Agricultural land prices in Uruguay in the long-run (1900-2010): an empirical approach from the technological change

Pablo Castro
castroscavone.pablo@gmail.com

Victoria Pradines
victoriapradines1984@hotmail.com

Verónica Rodríguez
vero.r.riestra@gmail.com

Henry Willebald
hwillebald@iecon.ccee.edu.uy
Economic Institute, Faculty of Economics, Universidad de la República, Uruguay*

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[Abstract]

We demonstrate that the dynamics of the technological change determines the trajectory of the prices of the land used for agricultural activities even when we control with other explicative variables related to the agrarian market (prices of agricultural commodities and interest rate), institutions (holding regime, size of the holding and landownership concentration) and endowments (land quality and distance). We represent the technological change applying a Neo-schumpeterian approach and admitting that the formation of land prices responds to long-run forces (in an accumulative way) and localization factors. Therefore we propose empirical exercises considering a panel data analysis for a very long run period (1900-2010) and provincial data (18 administrative jurisdictions in Uruguay). Literature about technological change offers scarce suitable indicators for representing the improvements in the technical conditions of the agriculture in the long run. Our empirical strategy presents two steps to solve this problem. First, we review an extensive literature about the agriculture in Uruguay and interview qualified informers considering the main types of production (cattle, crops, dairy industry and forest) to obtain a description of the activity along the 20th century. Second, we represent numerically this qualitative description using a dummy variable and a functional approximation according to a Cauchy function. We test the statistical relation with promising results.

Keywords: agricultural land prices, technical change, Uruguay
JEL: N5, N56, O33, Q15.

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1. Introduction

Agriculture in Uruguay has been one of the main activities of the national productive development from the constitution of the country as an independent nation. The agriculture has followed different trajectories from the leadership of the 19th century as a real driven-force of the economic growth, until becoming a complementary and subsidiary sector of other activities along the 20th century. The sectoral specialization introduced cattle farming as the main agrarian activity but the transformation of the sector left the way for other productions in the second half of the 20th century as dairy industry, intensive farming and recently forestry and timber industry.

Since the beginning of the 21st century it is evident that agriculture has incorporated diverse modalities of technical progress expressed in terms of crops (soya, blueberry, pine, eucalyptus), new entrepreneurial organizations (large dairy estates) and the increasing application of biotechnology research. These trajectories have coincided with a sustained (and impressive) land price increasing (and the land rents) in agriculture. In particular, the coincidence of both types of trajectory is the motivation of our research. In other words, our initial question is, which is the role of the technological changes in different agricultural activities for the evolution of land prices?

In order to study the incidence of technological change in the economic performance we apply a long-run approach as technical progress is, by nature, an accumulative and tacit process with path-dependency specificity and long-term consequences. In addition, technological progress usually presents regional localization and geographical features. We propose to study the evolution of land prices in a very long period, from the beginning of the 20th century until 2010, considering regional disparities (provincial data) and adopting a sectoral approach (only considering agricultural lands for livestock, crops and timber industry).

Therefore, the aim of our paper is to study the influence of technological change on the conformation –regional and temporally– of rural land prices controlling for a set of variables and applying the panel data technique.

One of our main contributions is to represent technological change in the agriculture according to specific indicators developed within a Neo-schumpeterian approach of technical progress. In accordance with a Neo-schumpeterian approach, the technical progress follows different technological trajectories associated with the generation, application and diffusion of new knowledge, learning and creation of new capabilities. According to a deep revision of the technical literature and the systematization of specialized opinions (see Appendix 1), we construct a technological change index (TCI) for each province of the country to represent quantitatively the qualitative evidence initially surveyed.

Our control variables represent three explicative factors: institutional structure, market relations and endowments. As representative of the institutional structure we select variables related to land tenure modalities and the concentration of landownership. As measures of market conditions we use the real interest rate (as an opportunity cost of the financial resources) and the relative price of the agricultural production. Finally, endowments are represented by variables related to infrastructure –road density–, land quality and urban population.

The empirical results we arrived at support our initial hypothesis. Technological change is positively related to the rural land prices even when controlling with institutional, market and endowments conditions. The majority of the control variables are statistically significant and with the expected effects confirming our theoretical expectations.

2. Theoretical framework and analytical model

2.1 Conceptual issues

Land price presents particularities derived from its especial condition of immobile, durable and non-reproducible productive factor.

Most of the literature which attempts to identify and measure the determinants of agrarian land prices is based on the capitalization approach. The core of this approach is the principle that the price of agrarian land equals the net present value (NPV) of the stream of all future net incomes to land, as in the case of any other asset (Featherstone & Baker, 1987; Word Bank, 2011). According to this framework, the price of land is a function of the rents that will be obtained in the future from the use of land for productive activities. Therefore, the higher the expected rents, the higher are the land prices. However, as the landowner must wait to get the future rents, they must be actualized by a discounting rate and, in consequence, the land price results a function of the inverse of the interest rate (according to its feature of opportunity cost), meaning that higher interest rates will imply lower land prices.

