Spatial Spillovers in the Implicit Market Price of Soil Erosion: An Estimation using a Spatio-temporal Hedonic Model

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Spatial Spillovers in the Implicit Market Price of Soil Erosion: An Estimation using a Spatio-temporal Hedonic Model [1]

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Abstract: We estimate the implicit market price of soil erosion, fitting a spatio-temporal hedonic price model using quarterly data of 3,563 agricultural farms traded in Uruguay between 2000 and 2014. A unique feature of our estimation is that we allow for possible spatial spillovers. We find evidence of a negative and statistically significant association between erosion and land values. A 1% increase in own topsoil loss due to own erosion is associated with a decrease of 0.22% in the per-hectare price of agricultural land (p-value: 0.013, 95% CI: -0.0039, -0.0005). This is equivalent to a decrease of 7.7 USD in the average price per hectare and USD 1,040 in the price of the average farm (134 hectares). This value increases to USD 1,277 when we add the average cross marginal effect of erosion in nearby farms. Our estimates are sensitive to our measure of erosion and our specification of the spatio-temporal weighting matrix. We also find evidence consistent with our hypothesis that farms entering a governmental erosion control plan sent a valuable signal to the market regarding soil management. An indicator of whether the farm has at least one parcel under the government erosion control plans is associated with a 29% increase in the farm´s per-hectare price (p-value: 0.000, 95% CI: 16.26%, 41.53%) higher than those with no parcel under these plans. The average total marginal effect (own plus cross effects) of the erosion control plans is 35.37% (p-value: 0.000, 95% CI: 20.33%, 50.40%).

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Keywords: spatial spillovers, spatio-temporal hedonic model, soil erosion, farmland values, Uruguay

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1 Introduction

Uruguay experienced an unprecedented increase in agricultural production between 2000 and 2014. The total number of hectares devoted to soybean cultivation, for example, rose from 19,000 in 2000 to 1.32 million in September 2014 (DIEA, 2014; DIEA, 2015). The phenomenon was the result of record profits caused by the well-known increase in international prices of agricultural commodities that occurred during this period. But record profits did not only increase domestic agricultural production; they also brought other changes to Uruguay. Argentinian authorities seized the opportunity of record profits in the agricultural sector to increase export taxes.[2] For soybean, for example, export "retentions" jumped from 3.5% of the FOB value of exports in 2001 to 35% in 2007. This led Argentinian producers to shift production to Uruguay Permanent soybean cultivation, which substituted conventional rotation schemes, was another change observed during this period of record profits (Pauletti, Terra and Perranchon, 2016). At the same time, the number of hectares under exploitation by tenants instead of landowners increased by 20% between 2000 and 2011 (DIEA, 2011) and tenancy with sharecropping grew by 96%. Some of these tenants were "sowing pools": agricultural trusts constituted by capital investors to manage companies that rent land to produce and also provide essential services for agricultural production.[3] Finally, this increase in agricultural production decreased soil quality (Beretta, et al., 2019) and increased water pollution by agricultural runoff (Alonso et al., 2019). Phosphorus and nitrogen pollution affected the quality of water bodies all over the country, even those used as sources for drinking water. The problem gained national priority status after it affected the quality of the tap water, which made the public became aware of it.

Permanent soybean cultivation, the increase in tenancy, the appearance of sowing pools and the increase in water pollution raised concerns for soil erosion in the government of Uruguay.[4] Soil

[2] Exports retentions in Argentina have a long history. One of the reasons for its existence is the use of them as specific taxes for fiscal purposes (Rossi, 2015).
[3] Sowing pools were also new players in the agricultural land market in Argentina during those years (see Choumert and Phélinas, 2015)
[4] Interestingly, this chain of events (agricultural export boom, nonpoint water pollution and erosion, government concern) is similar to what happened in the 70s in the US. (Ervin and Mill, 1984).

erosion was declared "the main environmental problem in Uruguay linked to agricultural activities" (Hill, Freeman and Orejas, 2016, p.3). With a notable role of José Mujica, first as Minister of Agriculture and then as President, the government´s policy response was a nationwide soil conservation program called "Responsible Soil Use and Management Plans". These Plans established that producers need to report crop rotation schedules to the regulator. If the estimated soil erosion from these schedules is below a maximum legal level, the regulator approves them. Policymakers implemented an experimental phase of the Plans in 2011. In the winter of 2013, the plans became compulsory for landowners and land tenants planting more than 100 hectares of wheat and barley.[5] The government extended the plans to sorghum, corn, soybean, sunflower and dairy producers in the Santa Lucía river basin in the summer of 2013–2014.[6]

We are not aware of a similar, nationwide soil conservation policy implemented elsewhere. Moreover, relevant as it may be in a scenario of climate change, its impact remains to be evaluated. An important limitation for the economic evaluation of this policy experiment is the lack of recent comprehensive estimations of the implicit market price of soil erosion in the literature. In this paper, we help to fill this gap by estimating the implicit market price of soil erosion, using information on agricultural land transactions in Uruguay between 2000 and 2014, along with information on several physical characteristics of the farm´s soil and other relevant controls. With this information, we construct a unique database and fit a spatio-temporal hedonic equation to the data (Rosen, 1974; Vásquez, Cerda and Orrego, 2007).

The paper contributes to the rather scarce literature of the estimation of the implicit market price of soil erosion in several ways, the most distinguishable of which is that we test and take into account the spatio-temporal correlation of land prices. None of the previous estimations of the implicit market price of soil erosion do this. This gap in the literature is important because not

[5] Holders of separated plots (that add up to more than 100 hectares) should present a plan only for plots of more than 50 hectares.

[6] The Santa Lucía River is the main source of drinking water for half the population in Uruguay, including the metropolitan area of Montevideo; it has had severe episodes of algae blooms. In 2013, the government implemented a plan to control the level of phosphorous in soil and water in the basin. Dairy farmers in the Santa Lucía basin also have to present plans for fertilizer use. (Hill et al. 2016).

controlling for spatial correlation biases estimates (Anselin, 1988; LeSage, 1999; Anselin, Florax and Rey, 2004; Maddison, 2009). Spatial correlation of land prices may be common; the value of land traded in the recent past near a farm could be a source of information for prospective buyers and sellers of that farm. Boxall et al. (2005) found evidence of spatial correlation of rural residential property values in Canada. Similarly, Huang et al. (2006) cannot reject the hypothesis that farmland prices in Illinois are spatially independent. Spatial correlation in the analysis of land prices may be present also because of unobservable characteristics or shocks follow a spatial pattern. Maddison (2009) found evidence of spatial and temporal correlation of land prices and other characteristics in England and Wales in the nineties.

In addition, to the best of our knowledge, we are the first to "cross" GIS maps of parcels, anthropogenic erosion and soil depth to obtain a unique measure of soil erosion: the ratio of the volume of the soil lost due to erosion to the volume of original topsoil in every parcel of Uruguay.[7] To construct this variable we use measures of the depth of the original topsoil, the percentage of the topsoil eroded and the depth of the gullies. This is a considerable improvement with respect to the measures of soil erosion in the literature.

Other characteristics of our data are worth mentioning. First, 3,563 observations comprise our database. All but one of the previous studies use databases with less than 400 observations. We therefore use a considerably larger number of observations. Second, ours is also the first paper that uses transactions of agricultural land covering a whole country and a period of fifteen years. Lastly, we are the first to use data on land transactions outside the US. Donoso and Vicente (2001), the only example in the literature of an estimation outside the US, use experts´ assessments to estimate erosion, not an erosion map as we do, and they use the owner´s or the renter's perceptions to estimate land values, not actual prices as we do

[7] A parcel ("padrón") is the smallest official division of land for registry purposes. Each parcel in Uruguay has an official identification number.

In sum, we believe our work makes a contribution to the current state of the literature by providing a recent estimation of the implicit price of soil erosion that uses, at the same time, actual land transactions as the source of land values, a more detailed measure of soil erosion in each farm (based on GIS maps), a large sample size and that takes into account the spatial spillovers in the determination of the market price for land. Finally, by doing this, we provide a key ingredient for the economic evaluation of the Uruguayan erosion control policy recently implemented.

The rest of the paper is organized as follows. In Section 2 we present an overview of the literature on the estimation of the implicit market price of soil erosion. In Section 3 we present our methodology and empirical strategy. The dataset is presented in Section 4. Section 5 presents the results of our estimation. Finally, we conclude in Section 6.

