(3.726)$^{+}$	(-1.795)$^{+}$	(-0.973)	(2.433)$^{+}$	(-0.423)	(0.011)	(-1.666)$^{+}$		(0.818)
	[0,523]			[0,000]	[0,073]	[0,331]	[0,015]	[0,672]	[0,991]	[0,096]		[0,414]
Soybeans	-0.005				0.014	-0.002	-0.008	0.016	0.012	0.005	-0.003	-0.134
	(-0.345)				(0.568)	(-0.093)	(-0.502)	(1.361)	(2.003)$^{+}$	(0.698)		(0.416)
	[0,730]				[0,570]	[0,926]	[0,616]	[0,174]	[0,046]	[0,486]		[0,678]
Bovine	0.025					0.172	-0.110	0.041	-0.010	0.025	0.026	-0.146
	(0.725)					(3.772)$^{+}$	(-5.005)$^{+}$	(2.530)$^{+}$	(-1.286)	(2.265)$^{+}$		(0.288)
	[0,469]					[0,000]	[0,000]	[0,012]	[0,199]	[0,024]		[0,774]
Milk	0.007						0.033	0.034	-0.010	-0.005	0.031	0.286
	(0.626)			Symmetric			(1.296)	(3.631)$^{+}$	(-2.238)$^{+}$	(-0.508)		(0.334)
	[0,531]						[0,195]	[0,000]	[0,026]	[0,612]		[0,738]
Hired Labor	-0.035							-0.058	-0.007	-0.007	-0.032	-0.023
	(-0.257)							(-3.474)$^{+}$	(-1.228)	(-1.237)		(0.081)
	[0,798]							[0,001]	[0,220]	[0,217]		[0,935]
Rented Land	-0.006								-0.001	0.006	-0.017	0.007
	(-0.305)								(-0.320)	(2.279)$^{+}$		(0.657)
	[0,760]								[0,749]	[0,023]		[0,512]
Fuel	-0.175									-0.023	-0.009	-0.004
	(-1.353)									(-1.442)		(0.398)
	[0,177]									[0,150]		[0,691]
Fertilizers	1.183									-0.009	0.027	

Source: Research data. * Pi indicates prices for i = rice (ar); edible beans (fe); corn (mi); soy (so); cattle (bv); milk (le); hired labor (mc); rented land (te); fuel (ds); fertilizers (fr). ** Values between parentheses are t statistics and p-values between brackets; $^{+}$ statistically significant at 10%.

Table 2. Profit Shares System Parameters Estimated Using the SSUR Method, Brazil, Center-West, 1975-1995

Equation	Fixed Factors*			
	Lmf	Ltp	Ltr	Lbv
Rice	0.031	0.150	0.059	-0.238
	(2.911)+ **	(7.271)+	(4.971)+	(-12.106)+
	[0,004]	[0,000]	[0,000]	[0,000]
Edible Beans	0.027	0.037	-0.003	-0.063
	(8.144)+	(5.821)+	(-0.724)	(-10.206)+
	[0,000]	[0,000]	[0,469]	[0,000]
Corn	0.034	0.019	0.047	-0.102
	(3.039)+	(1.139)	(3.671)+	(-5.540)+
	[0,002]	[0,255]	[0,000]	[0,000]
Soybeans	-0.017	0.051	0.120	-0.134
	(-1.560)	(2.526)+	(9.914)+	(-6.800)+
	[0,119]	[0,012]	[0,000]	[0,000]
Bovine	-0.057	-0.164	-0.122	0.319
	(-3.979)+	(-6.782)+	(-7.464)+	(12.592)+
	[0,000]	[0,000]	[0,000]	[0,000]
Milk	0.062	-0.058	0.006	-0.017
	(7.678)+	(-4.205)+	(0.646)	(-1.176)
	[0,000]	[0,000]	[0,519]	[0,240]
Hired Labor	-0.055	0.005	-0.017	0.078
	(-5.294)+	(0.844)	(-1.383)	(5.301)+
	[0,000]	[0,399]	[0,167]	[0,000]
Rented Land	-0.017	0.009	-0.016	0.028
	(-2.865)+	(1.438)	(-2.449)+	(3.204)+
	[0,004]	[0,151]	[0,015]	[0,001]
Fuel	-0.003	-0.002	-0.028	0.032
	(-0.851)	(-1.125)	(-7.165)+	(6.420)+
	[0,395]	[0,261]	[0,000]	[0,000]
Fertilizers	-0.006	-0.046	-0.047	0.097

Source: Research data. * Fixed factors: family labor (Lmf); available owned land (Ltp); tractors (Ltr); and livestock (Lbv). ** Values between parentheses are t statistics and p-values between brackets; + statistically significant at 10%.