More specifically, and following Carmona & Rosés (2012), the NPV is calculated by estimating the future stream of cash returns resulting from ownership of land, and discounting this cash flow based on the level of uncertainty inherent in the expected revenues. Analytically, the formulation is the following:

$$V_t = \alpha \sum_{j=1}^{\infty} \alpha^j E_t\left[R_{t+j}\right] \qquad (1)$$

Where,

V_t: is the equilibrium land value at the beginning of period *t*;

R_t: is the land rent paid in period *t*;

α: is a constant discount factor equal to 1/(1+*i*) where *i* is the constant real discount rate and determined elsewhere;

E_t: is the conditional expectations operator based on information available at time *t*.

In general, when the value of land is stable, land income is the annual rental for the land. However, when land value increases, the future rents are expected to be higher. As a result, land has two types of yields or returns, one directly associated with the productive activity and the other with land value appreciation (Dwyer, 2003; Gaffney, 1970). Our concept does not necessarily denote that the land market price results always equal to the present value of the future returns because there could be diverse circumstances affecting the market price but they do not have consequences on the present value (Burt, 1986; Alston, 1986). Therefore, land rents result from the aggregation of two factors (Melichar, 1979; Carmona & Rosés, 2012): the net residual income (R^r) and the net capital gains (R^c).

On the one hand, R^r represents the net return to land, accruing from the residual income after subtracting the return to farm labour, management and inputs that participate in the agricultural production (with the exception of land). In perfect markets, R^r equals the value of land marginal product (VLMP) or, equivalently, the marginal productivity of land times the output price (P*LMP). This is a long-run equilibrium identified with a market fundamental because it is based on fundamental economic variables (Featherstone and Baker, 1987). Assuming a constant land supply, the VLMP is a function of technological improvements, the cost of inputs (including labour and management), the marketing system (more market efficiency then less marketing costs), the distance and transportation systems, the market information system (which reduces uncertainty and also the probability of an inefficient transaction), tariffs and other macroeconomic measures affecting agricultural production and prices. The local demographic conditions also have a direct effect on VLMP because a growing population demands more agricultural goods and space for non-agricultural uses (Plantinga et al., 2002). When the land supply increases, this leads to a decreasing in land prices. This is the typical historical case of settler economies characterized by sustained land frontier expansion and the occupation of "new land".[1] When the land extension happens through low-quality, marginal or relatively isolated lands, average prices decreased more than predicted using constant quality supply shifts.[2]

On the other hand, R^c is defined as the change in land value induced by variations in opportunity costs or inflation (Lloyd *et al.*, 1991). This component is more related to land used as stores of wealth than to land used as a productive factor and, in this sense, it represents the non-fundamental price. It responds to expectations about the changes in the value of land due to alterations in prices and opportunity costs in other economic activities and, in consequence, it may be governed by arbitrage conditions (Bergoeing et al., 2002). Even though there are many varieties of speculative behavior that could cause actual land prices to diverge from market fundamental values. The stochastic bubble model developed by Blanchard and Watson (1982) and the fads model developed by Summers (1986) are the most cited models in the literature that refer to speculative process (Roche and McQuinn, 2001; Carmona & Rosés, 2012). Each

[1] See Willebald (2011) for a recent review on the matter.
[2] However, historically, the land frontier expansion was not always a Ricardian process (see Willebald, 2011).

effect stems from a different type of expectations that the relevant economic agents (decision makers) have and from the available information in the market (Featherstone and Baker, 1987). On the one hand, bubbles are of explosive nature and appear when investors trade in high volumes at prices that are considerably at variance with fundamental values. On the other hand, a fad is characterized by slower but more sustained price increases and falls (West, 1988). In particular, this could be the case of speculative movements of land prices based on the expectations that potential investors have about the trend of real land prices under inflation (or huge demand pressures) (Lloyd, 1994). There are also other non-fundamental factors, other than speculative behaviour, which could affect the evolution of land prices, such as state regulations, sectoral policies, taxation (Hoff and Stiglitz, 1993), transaction costs, liquidity constraints (Shalit and Schmitz, 1982), and institutional framework (Feder and Feeny, 1991).

2.2 Explicative factors and expected effects

In Table 1, we classify the factors that influence on the land price according to five set of conditions related to: market; endowments; technical progress; institutional; and public policy. We consider the expected effect of changes in these variables (*ceteris paribus*) and the incidence on R^r or R^c.