2 An Overview of the Literature

The literature on the estimation of the implicit market price of soil erosion is rather thin. We are aware of only six papers that estimate the implicit price of soil erosion or soil erodibility (Miranowski and Hammes, 1984; Ervin and Mill, 1985; Gardner and Barrows, 1985; Palmquist and Danielson, 1989; Mendelsohn, et al, 1994; Donoso and Vicente, 2001).[8] Only two of these papers used a measure of erosion: Gardner and Barrows (1985) and Ervin and Mill (1985). Based on 158 transaction occurred in the Crawford and Vernon counties of southwestern Wisconsin during 1977 - 1979, Gardner and Barrows (1985) find that a 1% increase in the proportion of the parcel under Phase 3 (in which the topsoil is almost totally lost) decreased per acre prices for parcels with less than 34% of their surface contour-plowed. On average, a percentage point of the parcel contour plowed above this percentage of the surface compensates a percentage point of topsoil lost due to severe erosion. Using an unreported number of sales of farmland during 1976-78 in page County, Iowa, Ervin and Miller (1985) could not find a negative and statistically significant effect of the proportion of parcel under phase 2 of erosion on per-acre prices. Donoso and Vicente (2001)

[8] King and Sinden (1988) estimate the implicit price of soil conservation practices, using a measure of under-investment in erosion control measures with respect to a regulator-recommended level. Boisvert et al. (1997) estimate the implicit price of the “environmental vulnerability” of soil, as measured by nitrate leaching and runoff.

attempted to estimate the implicit price of soil erosion in a somewhat different manner. Using data obtained from surveyed wheat producers renting farmland in Tandil, Argentina, in 1996, the authors find that, on average, a cm of soil depth added 0.53 US$ of 2001 to the rental price of land. Alternatively, based on 252 transactions of farmland in North Carolina between 1979 and 1980, Palmquist and Danielson (1989) estimate the implicit price of a ton of soil by estimating how much the market valued a decrease in the soil´s potential erosion, as measured by the RKLS factors of the Universal Soil Loss Equation (USLE).[9] Based on an estimated value for the C factor of 0.494 in North Carolina and the hedonic price function estimate of the RKLS coefficient, the authors conclude that the market valued US$ 6.05 a decrease of the potential loss of one ton of soil per year. Using 94 individual farms transactions in Iowa between 1974 and 1979, and checked with a model at the county level with the 99 Iowa counties, Miranowski and Hammes (1984) report that the market valued 5.7 US$ of 1978 a one unit decrease in the RKLS factor (potential erosivity). Finally, Mendelsohn et al (1994) used 2,933 observations of farm values in the US and report that a decrease of a hundred of inches in the potential loss of soil due to erosion (K-factor) decreases farm values between 1.2 and 2.9 US$ of 1982 per acre.

As commented in the introduction, we improve this state of the literature in several ways. First, we "cross" GIS maps of parcels, anthropogenic erosion and topsoil depth to obtain a unique measure of erosion: the ratio of the volume of the soil lost due to erosion (including gullies) to the volume of original topsoil in every parcel of the country. Second, our data base consists of 3,563 farms traded in Uruguay between 2000 and 2014. As just seen, with the exception of Mendelsohn et al (1994), who have a sample size of 2,933 observations, the rest of the papers have sample sizes below a hundred observations (Donoso and Vicente, 2001; Miranowski and Hammes, 1984), or two hundred (Gardener and Barrows (1985), Palmquist and Danielson (1989). Part of the reason for the short databases of previous studies may be that the computational costs involved in the construction of the soil characteristics where higher in the years when most of these papers were

[9] "R" stands for rainfall factor, an index that measures the energy of rainfall. "K" is the erodibility factor, a measure of soil resistance to rainfall energy, "LS" is the is the slope length-gradient factor, a ratio of soil loss under the slope and length of the site in question relative to a "standard" slope and length.

published. This observation implies another shortcoming: the literature does not provide recent estimates of the implicit price of soil erosion. Third, we use actual market data for prices of farmlands, based on the market value of all farmlands traded in Uruguay between the years 2000 and 2014, as registered by the national registry office of Uruguay. Gardener and Burrows (1985) and Ervin and Mill (1985) seem to be the only ones that used data on actual transactions of land. The rest of the papers relied on estimates from farmers interviewed in a Census (Mendelshon et al, 1994), or surveyed renters, brokers, realtors, appraisers, etc. (Donoso and Vicente, 2001; Palmquist and Danielson, 1989; Marinowski and Hammes, 1984)).

Finally, on a second order, with the exception of Donoso and Vicente (2001), who work with data from wheat producers in Tandil, Argentina, the rest of the studies in the literature are applications of the methodology in the United States (Palmquist and Danielson, 1989; Mendelsohn, et al, 1994; Miranowski and Hammes, 1984; Ervin and Mill, 1985; Gardner and Barrows, 1985).

3 Methodology and Empirical Strategy

Based on Palmquist (1989) and Palmquist and Danielson (1989), we write our hedonic price equation as:

$$log\left(v_{i,t}\right) = f(E_i, F_i, B_i, M_t) \qquad (1)$$

Where $v_{i,t}$ is the per-hectare price at which farm i was sold in quarter t, E_i is the average level of erosion of farm i in 2004, F_i is a set of other relevant characteristics of the farm (area, productivity of soil, distance to the nearest town and port, whether it was requested for mining, whether the farm entered the erosion control plans in 2011-2014), B_i is a dummy variable indicating whether the buyer is a physical person or another type of buyer, and $P_{i,t}$ is a set of other controls (soybean price, the nationality composition of buyers in the market).

We test for the presence of spatio-temporal correlation in the determination or rural land prices. We believe there are several channels by which this correlation can be observed. First, it is costly for potential buyers of land to observe the relevant characteristics of the farm. Consequently, they may use the value of recently sold nearby farms as a source of information about the value of the farm in question. Under this phenomenon, we would need to include the prices of relevant farms in the right hand side of equation (1), a model known as SAR. Alternatively, prospective buyers could base their willingness to pay on the information they have on the level of erosion in nearby properties. In this case, we would need to include space lagged values of the level of erosion on nearby farms on the right hand side of equation 1, model known as SLX model (LeSage and Pace, 2009). Alternatively, the spatial correlation may affect only the disturbance process, leading to what is known as spatial error model (SEM). This is the case where an unobserved determinant of the value of land is spatially correlated or when shocks follow a spatial pattern (Elhorst, 2014). More recently, the literature developed estimation procedures for models incorporating the different combinations of these channels of spatial correlations. These are: the SARAR model (with spatial correlation of the dependent variable and the error term), the spatial Durbin model (SDM; with spatial correlation of the dependent variable and covariates), or the spatial Durbin error model (SDEM; with spatial correlation of the covariates and the error term).[10] Finally, the general nesting spatial model (Elhorst, 2014) allows for the presence of the three processes. We present this general specification below in matrix form, assuming E is the single covariate variable that causes spatial spillovers:

$$\boldsymbol{v} = \alpha\boldsymbol{\iota}_N + \rho\boldsymbol{W}\boldsymbol{v} + \boldsymbol{W}\boldsymbol{E}\gamma + \boldsymbol{X}\boldsymbol{\beta} + u \tag{2.a}$$

$$\boldsymbol{u} = \theta\boldsymbol{W}\boldsymbol{u} + \boldsymbol{\varepsilon} \tag{2.b}$$

$$\boldsymbol{\varepsilon} \sim N(0, \sigma^2\boldsymbol{I}_n) \tag{2.c}$$

In equation (2.a), $\boldsymbol{v}$ is the $n \times 1$ vector of per-hectare prices, $\boldsymbol{\iota}_N$ is an $n \times 1$ vector of ones and α is a parameter to be estimated, $\boldsymbol{X}$ is the $n \times k$ matrix of covariates, $\boldsymbol{\beta}$ is a vector of $k \times 1$ parameters to be estimated, and $\boldsymbol{\varepsilon}$ is an $n \times 1$ vector of disturbances terms, such that $\boldsymbol{\varepsilon} \sim N(0, \sigma^2 I_n)$. $\boldsymbol{W}$ is a

[10] LeSage and Pace (2009, p.32) name this model SAC, without an explanation for what the acronym stands for. We prefer to use term SARAR, originally used by Kelejian and Prucha (1998), who first estimated such a model.

$n \times n$ spatial weighting matrix, every element w_{ij} of which represents the spillover of observation j on observation i. Lastly, ρ, γ and θ represent the spatial correlation coefficients, to be estimated.

Our weighting matrix **W** is an inverse spatial and temporal distance matrix. Each element w_{ij} is the multiplication of the inverse of the km between the centroids of lots j and lot i (if the number of km is less than 50) and the inverse of the number of quarters between the trade of lot j and that of lot i (if the number of quarters is less than 8). That is, we truncate our matrix **W** spatially and temporally, in a way similar to Maddison (2009). The idea behind truncating is that only trades close in space and time can influence other trades. In our robustness check analysis, we repeat our estimations using matrices truncated at other maximum distances in time and space. Finally, because it simplifies calculations greatly, we normalize the spatial weighting matrix dividing each element of W by the corresponding row´s highest value.