0.9". The (λ) values showed strong influence from non-included factors in the model, affecting the residuals exclusively by localization. The relief map, soil type, precipitation, temperature, altitude, latitude and longitude are some factors highly correlated to localization which may have caused these effects.

Table 3. Spatial parameters estimated using an iterative SSUR Method, Brazil, Center-West, 1975-1995.

	Rice	Edible Beans	Corn	Soy	Cattle	Milk	Hired Labor	Rented Land	Fuel
λ*	1.000	0.999	0.999	0.974	0.944	0.990	0.300	0.861	-0.004

Source: Research data. * λ is the spatial error autocorrelation parameter.

The hired labor spatial parameter was small (0.3), reflecting a reasonable geographical independence among neighbors to contract this factor. Only fuel showed to have no spatial autocorrelation, due to an imperfect market of distribution and marketing services, a relatively easy storage, and also to some independence from geographical factors. Rented land exhibited a high value (0.86) and can be attributed to soil and climate characteristics.

As pointed out by Fotheringham, Charlton and Brunsdon (1997) and Elhorst (2003), estimates at average points are not reliable under spatial effects, and does not show the differences among spatial units' behaviors. So, we calculated elasticities for each comparable area (CA) in order to analyze the supply response to prices and fixed factors.

We may observe the map for direct price elasticities of output supply and input demand for each year and equation (Tables 4, 5, 6). We opted here to present only maps for 1995 (Figure 1) though the analysis was conducted for each year (1975, 1980, 1985 and 1995).

Table 4. Median partial elasticities of substitution for the Brazilian Center-West, 1975-1995.

	Price Variables*									
Equation	Rice	Edible Beans	Corn	Soybeans	Bovine	Milk	Hired Labor	Rented Land	Fuel	Fertilizers
Rice	-2.315	1.163	6.403	0.090	0.859	0.295	-0.180	-0.057	-0.066	-5.966
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
Edible Beans	-1.212	0.160	6.368	0.087	0.762	0.288	-0.168	-0.037	-0.045	-5.974
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
Corn	-1.201	1.145	5.385	0.075	0.763	0.304	-0.166	-0.043	-0.062	-5.979
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
Soybeans	-1.205	1.198	6.081	-0.756	0.774	0.141^{ns}	-0.096^{ns}	0.003	-0.043^{ns}	-5.873
	[0.000]	[0.000]	[0.000]	[0.014]	[0.086]	[0.183]	[0.552]	[0.095]	[0.737]	
Bovine	-1.416	1.136	6.339	0.076	-0.003^{ns}	0.043^{ns}	-0.099	-0.060	-0.018^{ns}	-5.941
	[0.000]	[0.000]	[0.000]	[0.086]	[0.955]	[0.219]	[0.000]	[0.000]	[0.286]	
Milk	-1.195	1.129	6.470	0.036^{ns}	0.483^{ns}	-0.527^{ns}	-0.141^{ns}	-0.074	-0.075	-5.908
	[0.000]	[0.000]	[0.000]	[0.183]	[0.219]	[0.704]	[0.768]	[0.000]	[0.083]	
Hired Labor	-1.317	1.162	6.408	-0.045^{ns}	0.454	-0.014^{ns}	-0.821	-0.004^{ns}	-0.014^{ns}	-5.621
	[0.000]	[0.000]	[0.000]	[0.552]	[0.000]	[0.768]	[0.000]	[0.935]	[0.739]	
Rented Land	-1.696	0.995	6.370	-0.263	1.066	0.620	-0.022^{ns}	-1.022	-0.188	-4.966
	[0.000]	[0.000]	[0.000]	[0.095]	[0.000]	[0.000]	[0.935]	[0.000]	[0.001]	
Fuel	-1.532	0.994	6.676	-0.036^{ns}	0.215^{ns}	0.413	-0.039^{ns}	-0.163	-0.677	-5.717
	[0.000]	[0.000]	[0.000]	[0.737]	[0.286]	[0.083]	[0.739]	[0.001]	[0.013]	
Fertilizers	-1.192	1.145	6.373	0.081	0.762	0.292	-0.159	-0.040	-0.057	-6.982

Source: Research data. *P-values between brackets. ^{ns} Statistically not significant at 10%.