In term of the effects related to market conditions, permanent increasing in the prices of the agricultural commodities –factor *(a)*– imply rising in the VLMP and, in consequence, in the land price. However, the effect of an increasing in the prices of the input *(b)* has an ambiguous sign because it depends on the elasticities. Usually, it implies a reduction in the returns of the activity, in the VLMP and, in consequence, in the land price but in some circumstances the final effect can be the opposite. Other factor related with the market is the inflation *(c)*. When the general level of prices increases it is usual that agents reassign wealth from monetary assets to real assets (land) to reserve value and, in consequence, the VLMP and the land price rise. Increasing in the interest rate *(d)* has an ambiguous effect. On the one hand, it is reasonable to expect a reduction of the VLMP because it reduces de present value of the future returns. But, on the other hand, it can increase the land demand by wealth substitution (if the increasing of the interest rate reduces the relative returns of other assets, the investors react buying land).

Table 1

CONDITIONS, FACTORS AND EXPECTED EFFECTS ON THE LAND PRICE

Conditions related to:		Permanent change in (ceteris paribus):	Expected effect:	Affect:	
Market	(a)	Increasing in output prices	+	R^r	
	(b)	Increasing in input prices	? (-)	R^r	
	(c)	Inflation	+		R^c
	(d)	Increasing in the interest rate	? (-)		R^c
Endowents	(e)	Land aptitude	+	R^r	
	(f)	Location (distance to market)	-	R^r	
	(g)	Population increasing	+	R^r	
Technical progress	(h)	Incorporation of machinery and equipment	+	R^r	
	(i)	Improvement in the land management and input	+	R^r	
	(j)	Improvement in the agricultural marketing	+	R^r	
Institutional	(k)	Reduction in the costs of ownership transference	+	R^r	R^c
	(l)	Land fragmentation	-	R^r	R^c
	(m)	Tenure system (landownership vs leasing)	? (+)	R^r	R^c
Public policy	(n)	Investment in public infrastructure	+	R^r	
	(o)	Soil preservation programmes	+	R^r	
	(p)	Subsides to agricultural goods	+	R^r	
	(q)	Credits to land purchasing	+	R^r	
	(r)	Urban zoning	+	R^r	
	(s)	Land ownership taxes and agricultural income	-	R^r	

Source: Soto (2005) and own elaboration.

Considering the endowment effects, the agrarian aptitude (*e*) of the land is the more important factor. High quality land implies higher VLMP and superior prices. However, the location of the land (*f*) can be as important as the agrarian aptitude to determine the price. Those plots placed close to the points of sale or with access to better transport infrastructure or logistic system will have a higher price because the costs to putting the products in the markets are lowers. Finally, when population increases this means higher demand of goods and dwelling and the VLMP of agrarian land rises.

That technological progress –incorporation of machinery and equipment (*h*), improvements in the land and inputs management (*i*), and in the agricultural marketing (*j*)– that improves the land productivity increases the VLMP and, in consequence, the land price.

In institutional terms, the effects include contracting institutions and property rights institutions (Acemoglu & Johnson, 2005). Rules that reduce the costs of ownership transference (*k*) enlarge the size of the market, decrease the transaction costs between agents and increase the VLMP. The contrary happens when the fragmentation of land (*l*) is higher. The transaction costs result superior, usually the activity loses scale economies and the VLMP is lower. Finally, the tenure system (*m*) may induce certain behaviors in the economic agents that affect the land price. The higher quantity of proprietors in relation to tenants, the larger the land market, and it decreases the costs of transactions and the land price results higher. On the contrary, if the tenants are the majority of the contracts, the cost transactions are higher because the contracts are repeatedly celebrated and the disposition to invest results inferior, meaning lower land values. However, this relation may be mediated by other opposed effects. On the one hand, the number of transactions it is important to expect these relationships and, in fact, to consider a market that really works. On the other hand, the situations change depending on the time leasing of contracts. If in the economy predominates long-time contracts this mean a situation where landownership and tenancy are almost equivalent positions and the sign of the relationship would result ambiguous. Both points are important in Latin America because the *latifundia* has been an structural feature of the landownership system and the leases have been, mostly, short-time contracts.

Lastly, the public policy has a broad and varied field of action to influence on the land price. Investment in public infrastructure (*n*) reduces the costs of transport and communication. Soil preservation programmes (*o*) improve the land productivity. Subsides to agricultural goods (*p*) increase the consumption and, probably, the land demand to produce primary commodities. Similar effect presents the credits to land purchasing (*q*). Changes in the regulation that implies urban zoning (*r*) can mean the substitution of agricultural land by real-estate projects. All these factors increase the VLMP and, in consequence, the land price. A couple of possible factors of decreasing in the land price are the land ownership taxes and agricultural income taxes because they reduce the VLMP.

In section 4, we present a set of variables as proxies of these different factors and an analytical model to represent their influence on land price. Previously, it is convenient to discuss about three topics because they will organize the proposal; they refer to the techniques of estimation, the analytical modelization and the special focus of our study on technological progress.