We estimate our models by generalized spatial two stages least squares (GS2SLS) as in Kelejian and Prucha (2010), using the command spregress in Stata. GS2SLS estimates parameters β, ρ and γ by a 2SLS procedure and the parameter θ by a GMM procedure. We test for spatial correlation using Global Moran's I-statistic (LeSage, 1999). Nevertheless, Moran's I statistic does not inform us about the channel by which the spatial correlation operates (whether it through the dependent variables, the covariates, the error term, or combinations). Therefore, we run our model assuming all three channels of spatial correlation and use a stepwise approach based on the statistical significance of the spatial coefficients to decide on the final structure of our equation. This approach conducts to model specifications that have very similar predictive powers to other approaches based on Akaike´s or Schwarz´s Bayesian information criteria (Murtaugh, 2009)..

4 The Dataset

We obtained our rural land transaction data from the Directorate of Agricultural Statistics (DIEA) of the Ministry of Agriculture. This database lists all trades of rural land with the following information: the total value at which the farm was traded (in US dollars), the official identification number of each of the parcels comprising the traded farm, its area, the nationality of the buyer, whether the buyer is a subject, a commercial society, other type of society, a government agency, or other type of institution, and the date of the transaction.[11]

We construct our dependent variable in equation (1) (price per hectare) by dividing the total value at which the farm was traded by its area. To measure soil productivity, we use the most widely used soil productivity index in Uruguay; the CONEAT index. This measures the productivity of soils in terms of meat and wool (Durán and García Préchac, 2007). It is a good predictor of cropland productivity as well. The index classifies soils in groups with similar properties (CONEAT groups). Crossing the CONEAT map with the cadaster map we assign every parcel of the sample with a productivity index number. Then, we calculate the mean productivity index of the farm by calculating the weighted average of the productivity indexes of the parcels comprising the farm. We use the area of each parcel as the weight.

An important issue in our work is to identify agricultural farms. That is, land that is actually being used for agricultural production. For the construction of the database that we use, DIEA defines "agricultural land transactions" as those involving at least 10 hectares of land, with a total value of at least USD 1,000 and a per-hectare price between USD 50 and USD 30,000 (DIEA, n.d.). In spite of being a database a rural land transactions, DIEA's database included parcels defined as urban by the National Directorate of Cadaster.[12] For this reason, we decided to drop from the sample all the farms with at least one urban parcel and farms with at least one parcel within 30 km from downtown Montevideo, the capital city of Uruguay.[13] Moreover, since there is no information that we know of that identifies which use was given to every rural parcel in Uruguay in a given moment of time, what we do next is to identify each of the parcels in our database belonging to any of the CONEAT groups of soils defined by Molfino (2013) as those with the highest potential for agriculture. After this, we dropped from our sample all the farms with less than 50% of its area covered by one or more of these groups. Unsurprisingly, most of the farms in the resulting sample are located in the south west belt of Uruguay, were the best soils and the agricultural production

[11] For the estimation, we expressed all monetary values in USD of the year 2000 using inflation in US dollars in Uruguay as a deflator.

[12] Farms are comprised by more than one parcel, in almost every case.

[13] This criterion matches with several definitions of the Metropolitan Area of Montevideo (Martínez, 2007)

are located. Because the CONEAT index uses the level of soil erosion to calculate the productivity of some of the groups of soils identified by Molfino (2013) as those with the highest potential for agriculture, and we want to control for the original productivity of soils, not one affected by erosion, we dropped from our sample all farms with more than 1% of its area in one of these sub-set of groups. The remaining sample included farms with at least one parcel officially declared by the owners or renters as dedicated to the production of milk in at least one year after 2005, according to the National Livestock Information System of the Ministry of Livestock, Agriculture and Fishery. As erosion is not as important for dairy farms as it is for agricultural farms, we dropped these farms from the sample too. Lastly, we also excluded from the sample any farm that included at least one parcel under "forestry priority".[14] We use the official identification number of each of the parcels of the remaining farms in our database to assign all the characteristics for which we control in the regression to each of the parcels. To do it, we cross the cadaster map with the corresponding characteristic´s map.[15]

Our variable of interest is the level of soil erosion. We measure this level as the ratio of the volume of the farm´s soil lost due to sheet and gully erosion to the volume of the farm´s original A-horizon. We obtain the volume of the farm´s soil lost due to sheet and gully erosion from the 2004 Anthropic Erosion Map, provided by the Directorate of Natural Resources (RENARE) of the Ministry of Agriculture. The Anthropic Erosion Map defines landscape units that divide the Uruguayan territory in "iso-erosion" polygons. Each of these polygons have the same intensity and extension of erosion. Intensity of erosion measures the percentage of the A-horizon lost and the depth of

[14] This status was created by the 1988 Forestry Act (Ley Forestal, 1988), a law that launched a national policy aimed at fostering forestry in Uruguay. (Plantations of artificial forest in these lands do not pay income, land and other taxes). The data was obtained from the 2010 Forestry Priority Soils Map, through RENARE.

[15] We identified 192 farms for which the total surface of the farm informed by DIEA do not match by more than 5% the sum of the surfaces of the parcels that conform the farm, according to the national Directorate of Registries. This is probably because some of the parcels involved in the transaction were not totally traded or because of errors. We dropped these farms from the sample. Including a dummy variable indicating whether the traded farm is one of these 192 do not change the results of the estimations presented below.

gullies (in the cases where these are present). Extension measures the proportion of the polygon under each level of erosion intensity. The Erosion Map classifies the intensity and the extension of erosion, as well as the depth and the extension of gullies, into different phases.[16] We set the volume of the farm´s original A-horizon as the average depth of the original A-horizon of the CONEAT soil group to which the parcel belongs, taken from Molfino (2012). These measures were taken in field trips during the seventies. According to Molfino (personal conversation), measures were taken in the parts of the field were the soil kept its original average depth. With the original depth of the A-horizon (in meters), as well as the percentage of this depth lost due to erosion, the area (in square meters) of the parcel and the percentage of this area (extension) affected by this erosion, we calculate the percentage of the total volume of the original A-horizon that is lost due to erosion in every parcel of the traded farms. In the calculations, we use the midpoint of each of the intensity and extension phases, except for the intensity of the last two erosion phases, in which all the A-horizon of the soil *or more* is lost on average. In these cases, we use the depth of the original A-horizon as the intensity of the erosion process. We also use the midpoint of the different phases of the depth and extension of gullies. The exception here is for the phase "Very deep" gullies ("more than 100 cm"). In this case we take 100 cm as the depth of these gullies. We assume erosion to be uniform across parcels within a landscape unit. In the case of parcels extending over different iso-erosion polygons, we calculate the average value of erosion of the parcel, weighted by the percentage of the parcel that lies in each iso-erosion polygon. In the soils with severer phases of erosion, gullies may extend into the next horizons. Therefore, the erosion rate that we build may be greater than one. We opt for this measure of erosion because it is cardinal and because according to several interviews, as they are easy to see, gullies may be an important factor in the determination of the value of a farm. Finally, we calculate the average erosion of the farm by weighting the erosion of each of its parcels by the proportion of the parcel in the farm's total area.

We incorporate two variables regarding the farm's location: distance to the closest non-port relevant town and distance to the closest commercial port. We define "relevant towns" as those towns and

[16] See Appendix 1 for further details.