The Brazilian Center-West exhibited an impressive structural change in the period 1975-1995. The changes were in general related to the opening of new agricultural frontiers following a relatively clear pattern: first, farmers cultivate rice and make soil corrections so that it makes possible to introduce other activities: in some regions, soybeans, in others corn or bovine. Edible beans are more related to family and small farmers. Soybeans are more important (in the 70's and 80's) in Goias and Mato Grosso do Sul. Corn is many times an off-season crop, especially in rotation with soybeans and rice.

Looking at the median own price elasticities for output supply and input demand, we observe in Table 4 that most of them were statistically significant at the 10% level, though some were

Table 5. Median partial price-elasticities of substitution for the Brazilian Center-West, 1975 and 1980.

Year	Equation \ Prices	Rice	Edible Beans	Corn	Soybeans	Bovine	Milk	Hired Labor	Rented Land	Fuel	Fertilizers
1975	Rice	-2.155	1.170	4.215	0.242	1.006	-0.164	-0.182	-0.067	-0.060	-3.991
		[0.000]*	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Edible Beans	-1.004	0.162	4.174	0.223	0.825	-0.168	-0.154	-0.034	-0.031	-4.011
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Corn	-0.997	1.146	3.199	0.209	0.825	-0.148	-0.153	-0.039	-0.042	-4.017
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Soybeans	-1.048	1.191	3.899	-0.708	0.817	-0.208	-0.083^{ns}	0.011^{ns}	-0.015^{ns}	-4.048
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.010]	[0.119]	[0.625]	[0.700]	
	Bovine	-1.140	1.140	4.157	0.213	0.041^{ns}	-0.294	-0.103	-0.051	-0.006^{ns}	-3.974
		[0.000]	[0.000]	[0.000]	[0.000]	[0.449]	[0.000]	[0.000]	[0.000]	[0.669]	
	Milk	-1.043	1.209	3.768	0.278	1.560	-1.381	-0.374	0.034^{ns}	0.002^{ns}	-4.200
		[0.000]	[0.000]	[0.000]	[0.010]	[0.000]	[0.000]	[0.000]	[0.281]	[0.977]	
	Hired Labor	-1.104	1.169	4.225	0.127^{ns}	0.541	-0.376	-0.781	0.005^{ns}	0.005^{ns}	-3.762
		[0.000]	[0.000]	[0.000]	[0.119]	[0.000]	[0.000]	[0.000]	[0.845]	[0.845]	
	Rented Land	-1.451	0.987	4.175	-0.049^{ns}	1.087	0.096^{ns}	0.005^{ns}	-1.013	-0.191	-3.496
		[0.000]	[0.000]	[0.000]	[0.625]	[0.000]	[0.281]	[0.845]	[0.000]	[0.004]	
	Fuel	-1.404	0.916	4.620	0.116^{ns}	0.196^{ns}	-0.019^{ns}	0.003^{ns}	-0.194	-0.479^{ns}	-3.675
		[0.000]	[0.000]	[0.000]	[0.700]	[0.669]	[0.977]	[0.845]	[0.004]	[0.317]	
	Fertilizers	-0.983	1.146	4.180	0.217	0.825	-0.168	-0.144	-0.035	-0.035	-5.021
1980	Rice	-4.271	1.482	6.564	0.170	0.760	0.085	-0.139	-0.045	-0.056	-4.561
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Edible Beans	-3.241	0.487	6.548	0.171	0.721	0.079	-0.135	-0.034	-0.045	-4.563
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Corn	-3.234	1.475	5.564	0.161	0.722	0.092	-0.134	-0.038	-0.053	-4.567
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Soybeans	-3.296	1.529	6.391	-0.739	0.706	0.040^{ns}	-0.035^{ns}	0.029^{ns}	-0.020^{ns}	-4.585
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.754]	[0.684]	[0.342]	[0.721]	
	Bovine	-3.383	1.466	6.521	0.162	-0.038^{ns}	-0.073	-0.069	-0.053	-0.012^{ns}	-4.528
		[0.000]	[0.000]	[0.000]	[0.000]	[0.548]	[0.017]	[0.006]	[0.000]	[0.439]	
	Milk	-3.180	1.387	6.989	0.076^{ns}	-0.400	-0.586	0.187	-0.145	-0.101^{ns}	-4.251
		[0.000]	[0.000]	[0.000]	[0.754]	[0.017]	[0.069]	[0.014]	[0.003]	[0.365]	
	Hired Labor	-3.381	1.499	6.599	0.040^{ns}	0.356	-0.154	-0.704	0.010^{ns}	0.005^{ns}	-4.317
		[0.000]	[0.000]	[0.000]	[0.684]	[0.006]	[0.014]	[0.000]	[0.760]	[0.890]	
	Rented Land	-3.740	1.329	6.549	-0.128^{ns}	0.971	0.362	0.031^{ns}	-1.010	-0.208	-4.156
		[0.000]	[0.000]	[0.000]	[0.342]	[0.000]	[0.003]	[0.760]	[0.000]	[0.003]	
	Fuel	-3.581	1.326	6.943	0.058^{ns}	0.167^{ns}	0.193^{ns}	0.012^{ns}	-0.164	-0.595	-4.388
		[0.000]	[0.000]	[0.000]	[0.721]	[0.439]	[0.365]	[0.890]	[0.003]	[0.067]	
	Fertilizers	-3.224	1.475	6.553	0.166	0.720	0.079	-0.126	-0.034	-0.048	-5.571