(i) Estimation method: several explicative factors of the land price have a long term orientation. In particular, institutional and technological issues constitute subject of the long term analysis and our efforts are in the explanation of long-run processes. In addition, the location of land constitutes a key determinant of the land price and, in consequence, to introduce the regional analysis contribute with the explanation of the price evolution. We face the double necessity of analyzing the price of the land, for different places and for long periods. Therefore, we consider annual data for 1900-2010 and single out several regions of Uruguay that we identify with administrative spaces of the territory (*departamentos* or provinces). We consider that panel data (or cross-sectional time series data) constitute a good technique to face our problem because it is able to work with two dimensions. In effect, there are two kinds of information in cross-sectional time-series data: the cross-sectional information reflected in the differences between subjects (20 *departamentos*), and the time-series or within-subject information reflected in the changes within subjects over time (110 years). Panel data regression techniques allow us to take advantage of these different types of information.

(ii) Analytical modelization: We use a model to represent the influence of each factor on the land price assuming additive and linear relationships. Soto (2005) offers a theoretical perspective to represent some of the main stylized facts of the land markets in Latin America and our analysis is consistent with his approach.

(iii) Technological progress: technological and institutional factors constitute those of more difficulty empirical representation. Our efforts focus on representing adequately the technological change in the agriculture in accordance with the Neo-Schumpeterian Economics. In next stages of the research we will advance into discussing and identifying more properly the institutional factors. Considering we pay especial attention to the construction of technological change indicators, we devote a particular section to this topic and afterwards we present our analytical model.

3. Technological change: theoretical and empirical issues

This section focuses onto three related issues. First, we present a conceptual framework to understand the technological change from a Neo-schumpeterian approach. Second, we describe the main features of technological change in the Uruguayan agriculture in the course of the 20th century. Finally, we present our indicators of technological change and different measures to approximate the evolution and the level of the technical progress.

3.1 A framework to understand technological change

Following the Neo-Schumpeterian theory of competition and its microeconomics analytical framework (mainly the precursor studies of Richard Nelson, Sydney Winter, Christopher Freeman and Giovanni Dosi, among others, in the 1980s), static equilibrium analysis is considered as inadequate to deal with the essentially dynamic features of the capitalist economy (Possas, 1989). It is replaced by the analysis of endogenous industrial dynamics, where equilibrium is neither a necessary outcome, nor a methodological requirement.

In this conceptualization, competition is in the centre of the theory and technological paradigms and trajectories are the basic evolutionary analytical tools (Dosi, 1984) because they explain the long-run performance of economies and sectors (both regularities and changes). Technological paradigm is a concept borrowed from Kuhn's scientific paradigms, sharing its cyclical, non-linear direction of knowledge evolution in specific areas, as well as the relevance of the diffusion and reproduction of common references, procedures and approaches within a relevant community. Technological trajectories are seen as a time sequence of progressive shifts of trade-offs between techno-economic variables, corresponding to a given technology, which indicate technological progress and which derive from innovative efforts of firms and institutions. A paradigm may entail different trajectories (corresponding to products and processes) that make possible it evolves and reproduces itself, and to whose progressive exhaustion it owes its being transformed in (or surpassed by) other paradigm.

With this theoretical framework, sector, firm and institutional specificities should receive great emphasis, since innovative efforts, by definition, lay on the search of technological diversity and market opportunities to get differential returns from de productive activities (Possas, 1996). The analysis of competitive forces should focus mainly on factors that generate structural competitive advantages such as technological prospects, cumulativeness (learning process) and appropriability (profitability) that characterize the economic performance (Dosi,1984). Competitive capacity depends on the ability to match a firm's organization and strategy to the technological, social and economic restrictions imposed by the business environment. They are, in particular, the notions of technological trajectories (Nelson & Winter, 1982; Winter, 1984; Malerba & Orsenigo, 1993, 1996), technological paradigms (Dosi, 1982, 1988) and sectoral systems of innovation (Malerba, 2004), which put especial emphasis on the importance of sectoral characteristics of technological change and the competitive process more generally.

On the one hand, Nelson & Winter (1982) and Winter (1984) consider two modes of innovation as valid characterizations of distinct technological trajectories or "regimes" that represent intrinsic differences between particular sectors (Prenader, 2007). The "distinction between the two Schumpeterian regimes involves a reversal of the relative roles of innovation by entrants and established firms. An 'entrepreneurial' regime is one that is favourable to innovative entry and unfavourable to innovative activity by established firms; a 'routinized regime' is one in which conditions are the other way round" (Winter, 1984, p. 297). The first regime is characterized by the "creative destruction" and the evidence of "radical innovations", and the second one by "creative accumulation" and the predominance of "incremental innovations" (Malerba, 2007).

On the other hand, combining quantitative information with visual inspection and inductive reasoning, Pavitt (1984) created an empirical classification of sectors according to the main features of the technological paradigms among its innovating firms. His taxonomy of "sectoral technological trajectories" classifies industries according to three categories (i) science-based firms; (ii) production-intensive firms; and (iii) supplier-dominated firms; and the second group is further subdivided into the classes of scale-intensive production or specialized suppliers. Pavitt's taxonomy has been extremely influential shaping the basic conceptual categories for a number of related classifications but it has been seriously challenged by scholars put a strong emphasis on the observed variety of technological behaviour within sectors (see a review and a new proposal in Prenader, 2007).