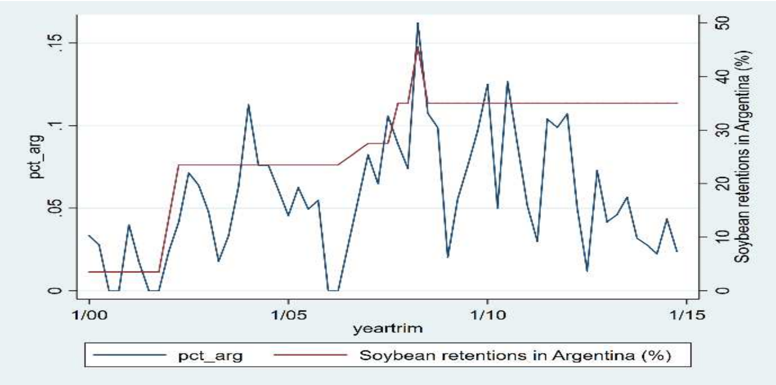
cities having both a branch of the public national bank (Banco República) and a gas station from the government-owned oil company (ANCAP). We calculate these distances using Google Maps and GIS software. Both distances capture the value of being closer to goods and services markets. Another control that we include is an indication of whether the farm entered the erosion control plans. We obtain this information from the Ministry of Agriculture. The plans started with an experimental phase in 2011 and became mandatory for all crops in 2014, the last year of our sample period. Therefore, our indicator variable takes the value of zero for all farms traded before 2011, and between 2011 and 2014 it takes de value of one if at least one of the parcels in the farm was under the erosion control plans. Farms with at least one parcel under the erosion control plans comprised 25% (230) of the 927 farms traded during 2011 and 2014. Interestingly, they are similar to those not covered by the plans in terms of erosion and productivity. While the former have and average level of erosion of 19.15% and a productivity index of 164.87, these numbers are 22.99% and 174.77 for the latter. They are similar also to all farms traded before the plans. These farms have an average erosion level of 21.12 and an average productivity index of 163.95. Our indicator variable then clearly captures the effect of being covered by the erosion control plans on the price of the farm. We hypothesize that the effect is positive because the information that the buyer needs to observe the way in which a producer managed the soil previous to the trade and whether this management is enough to comply with the maximum level of erosion set by the government (7 tons of soil per hectare per year) is difficult to obtain. Being registered in the erosion control plans, therefore, acts as a (imperfect) signal that the owner of the land has given considerable care to the conservation of soil, in the recent past at least. Our last characteristic of the farm that we include is a dummy variable indicating whether at least one parcel of the farm was requested for mining activity at any time of the sample period. We obtain this data from the National Mining Directorate of the Ministry of Industry, Energy and Mining.

Finally, we include the average quarterly price of soybean and characteristics of the buyer as controls. Among the latter, we include a control variable indicating whether the buyer is a person or not (the omitted category includes commercial societies, other types of societies and public offices) and the cumulative percentage of Argentinians buyers in the total cumulative number of land transactions. As it can be seen in Figure 1, panel (a), increases in the retentions rates in Argentina were followed by waves of Argentinian buying agricultural land in Uruguay. These waves produced a sustained increase in the participation of Argentinian buyers in the Uruguayan market for agricultural land (Figure 1, panel (b)).

Figure 1

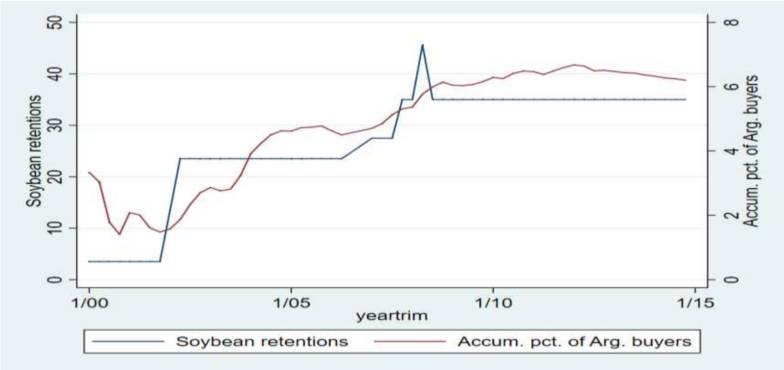
Panel (a)

Soybean exports retentions in Argentina (%) and percentage of Argentinians buyers in the Uruguayan market for agricultural land



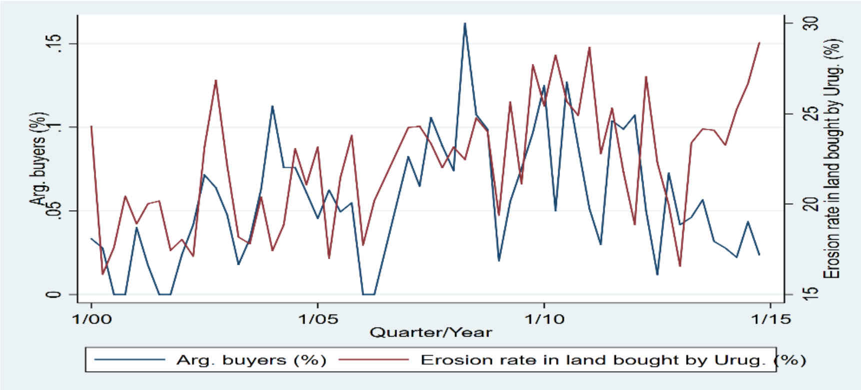
Panel (b)

Soybean exports retentions in Argentina (%) and cumulative percentage of Argentinians buyers in the Uruguayan market for agricultural land



Panel (c)

Percentage of Argentinian buyers and Mean erosion rate in land bought by Uruguayans



In spite of this noticeable behavior of Argentinians producers, they were never the majority of the buyers of agricultural land in Uruguay. We have a total number of 221 trades of land in our database in which the buyer is of Argentinian nationality, out of a total of 3,563. By quarter, the percentage of transactions in which the buyer was Argentinian averaged 5.62% in our sample period, reaching a maximum of 16.22%. On the other hand, the buyer was of Uruguayan nationality in 67% of all trades in our sample. The percentage of trades in which the buyer is a firm of unknown nationality is 23%. But, in spite of being a relative minority in the market, Argentinian buyers had a significantly different behavior, as compared to the rest of the buyers. There is a positive difference of 7.6 (95% CI: 3.2, 12) points in the productivity index of the land bought by Argentinians and that acquired by the rest of the buyers. There is also a positive significant difference of 2000 USD 1,021 (95% CI: 745.5, 1,296.4) in the price per hectare paid by them. That is, on average, Argentinians purchased more productive lands and paid higher prices. More importantly for this work, Argentinians buyers may have push Uruguayans buyer to more eroded lands. The pairwise correlation between the percentage of Argentinians buyers in the market and the erosion rate of lands bought by Argentinians is 0.06, while this correlation is 0.31 for the case of lands bought by Uruguayans (see Figure 1, panel (c)) Moreover, the pairwise correlation between the cumulative percentage of Argentinian buyers in the total number of buyers and the mean rate of erosion of traded land is 0.5.

Table 1 presents the summary statistics of the variables we use. As it can be seen, taking the midpoints of the erosion intensity and extension phases, versus taking the lower or upper bound, makes a difference. The mean level of erosion in the sample using the midpoint of the phases is 21%, while using the lower bound is 4.64% and using the upper bound 46.03%. As shown below, the three measures produce different estimates of the implicit price of soil erosion. Not shown in Table 1, the majority of the farms in our sample are in the departments of Soriano, Colonia and San José (56%), coincident with the location of the agricultural belt of Uruguay. The average price at which the farms in our sample were sold was 2,165 USD of 2000. This is a relatively high price in historical terms; signaling that the period of analysis coincides with the agricultural sector´s boom that followed the boom in commodity prices. (The soybean price reached a maximum of 442.6 USD of 2000 in our sample).

Table 1: Descriptive Statistics

Variable	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Farmland transaction price (USD of 2000)	2,165	2037	56.13	21,780
Percentage of original topsoil lost to erosion (%)				
Using midpoint of erosion phases	21.00	17.23	0.00	155.27
Using lower bound of erosion phases	4.64	5.89	0.00	52.91
Using upper bound of erosion phases	46.03	34.49	0.00	222.31
Farmland area (hectares)	134.40	319.39	10.00	10,235.00
Productivity Index	164.00	32.55	64.14	263.00
Distance to the nearest town (km)	17.43	12.78	0.55	79.46
Distance to the nearest port (km)	132.75	102.21	4.25	439.32
Soybean price (USD of 2000)	291.99	63.24	138.81	442.56
Cumulative percentage of Argentinian buyers	4.95	1.57	1.41	6.68
Buyer(s) is a(are) individual(s) (dummy)	0.77	0.42	0.00	1.00
At least one parcel in farm was requested for mining activity (dummy)	0.01	0.12	0.00	1.00
At least one parcel in farm included in erosion control plans in 2011-2014 (dummy)	0.06	0.25	0.00	1.00