Source: Research data. *P-values between brackets. ^{ns} Statistically not significant at 10%.

Table 6. Median partial price-elasticities of substitution for the Brazilian Center-West, 1985 and 1995.

Year	Equation \ Prices	Rice	Edible Beans	Corn	Soybeans	Bovine	Milk	Hired Labor	Rented Land	Fuel	Fertilizers
	Rice	-2.360	1.149	6.448	0.031	0.683	0.408	-0.180	-0.054	-0.079	-6.046
		[0.000]*	[0.000]	[0.000]	[0.097]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Edible Beans	-1.265	0.149	6.410	0.027	0.588	0.402	-0.165	-0.031	-0.057	-6.056
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Corn	-1.254	1.133	5.428	0.016	0.590	0.417	-0.164	-0.036	-0.067	-6.061
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Soybeans	-1.266	1.180	6.252	-0.761^{ns}	0.561^{ns}	0.345^{ns}	-0.072^{ns}	0.032	-0.053^{ns}	-6.100
		[0.097]	[0.000]	[0.000]	[0.812]	[0.764]	[0.998]	[0.283]	[0.060]	[0.600]	
	Bovine	-1.449	1.122	6.373	0.015^{ns}	-0.104^{ns}	0.200	-0.077	-0.055	-0.016^{ns}	-6.007
1985		[0.000]	[0.000]	[0.000]	[0.764]	[0.213]	[0.000]	[0.012]	[0.000]	[0.453]	
	Milk	-1.239	1.108	6.520	0.000^{ns}	0.315	-0.510	-0.083	-0.062	-0.077	-5.980
		[0.000]	[0.000]	[0.000]	[0.998]	[0.000]	[0.000]	[0.000]	[0.000]	[0.002]	
	Hired Labor	-1.387	1.151	6.445	-0.085^{ns}	0.282	0.204	-0.810	0.002^{ns}	-0.019^{ns}	-5.856
		[0.000]	[0.000]	[0.000]	[0.283]	[0.012]	[0.000]	[0.000]	[0.929]	[0.611]	
	Rented Land	-1.791	0.988	6.414	-0.292	0.831	0.694	0.001^{ns}	-1.007	-0.227	-5.624
		[0.000]	[0.000]	[0.000]	[0.060]	[0.000]	[0.000]	[0.929]	[0.000]	[0.002]	
	Fuel	-1.529	1.010	6.721	-0.059^{ns}	0.150^{ns}	0.491	-0.046^{ns}	-0.136	-0.702	-5.919
		[0.000]	[0.000]	[0.000]	[0.600]	[0.453]	[0.002]	[0.611]	[0.002]	[0.005]	
	Fertilizers	-1.244	1.133	6.415	0.020	0.589	0.405	-0.158	-0.033	-0.062	-7.063
	Rice	0.751	0.203	5.970	-0.548	1.403	1.393	-0.254	-0.079	-0.066	-8.766
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Edible Beans	1.571	-0.703	5.978	-0.496	1.443	1.346	-0.276	-0.065	-0.041^{ns}	-8.740
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.190]	
	Corn	1.660	0.214	5.011	-0.545	1.467	1.398	-0.266	-0.092	-0.081	-8.758
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Soybeans	1.694	0.198	6.050	-1.566	1.475	1.405	-0.296	-0.116	-0.087	-8.751
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Bovine	1.587	0.210	5.980	-0.542	0.587	1.314	-0.235	-0.099	-0.061	-8.739
1995		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Milk	1.670	0.208	6.026	-0.546	1.394	0.415	-0.241	-0.100	-0.082	-8.733
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
	Hired Labor	1.581	0.224	6.014	-0.605	1.298	1.257	-1.047	-0.067	-0.048	-8.635
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.002]	[0.022]	
	Rented Land	1.430	0.152	5.995	-0.679	1.571	1.508	-0.188	-1.080	-0.150	-8.575
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.002]	[0.000]	[0.000]	
	Fuel	1.414	0.114^{ns}	6.243	-0.606	1.145	1.452	-0.169	-0.172	-0.783	-8.635
		[0.000]	[0.190]	[0.000]	[0.000]	[0.000]	[0.000]	[0.022]	[0.000]	[0.000]	
	Fertilizers	1.669	0.214	5.997	-0.540	1.468	1.388	-0.262	-0.091	-0.077	-9.759