Under Pavitt's classification, agriculture should clearly be considered as a 'supplier dominated' sector. Like many industrial sectors under this heading, most of its markets show a very low concentration degree and (practically) absence of oligopolistic relations; product homogeneity and a high level of price competition; limited ratios of technical change and a very constrained capacity of innovating by its own means (generally with insignificant R&D expenditures). Innovations and technical change in agriculture are almost entirely due to supplier industries, both equipment manufacturers and input suppliers (fertilizers, seeds, pesticides). In addition, the remarkable presence of public policies and of public institutions providing research funds and carrying out research activities cannot be overlooked. All of this could be taken to suggest that an approach focusing on innovation and competition would be misplaced here. However, as mentioned before, sector specific characteristics are not only acknowledged in this approach; they constitute its very basis. Agriculture (and its specialists, economists or whoever else) should not claim to be so different from other (industrial) economic activity sectors as to justify a whole economic analysis, or even a theory, for its own use (Possas, 1996).

For instance, the existence of technological trajectories and even a convergence between some of them may be a decisive factor to understand the main long-run trends of this sector. The abundance of small business units in agriculture should not imply that they are nothing but price takers with no strategy at all and that would not have sense the study of their market and technological behaviour. The extended presence of the state –usually under specific programmes of regulation, productivity and financial support– and research institutions –in general supported by public funds– in the agriculture should not lead to the false presumption that deterministic nonmarket trends (either technological and/or institutional) definitely prevail over market concerns. Then, what are the fundamental specific features exhibited by agriculture for an economic dynamic analysis? In brief:

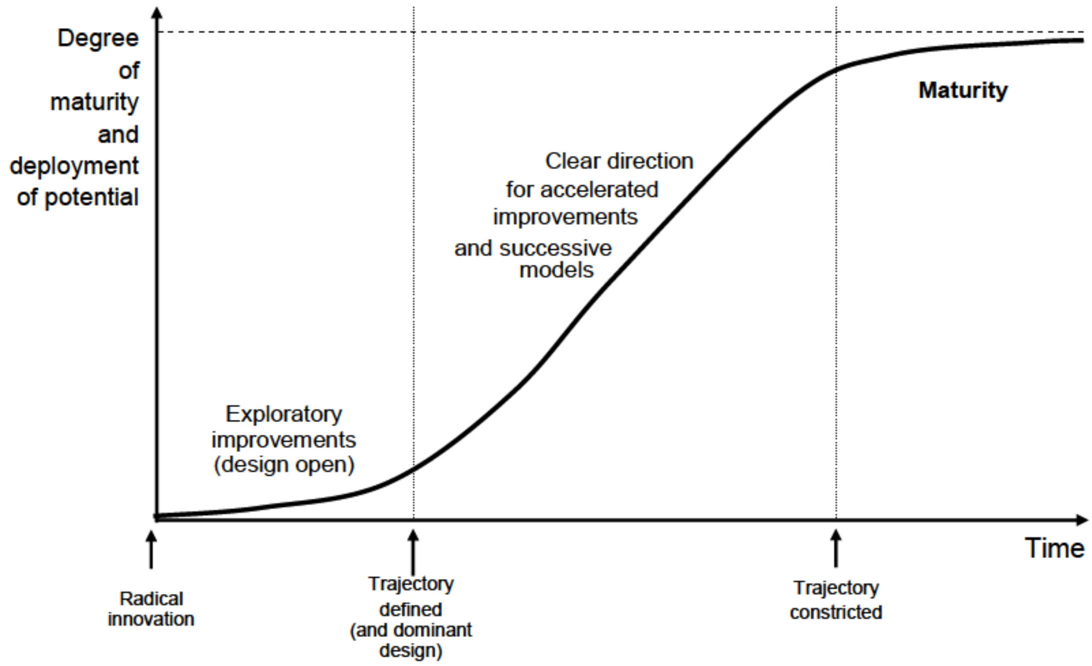
- Technical basis of production depends strongly on natural conditions, which affect its technological trends.
- Sources of cost reduction associated with business size and range (the economics of search and scope) are very limited.
- Size and organizational characteristics of productive units vary widely, but there are strong conditions limiting their growth and diversification range.
- Its degree of technological appropriability is very low implying a considerable lack of attractiveness of R&D and other innovation efforts specifically by agricultural firms. However, agricultural markets are also permanently subject to technology improvements, upstream innovations and learning processes through interaction with suppliers (for instance the equipment manufacturers) which create competitive advantages over competitors in terms of cost, price, productivity and quality, just as in other markets.

According to Pérez (2009), radical individual innovations are introduced in a relatively primitive version and, once market acceptance is achieved, they are subjected to a sequence of incremental innovations following the changing rhythm of a logistic curve (Figure 1). Changes occur slowly at first, while producers, designers, distributors and consumers become involved in feedback learning processes. They take place rapidly and intensively once a dominant pattern is established in the market and slowly once again when maturity is reached and operates diminishing returns to investment in innovation.