5 Results

Table 2 presents the results of the estimation of our hedonic price equation. Column 2 presents the results of the OLS estimates (as reference). The OLS model is the basis for the calculation of the Global Moran's I-statistic (LeSage, 1999). According to this statistic (152.13), we should reject the null hypothesis that the errors of the OLS estimation are i.i.d. in favor of the alternative that they are spatially correlated. Because we are agnostic with respect to the channel of the spatial correlation (the dependent variables, the covariates, the error term, or combinations), and Moran's I statistic does not inform us about this channel, we start by estimating the Generalized Nesting Spatial Model (GNSM) and use a stepwise approach based on the statistical significance of the spatial coefficients to decide on the final structure of our equation, as commented above (Murtaugh, 2009). The results are presented in column 3. These show that the only spatial coefficient that is statistically significant is that of the spatially lagged dependent variable. Because the estimate of the spatial coefficient γ of erosion exhibits a larger p-value (0.828) than that of the spatial coefficient θ of the errors (0.206), we first dropped the spatially lagged erosion term and estimate a SARAR model (with spatial correlation of the dependent variable and the error term). The results are shown in column 4. The spatially lagged error term, remains statistically insignificant, with a p-value of 0.222. This result led us to estimate the classical SAR model, with only the per-hectare price spatially lagged. The results are on column 5. As with the rest of the models, we allow for heteroscedasticity in the errors. Our coefficient of interest is that of the percentage of the volume of the original soil that is lost due to erosion. This coefficient is -0.0022 (p-value: 0.013, 95% CI: -0.0039, -0.0005). This means that, on average, a 1% increase in the ratio of the volume of erosion to the volume of the original A-horizon is associated with a decrease of 0.22% in the per-hectare price of agricultural land. Given that the average price per hectare is 2,165 USD of 2000 in our sample, a 1% increase in the rate of erosion is associated with a decrease of 4.76 USD of 2000 in the average price per hectare. In today's dollars, this is approximately USD 7.7 per hectare. Given that the average farm has an area of 134.4 hectares, the average farm in our sample loses USD 1,040 when it loses 1% of its A-horizon soil due to erosion. This magnitude is almost equivalent (in absolute terms) to the magnitude of the positive association between the per-hectare price of land and the productivity index. According to Table 2, a one-unit increase in the productivity index is associated with an increase of 0.28% in the per-hectare price of agricultural land (p-value: 0.000, 95% CI: 0.18%, 0.37%). Somewhat unexpectedly, the p-value of the soybean price is around 0.10 in all models. In our preferred SAR model is 0.105. This may be the result of a correlation of 0.6 with the cumulative ratio of Argentinians in the market. The association between the latter and the per-hectare price is worth noting. An additional 1% of Argentinians in the cumulative number of trades in the market is associated with an additional 0.18% in the per-hectare price (p-value: 0.000, 95% CI: 0.13%, 0.22%). This estimate is consistent with what we saw in the introduction; Argentinians producers reacted to the increases in soybean export retentions in Argentina by buying land in Uruguay, paying more than the rest of the buyers and buying more productive land on average. Estimates also show that individuals paid 30.87% (p-value: 0.000, 95% CI: -37.34%, -24.40%) less per hectare than commercial societies, other types of societies and public offices (the omitted category). Finally, farms with at least one parcel under the government erosion control plans have a per-hectare price that is, ceteris paribus, 28.89% higher (p-value: 0.000, 95% CI: 16.26%, 41.53%) than those with no parcel under these plans. The latter could be farms not affected to agricultural production or farms not complying with the regulation. In any case, this result is consistent with our hypothesis that farms under the plans signal the market that soil management in that farms is better, and this is strongly valued by the market.

Table 2: REGRESSIONS

	Model			
Dependent variable: Log of Per-hectare Price of farm	**OLS**	**GNSM**	**SARAR**	**SAR**
Covariates:				
Percentage of original topsoil lost to erosion	-0.0024***	-0.0023	-0.0021**	-0.0022**
	(0.0009)	(0.0014)	(0.0009)	(0.0009)
Log of farm area	-0.1001***	-0.0851***	-0.0853***	-0.0912***
	(0.0146)	(0.0150)	(0.0150)	(0.0149)
Productivity Index	0.0030***	0.0028***	0.0028***	0.0028***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Distance to the nearest town (km)	-0.0063***	-0.0056***	-0.0056***	-0.0056***
	(0.0014)	(0.0015)	(0.0015)	(0.0014)
Distance to the nearest port (km)	-0.0019***	-0.0015***	-0.0015***	-0.0015***
	(0.0002)	(0.0003)	(0.0003)	(0.0003)
Soybean price (USD of 2000)	0.0004	0.0005*	0.0005*	0.0004
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Cumulative percentage of Argentinian buyers	0.2236***	0.1818***	0.1815***	0.1805***
	(0.0116)	(0.0237)	(0.0238)	(0.0235)
At least one parcel in farm was requested for mining activity (dummy)	-0.0468	-0.0072	-0.0066	-0.0255
	(0.1132)	(0.1159)	(0.1159)	(0.1123)
Buyer(s) is an (are) individual(s) (dummy)	-0.3237***	-0.3041***	-0.3039***	-0.3087***
	(0.0332)	(0.0330)	(0.0329)	(0.0330)
At least one parcel in farm included in erosion control plans in 2011-2014 (dummy)	0.3305***	0.2757***	0.2753***	0.2889***
	(0.0630)	(0.0657)	(0.0657)	(0.0645)
Constant	6.5855***	5.4055***	5.4006***	5.3912***
	(0.1429)	(0.5901)	(0.5917)	(0.5972)
Spatial lags:				
Log of per-hectare price of farm (ρ)		0.1740**	0.1757**	0.1831**
		(0.0870)	(0.0873)	(0.0882)
Ratio of soil erosion volume to topsoil volume (γ)		0.0004		
		(0.0020)		
Error term (θ)		0.1202	0.1165	
		(0.0950)	(0.0954)	
Observations	3563	3563	3563	3563
R^2/R^{2*}	0.3160	0.3164	0.3164	0.3167
*p<0.10, **p<0.05, ***p<0.01				

The spatial correlation of prices give rise to own and cross marginal effects for each covariate on the price of agricultural land. In Table 3, we present the results of the estimation of the average of these effects using Stata.[17] The following results are worth commenting. First, the average cross effect (indirect effect) of erosion is not statistically significant at the 90% confidence level (p-value: 0.132, 95% CI: -0.0011, 0.0001). Nevertheless, the average total effect (0.27%) is significant at the 95% confidence level (p-value: 0.014, 95% CI: -0.0048, -0.0048, -0.0005). In today´s US dollars, the average price per hectare in our sample is 3,520. Therefore, a one-percent loss in topsoil is associated with a decrease of USD 9.5 in the price per hectare. In other words, the average farm in our sample (134.4 hectares) sees its value down by USD 1,277. The rest of the indirect effects are all somewhat less statistically significant than their direct counterparts. Worth mentioning is that, via prices, the fact that neighboring farms are under the erosion control plans is associated with a 6.3% increase in the price of a farm (p-value 0.071, 95% CI: -0.0055, 0.1315), on average. This indirect effect of the plans leads to a total effect (direct + indirect) of 35.37%.

[17] If there are n observations, the average own marginal effects is: $\frac{1}{n}\sum_{i=1}^{n}\frac{\partial E(y_i|\boldsymbol{X},\boldsymbol{W})}{\partial x_i}$. This is what is known as the direct effect, although it includes "feedback loops" effects (the change in x_i affects y_j and this change in y_j affects y_i, and longer loops (LeSage and pace, 2009)). The average of the cross marginal effects is: $\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n}\frac{\partial E(y_i|\boldsymbol{X},\boldsymbol{W})}{\partial x_j}$. This is what is commonly known as the indirect effect. The average total effect is the sum of the two.

Table 3: Direct and Indirect effects

	SAR		
Dependent variable: Log of per-hectare price of farm	Average own (direct) effect	Average cross (indirect) Effect	Average Total effect
	Coefficient	Coefficient	Coefficient
Covariates:	(Std. Error)	(Std. Error)	(Std. Error)
Percentage of original topsoil lost to erosion	-0.0022**	-0.0005	-0.0027**
	(0.0009)	(0.0003)	(0.0011)
Log of farm area	-0.0916***	-0.0199*	-0.1116***
	(0.0149)	(0.0110)	(0.0186)
Productivity Index	0.0029***	0.0006*	0.0034***
	(0.0005)	(0.0003)	(0.0006)
Distance to the nearest town (km)	-0.0056***	-0.0012*	-0.0068***
	(0.0014)	(0.0007)	(0.0017)
Distance to the nearest port (km)	-0.0015***	-0.0003**	-0.0018***
	(0.0003)	(0.0002)	(0.0002)
Soybean price (USD of 2000)	0.0004	0.0001	0.0005
	(0.0003)	(0.0001)	(0.0003)
Cumulative percentage of Argentinian buyers	0.1815***	0.0393**	0.2209***
	(0.0257)	(0.0185)	(0.0140)
At least one parcel in farm was requested for mining activity (dummy)	-0.0257	-0.0056	-0.0312
	(0.1129)	(0.0244)	(0.1371)
Buyer(s) is an (are) individual(s) (dummy)	-0.3105***	-0.0673*	-0.3779***
	(0.0329)	(0.0383)	(0.0516)
At least one parcel in farm included in erosion control plans in 2011-2014 (dummy)	0.2906***	0.0630*	0.3537***
	(0.0644)	(0.0349)	(0.0767)
Observations	3563	3563	3563