Source: Research data. *P-values between brackets. ^{ns} Statistically not significant at 10%.

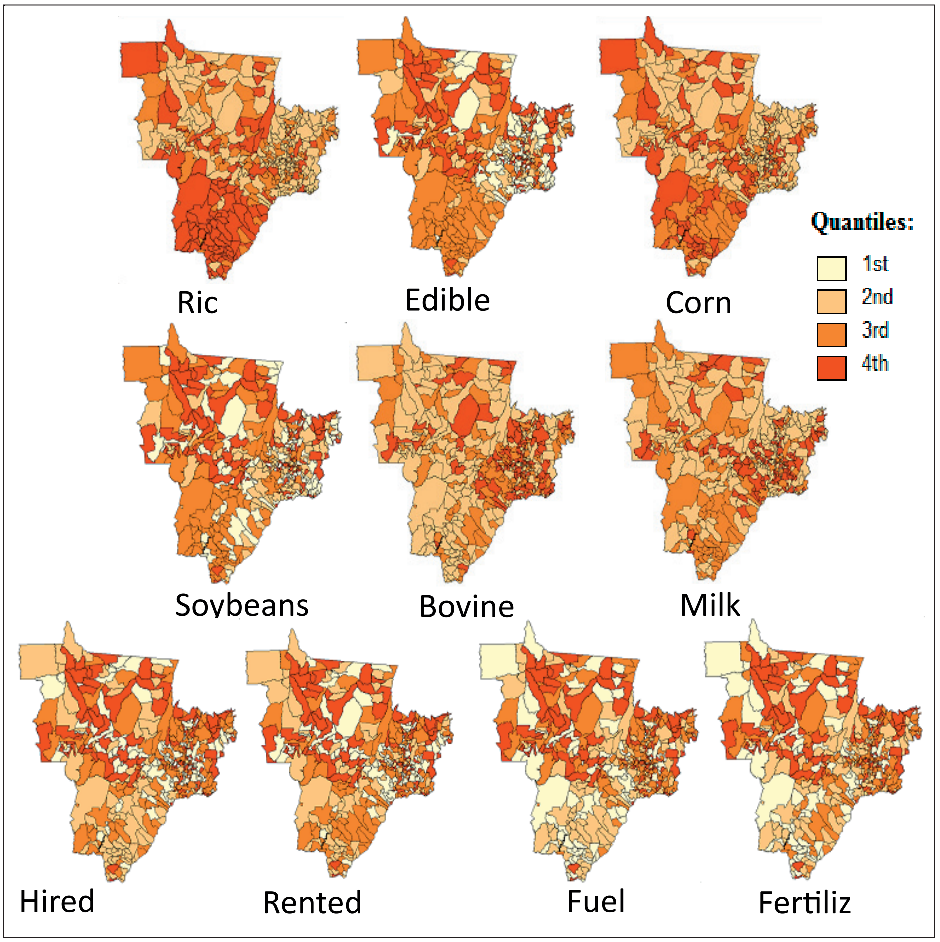

Figure 1. Own-Price Partial Output and Input Elasticities of Substitution, Brazilian Center-West, 1995.
Source: Research Results.

with wrong theoretical signs: rice and soybeans. Some were insignificant: bovine and milk. The input price demand elasticities were all significant with negative signs, as expected. Anyways, rice showed a positive price supply elasticity for 1995, when it was exhibiting a more rational production, mostly at Mato Grosso, with some industries being established.