The frequent minor innovations in product and process improvement that follow the introduction of any new product have an important impact on productivity and market growth. It has been shown that, sometimes after the take-off, both the number and the importance of incremental innovations tend to overtake product changes. As production volume and productivity become crucial for market expansion, process innovations drive most of the scaling-up investment. What holds for individual technologies in terms of regularities in the dynamism and direction of technical change occurs also at the meso level, in relation to the evolution of all the products in an industry and to that of whole sets of interrelated industries. Obviously, these notions represent only the general patterns and there are multiple deviations and exceptions in specific cases.

Figure 1

THE TRAJECTORY OF AN INDIVIDUAL TECHNOLOGY



Source: extracted from Perez (2009), p. 3.

3.2 Technological change in the Uruguayan agriculture

The technological innovations in the agriculture are not isolated facts but they answer to certain processes that form a group of technical changes aimed to solve a problem which must be tackled from different angles. In consequence, the importance of having a theoretical framework to incorporate the accumulative and tacit character of the technological progress in our analysis results a fundamental issue to understand the process. The dynamics followed by the technological change in the Uruguayan agriculture should not be considered in an isolated way but in interaction with the technical changes in the rest of the world. However, dealing with this subject exceeds our aim and it will be matter of next steps in the research. Our analysis shows the modalities that characterized the technological development in the four most important activities of the agricultural production in Uruguay: cattle –dividing between, on the one side, meat and wool and, on the other, dairy industry–, crops and forestation.

The more important technological facts in the cattle farming section refer to animal feeding, health, genetic improving and management. We analyze each of these categories considering a review of the long-run evolution of these transformations in the agriculture to present an historical overview.

From 1860 to the first decade of the 20th century, the modernization of the national economy in productive terms was based on three basic pillars: the incorporation of the sheep in the national livestock in a significant scale, the agricultural fencing and the crossbreeding in the cattle production (Millot & Bertino, 1996). These elements meant a definition in the technological trajectories of the agriculture consisting of reaching the highest levels of productivity without promoting deep changes in the natural prairie. That stage based on the pressure on the natural prairie extended beyond the times of the First World War (WWI) and it would became in the main problem on the national cattle stagnation in the following decades that literature refer as the "fodder restriction" (Bertino et al., 2005).

The mechanical innovation such as wire-fencing, the biological innovation such as the introduction of sheep and the genetic improvement, should give spaces and opportunities for innovating in chemical and agronomical fields. These innovations would allow the development of the fodder growing, artificial prairies and other measurements able to break out the food restriction imposed by the natural prairie. The farming and the breeder societies had an active role in the first attempts to transfer technology from abroad and the state took part, more or less actively, in this process. In all cases, the private efforts meant a relevant contribution because the associations and corporations made easier the link between the knowledge supply from abroad and the local demand. However, efficiency in transferring technology between different realities could not be done in a natural way; it requires an effort in accumulative learning applied to specific context that rarely had successful results during all the first half of the century long.

In the 1950s, some types of fertilizers started to be used although the phosphate was the predominant to increase the production of legumes in the composition of the prairies. The fail in the intention of having artificial prairies in a permanent way or having new varieties is a matter recognized in the specialized literature. The activities developed by the individual producers lacked systematization and appeared with serious ignorance of the Uruguayan specify talking about an integrated ecosystem. For this reason the aim to successfully apply the technological packs that were used in Australia and New Zealand were resisted in the Uruguayan environment. This situation generated the self-conscience referring the importance of the state role in this subject. In the period 1961-1976 the new activities were encouraged by the Comision Honoraria del Plan Agropecuario (a special commission of the Agriculture Board) and the starting of researching and diffusion activities during the 1960s and the beginning of the 1970s. The most dynamic period in terms of scientific divulgation was from 1966 to 1970 and it represented a significant change for the national agriculture

In the late 1960s the Plan Agropecuario had advanced in the spreading of the material which covered several areas. In the mechanical techniques to improve lands was especially important the use of the Australian keel sowing machine, the use of aerial fertilizing and the use of sucking harvesting machines to produce clover seeds. In the biological area there were advances in the classification of different species and basic varieties of legumes and gramineous to be included in the improvements. In the chemical area there were no important changes while in the agronomical area it was recommended the subdivision of pasture-ground, the building of drinking-water areas, the preparation of the soil before planting and some regulation in the dealing with improved prairies.

In the late 20th century, the transformations showed an important increment of productivity in the subgroup of the bovine livestock which was based on three pillars. First, the improvements in the animal feeding consider forage and artificial pastures. Second, improvements regarding to changes in the management and diagnosis of cow pregnancy, as well as, the establishment of intensive feed lots, constituted important contributions for the progress of agriculture. Lastly, there were important changes in the feeding complements on basis of concentrated, supply, silos, packs, and mineral salt (Tommasino, 2010).