5.1 Robustness checks

In this section we check the robustness of our results to the use the lower and the upper limits of the erosion phases, instead of the midpoint, as we did above. We also check its robustness to the use of other weighting matrices. Table 4 presents the results of the estimation of the SAR model when we use the lower bound of the erosion phases to construct the erosion rate (column 3), and when we use the upper bound (column 4). For reference, we also include the results presented in Table 2 (column 2). To illustrate, suppose a farm´s soil has "Moderate erosion". Then, according to the 2004 Erosion Map (see Appendix 1), this means that the farm has lost between 25% and

75% of its original topsoil. To calculate the erosion rate of this farm, we multiply the original depth of the A-horizon in the farm by 50% in the case of the second column of Table 4, 25% in the case of the third column and 75% in the case of the fourth column. Results show that using the lower or the upper bound of erosion phases only changes the magnitude of the erosion coefficient, but not its statistical significance. When using the lower limits, the coefficient increases almost three-fold (from -0.22% to -0.57% (p-value: 0.023, 95% CI: -1.06%, -0.07%), while using the upper bounds decreases the coefficient in half (from 0.22% to 0.11% (p-value: 0.011, 95% CI: 0.19%, 0.02%). This makes sense because we set the maximum percentage of topsoil lost to 100% in the three cases, as explained above. Therefore, using the lower bounds of erosion in all the phases except the most severe decreases the estimated loss of topsoil with respect to using the midpoint. Hence, for the same variation in prices, the implicit price of a unit of erosion is higher. The opposite is true when we use the upper bounds. The rest of the coefficients remain unchanged in size and statistical significance.

Table 4: SAR estimates for different limits of erosion

	Erosion rate		
Dependent variable: Log of per-hectare price of farm	Midpoint	Minimum	Maximum
	Coefficient	Coefficient	Coefficient
Covariates:	(Std. Error)	(Std. Error)	(Std. Error)
Percentage of original topsoil lost to erosion	-0.0022**	-0.0057**	-0.0011**
	(0.0009)	(0.0025)	(0.0004)
Log of farm area	-0.0912***	-0.0914***	-0.0908***
	(0.0149)	(0.0149)	(0.0149)
Productivity Index	0.0028***	0.0028***	0.0027***
	(0.0005)	(0.0005)	(0.0005)
Distance to the nearest town (km)	-0.0056***	-0.0056***	-0.0056***
	(0.0014)	(0.0014)	(0.0014)
Distance to the nearest port (km)	-0.0015***	-0.0014***	-0.0015***
	(0.0003)	(0.0003)	(0.0003)
Soybean price (USD of 2000)	0.0004	0.0004	0.0004
	(0.0003)	(0.0003)	(0.0003)
Cumulative percentage of Argentinian buyers	0.1805***	0.1823***	0.1802***
	(0.0235)	(0.0235)	(0.0234)
At least one parcel in farm was requested for mining activity (dummy)	-0.0255	-0.0291	-0.0254
	(0.1123)	(0.1125)	(0.1118)
Buyer(s) is an (are) individual(s) (dummy)	-0.3087***	-0.3099***	-0.3083***
	(0.0330)	(0.0331)	(0.0330)
At least one parcel in farm included in erosion control plans in 2011-2014 (dummy)	0.2889***	0.2876***	0.2912***
	(0.0645)	(0.0645)	(0.0644)
Constant	5.3912***	5.3998***	5.4152***
	(0.5972)	(0.5931)	(0.5950)
Spatial lags			
Log of per-hectare price of farm (ρ)	0.1831**	0.1780**	0.1810**
	(0.0882)	(0.0879)	(0.0877)
Observations	3563	3563	3563
Pseudo R^2	0.3167	0.3164	0.3167
*p<0.10, **p<0.05, ***p<0.01			

Table 5 presents the results of the estimation of the SAR model when we use other weighting matrices. In column 3, the spatial limit is 25 km (instead of 50 km) and the time limit is 4 quarters (instead of 8 quarters). In column 4, the spatial limit is 100 km and the time limit is 16 quarters. For reference, we also include the results presented in Table 3 (column 2). Table 5 shows that our results are robust to different spatial and temporal limits used in the weighting matrix. The negative association between erosion and prices is slightly higher and more significant statistically when we construct the matrix with farms traded within 25km and one year, instead of farms traded within 50 km and two years. The opposite occurs when we use a higher distance in space in time to calculate the weights. The rest of the coefficients follow the same pattern. The estimate of the coefficient for the spatially lagged price is very sensitive to the specification of the weighting matrix. The per-hectare prices of farms traded within 25 km and one year are not correlated at the 90% confidence level (Point estimate: 0.0133. p-value: 0.314. 95% CI: -0.0126, 0.0391). On the other hand, when we set the limits to 100km and four years this coefficient is 0.4678, statistically significant at the 99% level (p-value: 0.0000, 95% CI: 0.3228, 0.6128). This is 2.5 times larger than when we set them in 50km and 2 years, in our main model. Moreover, when we lax the limits of the weighting matrix to 100 km and 4 years, the average own marginal effect of erosion stays in -0.2% (p-value: 0.029. 95% CI: -0.38%, -0. 02%), but the average marginal cross effect increases to 0.16% and becomes statistically significant at the 90% confidence level (p-value: 0.054, 95% CI: -0.32%, 0.003%). This makes the average total marginal effect of erosion to be -0.36% (p-value 0.032), 95% CI: -0.68%, -0.03%).

Table 5: Different weighting matrices

	Weighting matrix		
Dependent variable: Log of per/hectare price of Farm	Main	Closer spatial and temporal limits	More distant spatial and temporal limits
	Coefficient	Coefficient	Coefficient
Covariates:	(Std. Error)	(Std. Error)	(Std. Error)
Percentage of original topsoil lost to erosion	-0.0022**	-0.0024***	-0.0019**
	(0.0009)	(0.0009)	(0.0009)
Log of farm area	-0.0912***	-0.1002***	-0.0785***
	(0.0149)	(0.0145)	(0.0143)
Productivity Index	0.0028***	0.0030***	0.0024***
	(0.0005)	(0.0005)	(0.0005)
Distance to the nearest town (km)	-0.0056***	-0.0060***	-0.0045***
	(0.0014)	(0.0014)	(0.0014)
Distance to the nearest port (km)	-0.0015***	-0.0019***	-0.0009***
	(0.0003)	(0.0002)	(0.0002)
Soybean price (USD of 2000)	0.0004	0.0004	0.0006**
	(0.0003)	(0.0003)	(0.0003)
Cumulative percentage of Argentinian buyers	0.1805***	0.2204***	0.1157***
	(0.0235)	(0.0119)	(0.0199)
At least one parcel in farm was requested for mining activity (dummy)	-0.0255	-0.0455	-0.0096
	(0.1123)	(0.1129)	(0.1142)
Buyer(s) is an (are) individual(s) (dummy)	-0.3087***	-0.3227***	-0.2927***
	(0.0330)	(0.0331)	(0.0320)
At least one parcel in farm included in erosion control plans in 2011-2014 (dummy)	0.2889***	0.3281***	0.2400***
	(0.0645)	(0.0628)	(0.0619)
Constant	5.3912***	6.5073***	3.4869***
	(0.5972)	(0.1611)	(0.5136)
Spatial lags			
Log of per-hectare price of farm (ρ)	0.1831**	0.0133	0.4678***
	(0.0882)	(0.0132)	(0.0740)
Observations	3563	3563	3563
Pseudo R^2	0.3167	0.3160	0.3203
*p<0.10, **p<0.05, ***p<0.01			

6 Conclusion and discussion

We find evidence of a negative and significant impact of erosion on land values. We find that a 1% increase in the ratio of the volume of erosion to the volume of the original topsoil in a farm is associated with a decrease of 0.22% (p-value: 0.013, 95% CI: -0.39, -0.05) in its own per-hectare price, on average, according to our preferred SAR model. With an average price per hectare of USD 3,520 in our sample of 3,563 farms, this is approximately USD 7.7 per hectare, in today´s dollars. Given that the average farm has an area of 134.4 hectares, the average farm in our sample loses USD 1,040 when it loses 1% of its A-horizon soil due to erosion. In addition, we find evidence that a 1% increase in the erosion rate of farms within 50km and traded within two years of a given traded farm, reduces the per-hectare price of the farm by 0.05%, on average (indirect effect). This association is not statistically significant at the 90% confidence level (p-value: 0.132, 95% CI: -0.11, 0.01). However, the average total effect (0.27%) is significant at the 95% confidence level (p-value: 0.014, 95% CI: -0.0048, -0.0048, -0.0005). In today´s US dollars, this means that a one-percent loss in topsoil is associated with a decrease of USD 9.5 in the price per hectare. In other words, the value of the average farm in our sample (134.4 hectares) decreases USD 1,277. This magnitude is almost equivalent (in absolute terms) to the magnitude of the positive association between the per-hectare price of land and the productivity index.