Looking at the detailed elasticities by comparable area, we observe a change in result when the production turned out more rational and commercial, with increased production.

Edible beans had positive own price supply elasticities for 1975, 1980 and 1985, a period of more commercial production, but not in 1995, where it was restricted to small farmers. The median value for 1975-1995 was 0.16. The upper value was 0.487 in 1980. Corn had always high positive own price supply elasticities (median = 5.38), rotating with soybeans and rice, and many times as preparing for a future pasture.

For soybeans the equation was problematic with wrong theoretical signs. This is mainly to the fact that by 1975-1985 the production was not that expressive in the entire region, but specific to some localities. There was a huge increase in soybean production after 1995 and not captured in the model.

Bovine production showed not significant at most values, despite its presence in most of the municipalities. It can be attributed to small short run response, mainly related to the type of technology with large areas of pasture. The activity exhibited long cycle (about 4 years from birth to slaughter) and slow reaction to price changes. Milk had insignificant elasticity at the median of the whole period and some negative values for specific years. This is partially explained by its huge change in scale, with a markedly change in Goias and Mato Grosso at the end of the period (1985-1995), when the elasticity resulted in 0.415.

Producers react to changes in prices of rice, edible beans, corn, cattle and milk, mainly on the last year. As we expected, Center-West producers react to prices and substitute accordingly to relative price changes. In most of the cases, there are complementarities among outputs. Among crops these can be observed in crop rotation. Substitution effects were common as a reaction of rice price changes. This is comprehensible because these crops were technologically adapted to Cerrado's climate and soil. Soy showed to be substitute to rice but complementary to edible beans and corn. Soy is also a recent crop in expansion, and the covered period did not exactly reflect the nineties cultivated area expansion.

The bovine supply equation had results showing complementarities among most other products. In this region, areas were first used with rice and corn and just after one or two seasons they turned out to pastures. Most of the cattle were used both to milk and meat, with low productivity but increasing production over the decades.

All factors showed to be complement to others. The demand of factors was, in general, progressive with output prices. Supplies of products were regressive to prices of inputs. This result is coherent with the idea that crops were utilized with technology dependent to these factors.

In many regions, cattle production is preponderant, what conducted to low importance estimates for crops, but very impressive results for cattle and milk, products with huge production in many of the observed counties.

CONCLUSIONS

We conducted a supply response analysis in the Brazilian Center-West using a spatial error dependence model with a translog profit function approach. There was statistic evidence of interdependence among municipalities, say, spatial error dependence in the input demand and output supply. This fact shows that policy makers must observe regional interdependence as a factor that alters the way Brazilian farmers react to price changes and so, altering agricultural policy results, due to the fact that what happens in one location spreads out to its neighbors. Rice, edible beans, milk and corn were the products with spatial effects. Among inputs, fertilizer showed up as the highest price-elasticity.

We contributed to applied economic literature using a multi-equation multi-output-multi-input pooled model and at county level. The spatial effects really mattered, with results changing considerably with location specification, showing that non-spatial models could really bias the farmer response to price changes.

RESUMEN

Este estudio investiga la importancia de los efectos espaciales y las relaciones debido a la localización geográfica sobre la respuesta de la oferta a los precios agrícolas, en el Centro-Oeste brasileño. En concreto, se evaluó: la dependencia espacial en la demanda de insumos y la oferta de productos; y la importancia de los precios de insumos y productos en la respuesta de los agricultores. La contribución a la literatura es la combinación de una función translogarítmica de los beneficios con dependencia espacial en los errores del sistema de participaciones de los insumos y de los productos dentro de los beneficios, con sección cruzada y cuatro censos agrícolas. Se confirmó la estructura espacial en el término de error del sistema de ecuaciones. Hubo elevada autocorrelación espacial positiva en los términos de error para los productos. Existen relaciones de sustitución principalmente a cambios en los precios del arroz y algunas complementariedades entre otros. Existe complementariedad entre los factores. Los efectos espaciales en este estudio fueran muy importantes, cambiando de forma decisiva las elasticidades calculadas y demostrando que todos los productos analizados sufren estos efectos.

Palabras clave: Agricultura, Brasil, Dependencia espacial, Participación, Beneficios.

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