In this context, the dairy industry developed in a different way than meat and wool production. Dairy faces high cost, which are originated in more nutritional requirements from the milk cattle. This means a deeper transformation of the physical surrounding than the traditional agriculture to complement the natural prairie and to soften the annual variability of the production. This even leads to a higher endowment of productive means. The no-lasting of milk imposes additional cost such as storage and transportation and it even presents more requirements in the external infrastructure as bigger places where cattle-raising and a higher level in the capacity of working hands. It is a sector which historically has counted with the protection of the state in a context where internal market plays a leading role. These characteristics are taken in to account to expect the use of technology in the dairy activity and to allow a “technological leap” that has to be relevant to understand the process (Paolino et al., 1982).

The developed of the agro-industrial dairy complex was deepened in the middle 1970s. It was characterized by an increment in the agro-industrial productivity, diversification of the volumes of exported dairy derivatives, the renovation and amplification of the industrial park and the business restructuring in the dairy farming. In this context, the agro-industrial expansion and integration pulled relevant modifications based on productive techniques, cold storage, transport, manufacturing and entrepreneurial organization (Paolino, 1985, p. 121).

Nutrition was the technological subject with the major incidence in the productive result of the dairy activity in the period 1977-1982. Spreading of nutritional aspects of the new technology was done in a good rhythm. Spreading activities were, basically, the diffusion of agronomical practices related to the implantation and dealing with different fodder mixtures, supply of concentrated and the use of different kinds of pasture (Paolino et al., 1982).

In the 1990s some important changes in the animal alimentation started with increasing intensity. These consisted in the use of concentrated supplements and hay, and silos were employed at the same time as the increment in the productivity.

In addition, advances to a much more intensive use of the animal load/hectare, the pasturing regime and the pasture rotation in zones with electrical fences to preserve the forage potential constitute relevant subjects in this evolution. These measures imposed higher level of investment in fixed assets and more efforts in the administration of resources. Regarding the dealing with the milking stock some improvement were recorded to take advantage as much as possible of the pastures and some systems of control and record of the reproductive and productive performance. These practices require high levels of training of the staff. Finally, the practices of milking and preservation of milk in the off-premise demand requires higher levels of investment in fixed assets and a high qualification of the workers.

While the fodder restriction stops the adoption of new technology, the genetic level of cattle could be a brake for productive development. In this area the introduction of genetic plasma of high selection predominated, and it expressed in reproducers and imported frozen semen which meant very important technical advance. As well as genetic improvement, the knowledge added to the costs related to health made it possible to adopt and trade them in private enterprises. Many health campaigns have been done in the country to struggle diseases as brucellosis, aphthous, tuberculosis, sheep-tick and echinococcosis. These campaigns generally happened between the early 1960s and late 1970s directed to cattle in general. They were intensified in the dairy industry in the last years, particularly in the dairy valley of Montevideo.

The advance in machinery directly affected the reserve of animal food. It is notorious the important presence of forage choppers and, in the 2000, one of five farms had this kind of machinery. On the other hand, direct sawing showed a very important role in the technological changes in last decades. The substitution of conventional forage agriculture for direct sawing represents one of the most relevant changes in this period. Some of the more promising consequences were as less soil erosion, minor needs of inputs (fuel, labor) decreasing levels of capital in machinery, less traction power and lower efforts in ploughing. At the same time, the direct sawing system allows a greater use of nitrogen fixed in leguminous, reducing urea dependency, proving convenient in economical results and for long run effects on the environment (Duran, 2004, p.119).

In agriculture, until the end of the 1960s the most relevant technical change was the mechanization which, associated with some management practices, enabled the expansion of the wheat. This did not cause a relevant change in the levels of productivity of the farms but it increased the labor productivity. At the beginning of the 1970s, it was a technological package which provided the main limiting physical factors of the crop productivity (Duran et al., 1985). This technological pack included improvements in several ways. They included rotation systems, preparation and management of the soil erosion and sawing season. Regarding genetic material the main improvements included a higher variety of seeds with superior quality. There was an advance in the use of agrochemicals such as fertilizers, products for the control of underbrush, plagues and diseases. Lastly, there was a major use of farming machinery which allowed enlarging the rate of production and income.

During the period, one of the most important changes was the increment in the number and power of tractors. Numbers show that in 2000 the 80% of the farms used tractors. A remarkable complement of farming tools are the chisels, the ploughing machines (they substitute the disc and reil plough) and lastly the sawing machine for direct sawing which had an important role during the last decades.

Regarding to chemical innovations the use of fertilizers has been an essential need to increase the levels of productivity during the 1970s. Historically, the farming production was based on the development of natural resources, and this led to a bad damage to then physical and chemical characteristics of the soil.