These estimates, nevertheless, are very sensitive to the specification of the spatial weighting matrix. Setting the spatial limit to a radius of 25km from the traded property and the temporal limit to 1 year from the date of the transaction makes the spatial correlation of land prices to be statistically insignificant at the 90% confidence level (Point estimate: 0.0133. p-value: 0.314. 95% CI: -0.0126, 0.0391), and the marginal effect of own erosion on the property price to increase to 0.24% (p-value: 0.008. 95% CI: -0.41%, -0.06%). On the other hand, when we set the limits of the spatio-temporal weighting matrix to 100km and four years, the weighted average marginal association between the prices of farms within these limits jumps to 0.4678, statistically significant at the 99% level (p-value: 0.0000, 95% CI: 0.3228, 0.6128). In other words, a USD 1 increase in the per-hectare prices of all farms within 100km and traded within four years is associated with a 46.78% increase in the per-hectare price of a farm. This is 2.5 times larger than when we set them in 50km and 2 years, in our main model. Moreover, the average own marginal effect of erosion stays in -0.2% (p-value: 0.029. 95% CI: -0.38%, -0. 02%), but the average marginal cross effect increases to 0.16% and becomes statistically significant at the 90% confidence level (p-value: 0.054, 95% CI: -0.32%, 0.003%). This makes the average total marginal effect of erosion to be -0.36% (p-value 0.032), 95% CI: -0.68%, -0.03%).

Results are also sensitive to the way we measure erosion. Using the lower limits of the erosion phases defined in the anthropogenic erosion map, as compared with using the midpoints of the phases, causes the estimate of the negative association between erosion and the per hectare price to increase from increase from -0.22% to -0.57% (p-value: 0.023, 95% CI: -1.06%, -0.07%). On the other hand, using the upper bounds decreases the coefficient in half (from 0.22% to 0.11% (p-value: 0.011, 95% CI: 0.19%, 0.02%). This makes sense because we set maximum percentage of topsoil lost to 100% in the three cases. Therefore, using the lower bounds of erosion in all phases except the most severe decreases the estimated loss of topsoil for the same variation in prices. Hence, the implicit price of a unit of erosion is higher. The opposite is true when we use the upper bounds.

We also find that farms entering the erosion control plans of the government sent a valuable signal to the market regarding soil management; a farm having at least one parcel under the government erosion control plans is associated with a 29% increase in its per-hectare price, on average (p-value: 0.000, 95% CI: 16.26%, 41.53%) than those with no parcel under these plans. The average total marginal effect (own plus cross effects) is 35.37% (p-value: 0.000, 95% CI: 20.33%, 50.40%). This result is consistent with our hypothesis that, apart from a potential effect on land prices via erosion control, the plans had also an effect on land prices via signaling adequate soil management.

How our results compare with those obtained by previous studies? Results are not straightforward to compare because of all the differences in the measures of erosion. Gardner and Barrows (1985) find that a 1% increase in the proportion of the parcel under Phase 3 (in which the topsoil is almost all lost) decreased per acre prices for parcels with less than 34% of their surface contour-plowed. In the absence of contour plowing, the effect could be as high as -832 USD of 1977-1979 per acre. This result is difficult to compare because we measure erosion in terms of volume of topsoil lost in total, and not as percentages or area under each three erosion phases. Nevertheless, the estimate by Gardner and Barrows seems to be very large. Ervin and Miller (1985) could not find a negative and statistically significant effect of the proportion of parcel under phase 2 of erosion on per-acre prices. Donoso and Vicente (2001) estimate the implicit price of soil erosion in terms of cm of soil depth. The authors conclude that renters in 1996 valued 0.53 US$ of 2001 each cm of topsoil lost due to erosion. With an average erosion of 87 mm per year (10 tons of topsoil per hectare per year), their estimation translates into an implicit price of topsoil of 0.046 USD of 2001 per ton. Ignoring purchasing power disparities between Tandil and Uruguay, this is around 0.07 USD of today. The per hectare average volume of topsoil in sample: 2,875 m^3. The average apparent density of soil in Uruguay: 1.32 ton/m^3 (Califra, Beretta and Del Pino, 2014). Thus, per hectare average weight of topsoil in Uruguay is about 3,795 tons: a 1% loss of topsoil represents a 38-ton loss per hectare. Given that the average per-hectare price in today dollars in our sample is USD 3,520, and the average own marginal effect was estimated to be 0.22% of this price (USD 7.7), the average implicit price of a ton of soil according to our estimations is USD 0.2038 (7.7/38). Our estimate, in other words, is three times higher than that of Donoso and Vicente. Several issues could explain this difference. Among them, they use experts´ assessments to estimate erosion, not an erosion map as we do, and they use the owner´s or the renter's perceptions to estimate land values, not actual prices as we do. Palmquist and Danielson (1989) estimated a per ton 1989 price of US$ 6.05. This is approximately US$ 12 of today, taking into consideration the US inflation. Finally, Mendelsohn et al (1994) report that a decrease of a hundred of inches in the potential loss of soil due to erosion (K-factor) decreases farm values between 1.2 and 2.9 US$ of 1982 per acre. Again, the comparison of this estimate with ours is not straightforward. Apart from measuring erosion in different ways, in different moments in time, none of the above estimates take into account the spatial correlation of land prices. This heterogeneity of estimates of the implicit market price of soil erosion in the literature reflects what it was one of the main motivations of our study: to provide policy makers with an up-to-date estimation, given the difficulty that they would face if attempting to obtain this from the available studies.

We believe that with this work we provide a valuable input to policymakers in Uruguay and elsewhere for them to use to estimate the economic benefits of soil conservation plans. Notwithstanding, our estimate does not provide the total implicit market price of soil erosion, since it does not include the value of the public benefits arising from erosion control measures. These include the reduction in the negative externalities of soil erosion, such as: (a) blocking light penetration in water courses, which deteriorates biological functions (i.e. photosynthesis), (b) altering spawning places, (c) over-enriching water bodies with nitrogen, phosphorus and other nutrients transported with soil (eutrophication), (c) polluting water bodies with chemical products, (d) elevating watercourse beds as a consequence of sediment accumulation, making navigability more difficult, boosting the frequency and magnitude of floods (a particularly sensitive issue in scenarios of climate change), and contributing to the loss of reservoir capacity (Durán and García Préchac, 2007). These should be the objective of future works.

7 References

Alonso, Jimena & Quintans, Federico & Taks, Javier & Conde, Daniel & Chalar Marquisá, Guillermo & Bonilla, Sylvia & Arocena, Rafael & Haakonsson, Signe & Aubriot, Luis & al, et. (2019). Water Quality in Uruguay: Current status and challenges. In Water quality in the Americas, Publisher: IANAS, pp.561 - 599

Anselin, L. (1988). Spatial Econometrics: Methods and Models. Studies in Operational Regional Science. Springer.

Anselin, L., Florax, R. and Rey, S. (eds.) (2004). Advances in Spatial Econometrics. Methodology, Tools and Applications. Advances in Spatial Science. Springer.

Boisvert, R., Schmit, T. and Regmi, A. (1997). Spatial, Productivity, and Environmental Determinants of Farmland Values. American Journal of Agricultural Economics, Vol. 79, No. 5, Proceedings Issue (Dec. 1997), pp. 1657-1664.

Rossi, G. (2015). Informativo semanal de la Bolsa de Comercio de Rosario. Año XXXIII. N° 1737. 11 de diciembre de 2015. Available online at: https://www.bcr.com.ar/Publicaciones/Informativo%20semanal/bcr2015_12_11.pdf.

Beretta-Blanco, A., O. Pérez and L. Carrasco-Letellier (2019). "Soil quality decrease over 13 years of agricultural production". Nutrient Cycling in Agroecosystems. DOI: 10.1007/s10705-019-09990-3

Boxall, P. C., Chan, W. H., & McMillan, M. L. (2005). The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis. *Resource and Energy Economics*, *27*(3), 248-269.

Califra, A., Beretta, A. and Del Pino, A. (2014). Estimación de densidad aparente del suelo – Comparación del modelo SPAW con modelos desarrollados por investigación nacional. Congreso Uruguayo de Suelos 2014 – VI Encuentro de la SUCS, agosto 2014. Colonia, Uruguay.

Carrión-Flores, C. and Irwin, E. (2004). Determinants of Residential Land-Use Conversion and Sprawl at the Rural-Urban Fringe. American Journal of Agricultural Economics, 2004, vol. 86, issue 4, 889-904.

Choumert, J., & Phélinas, P. (2015). Determinants of agricultural land values in Argentina. *Ecological Economics*, *110*, 134-140.

Debolini, M., Valette, E., François, M. and Chéry, J. (2015). Mapping land use competition in the rural-urban fringe and future perspectives on land policies: A case study of Meknes (Morocco). Land Use Policy, 47 (2015), 373-381.

Dirección Nacional de Estadísticas Agropecuarias (DIEA) (n.d.). Metodología - Precio de la Tierra de Uso Agropecuario. Public access document, available at DIEA website: http://www.mgap.gub.uy/sites/default/files/multimedia/metodologia.pdf (in Spanish).

Dirección Nacional de Estadísticas Agropecuarias (DIEA) (2011). Censo General Agropecuario 2011: Resultados definitivos. MGAP, Montevideo, Uruguay.

Dirección Nacional de Estadísticas Agropecuarias (DIEA) (2014). Encuesta Agrícola Primavera 2014 Serie Encuestas Nº 323. MGAP, Montevideo, Uruguay.

Dirección Nacional de Estadísticas Agropecuarias (DIEA) (2015). Regiones Agropecuarias del Uruguay. MGAP, Montevideo, Uruguay.

Donoso, G. and Vicente, G. (2001). Caracterización hedónica de los precios de tierra agrícola en la región pampeana argentina. Ciencia e Investigación Agraria, 28(2), pp. 73-81.

Durán, A. and García Préchac, F. (2007). Suelos del Uruguay. Origen, clasificación, manejo y conservación. Ed. Hemisferio Sur, Montevideo, Uruguay.

Elhorst, J. P. (2014. Spatial Econometrics. From Cross-Sectional Data to Spatial Panels. Springer.

Ervin, D. and Mill, J. (1985). Agricultural Land Markets and Soil Erosion: Policy Relevance and Conceptual Issues. American Journal of Agricultural Economics, Vol. 67, No. 5, Proceedings Issue (Dec., 1985), pp. 938-942.

Gardner, K. and Barrows, R. (1985). The Impact of Soil Conservation Investments on Land Prices. American Journal of Agricultural Economics, Vol. 67, No. 5, pp. 943-947.

Hill, M., Freeman, K. and Orejas, R. (2016). Plotting Productivity: Soil Use Management Plans in Uruguay. 2016 Annual Conference on Land and Poverty. The World Bank - Washington DC, March 14-18, 2016.

Huang, H., Miller, G. Y., Sherrick, B. J., & Gomez, M. I. (2006). Factors influencing Illinois farmland values. *American Journal of Agricultural Economics*, *88*(2), 458-470.

Hushak, L. (1975). The Urban Demand for Urban-Rural Fringe Land. Land Economics, Vol. 51, No. 2 (May, 1975), pp. 112-123.

Kelejian, H. and Prucha, I. (1998). A Generalized Spatial Two Stages Least Squares Procedure for Estimating a Spatial Autoregressive Model with Autoregressive Disturbances. Journal of Real Estate Finance and Economics, Vol. 17:1, 99-121.

Kelejian, H. and Prucha, I. (2010). Specification and estimation of spatial autoregressive models with autoregressive and heteroskedastic disturbances. Journal of Econometrics, Volume 157, Issue 1, July 2010, p. 53-67.

King, D. and Sinden, J. (1988). Influence of Soil Conservation on Farm Land Values. Land Economics, Vol. 64, No. 3 (Aug., 1988), pp. 242-255.

LeSage, J. (1999). The Theory and Practice of Spatial Econometrics. Department of Economics, University of Toledo.

LeSage, J. and Pace, R. (2009). Introduction to Spatial Econometrics. CRC Press, Boca Raton.

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

Maddison, D. (2009). A Spatio-temporal Model of Farmland Values. Journal of Agricultural Economics, Vol. 60, No. 1, 2009, 171-189.

Martínez, R. (ed.) (2007). El Libro Blanco del Área Metropolitana: Canelones, Montevideo, San José. Universidad de la República, Montevideo, Uruguay.

Mendelsohn, R., Nordhaus, W. and Shaw, D. (1994). The Impact of Global Warming on Agriculture: A Ricardian Analysis. The American Economic Review, Vol. 84, No. 4 (Sep., 1994), pp. 753-771.

MGAP (2015). Anuario Estadístico Agropecuario 2015.

Miranowski, J. and Hammes, B. (1984). Implicit Prices of Soil Characteristics for Farmland in Iowa. American Journal of Agricultural Economics, Vol. 66, No. 5 (Dec. 1984), pp. 745-749.

Molfino, J.H. (2012). Características Grupos CONEAT (MGAP). INIA – GRASS. http://sig.inia.org.uy/sigras.

Molfino, J. (2013). Potencial agrícola: algunos cálculos para la agricultura en secano. Revista Cangüé 33:14-18.

Murtaugh, P. A. (2009). Performance of several variable-selection methods applied to real ecological data. *Ecology letters*, *12*(10), 1061-1068.

Pauletti, M., Terra, A. and Perranchon, J. (2016). Las rotaciones agrícolas - ganaderas en Uruguay "un clásico." Revista Plan Agropecuario, No. 159.

Palmquist, R. (1989). Land as a Differentiated Factor of Production: A Hedonic Model and Its Implications for Welfare Measurement. Land Economics, Vol. 65, No. 1 (Feb., 1989), pp. 23-28.

Palmquist, R. and Danielson, L. (1989). A Hedonic Study of the Effects of Erosion Control and Drainage on Farmland Values. American Journal of Agricultural Economics, Vol. 71, No. 1 (Feb., 1989), pp. 55-62.

Plantinga, A. and Miller, D. (2001). Agricultural Land Values and the Value of Rights to Future Land Development. Land Economics, Vol. 77, No. 1 (Feb., 2001), pp. 56-67.

Rosen, S. (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. Journal of Political Economy, Vol. 82, No. 1 (Jan. - Feb., 1974), pp. 34-55.

Smith, T. (n.d.). Notebook for Spatial Data Analysis. Part III: Aerial Data Analysis. Class notes, University of Pennsylvania. Retrieved from https://www.seas.upenn.edu/~ese502/NOTEBOOK/Part_III/2_Modeling_the_Spatial_Structure_of_AreaA_Units.pdf/ [Online Resource]

Vásquez, F., Cerda, A. and Orrego, S. (2007). Valoración económica del ambiente. Fundamentos económicos, econométricos y aplicaciones. Thomson Learning, Buenos Aires, Argentina.

8 Appendix 1: the 2004 Anthropic Erosion Map

The 2004 Anthropic Erosion Map defines four levels of erosion intensity:

- Mild erosion. Mainly sheet or inter-furrow erosive phenomenon. Reduces original topsoil by less than 25% in average. Soil loses productivity but not aptitudes or use capabilities.
- Moderate erosion. Sheet or inter-furrow erosive phenomenon with some canaliculus formation. Reduces original topsoil in between 25% and 75% in average. Soil loses part of its aptitudes and diminishes moderately its use capabilities.
- Severe erosion. Sheet or inter-furrow erosive phenomenon with formation of canaliculus and gullies that reduces the soil in an amount equal to original topsoil. Soil loses most of its aptitudes and diminishes its use capabilities significantly.
- Very severe erosion. Erosive phenomenon in canaliculus and gullies that reduces the soil in an amount greater than original topsoil and prevent the normal traffic of agricultural equipment. Soil diminishes its aptitudes and use capabilities to soil recovering activities.

Erosion extension is defined in the following way:

- Infrequent: 1-5% of land tract
- Common: 6-10% of land tract
- Frequent: 11-25% of land tract
- Very frequent: 26-50% of land tract
- Dominant: more than 50% of land tract

Gullies' depth and extension are defined in a similar fashion. Depth is defined as follows:

- Shallow: up to 50 cm
- Moderately deep: 50-100 cm
- Very deep: more than 100 cm

Extension is defined as follows:

- Isolated (less than 1% of land tract). Does not affect soil use.
- Common (1-10% of land tract). Affects soil use and modifies it in localized areas
- Frequent (11-50% of land tract). Affects soil use and modifies it in significant areas
- Dominant (more than 50% of land tract). Affects soil use and modifies it almost completely