Changes did not occur in available fertilizers nor emerged new varieties of grain. In the 1970s, the use of herbicides was one of the components of the transformations. In this period appeared new chemical formulations of broad spectrum and with great selectivity for different crops (summer or winter). In addition, highlighted significant changes in the quality of the products, pointing to that formulation had lower environmental impacts. An important contribution in the 1990s was the use of glyphosate, which opened the possibility of cultivation with minimum tillage of the soil and, in turn, also allowed a strong fuel economy as well as a system that made it possible to reduce the risk of soil erosion.

To conclude with this run over for the different sectors of activity, we refer to the forest activity. With the promulgation of specific norms in the second half of the 1980s, forest planting started to intensify until reaching nowadays a total of 1.292.348 implanted hectares (2010 census). This process was favoured by the high rates of growing in the main forest species and also topology that adapted very well to this activity. At the same time, the international context and institutional strength in Uruguay attracted national and foreign investments which guaranteed the development of the sector. From 2000 onward industrial activities were consolidated with a high level of technological development. The main areas are pulp and cellulose, chopping, boarded and serrated wooden panels. The National Institute of Agricultural Research (INIA) remarks the progress in the work done at National Research Programme for Forest Productivity, the support of the Agricultural Boar (MGAP) and Japanese cooperation (JICA). The most remarkable facts which result of the joining between demand and research are the following: design, fixing and consolidation of a program in genetics; the incorporation of Japanese technological cooperation, which ensures a last generation infrastructure in equipment and laboratory; the installation of more than 120 country essays in enhancing and dealing with in agreement with forest enterprises; the register in the INASE of the first variety of eucalyptus in the country; the installation of the first seed orchard of Pinus Taeda in the country; and the development of the first system of support for planting eucalyptus Grandis in Uruguay (SAG).

A remarkable element which has contributed to the development of the activity is the silvopastoralism that means integration of the forest and cattle production. This strategy makes an alternative to small cattle producers who show a growing interest in the incorporation of trees to their productive system. Forest activity is new in Uruguay and it seems to be going along the new paradigm of environmental sustainability. At INIA the forest program interacts with the Program of Sustainability Environmental, a specific project that aims to develop valid local indicators to foresee environmental impact of the forest productive system.

To sum, from a long run view, the literature analyzed in this section and the elements taken from diverse interviews with specialized informers leads to some conclusions. First, the main problem in the breeding of cattle has been mainly explained on basis of forage restriction. In spite of the important changes that happened in the 1960s referred to the transference of technology from abroad, the cattle stagnation in a great part of the country could not be overcome. On the other hand, dairy achieved better results adopting technology from abroad. This good performance was fundamentally given by dairy characteristics. However, results were different in the same group, favouring producers who were able to face the new context. Dairy sector has demonstrated great dynamics in the last decades of the 20^{th} century and this situation has deepened during the last years.

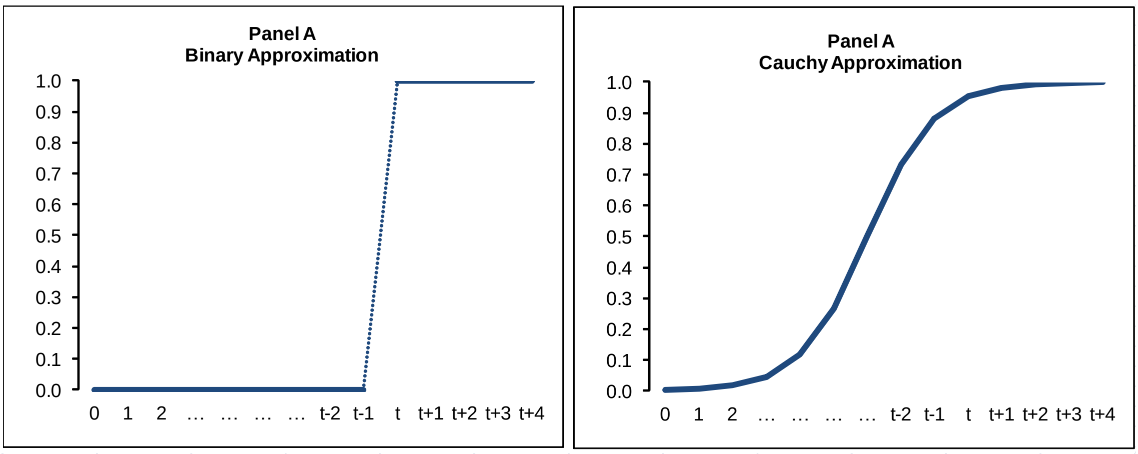
Meat, after a long period of steadiness, seems to have started an important growing process associated to technological, biological and agronomical changes under the slogan of "doing things" refer to intensive use of soil. Agriculture which historically occupied a secondary role seems to have started, since the 1990s, a growing process, mainly associated with the increasing of grain where wheat and soya present a central position. Lastly, forestation is a relatively new production in Uruguay but it has great potential to constitute a new agro-industrial activity. The strategy of public-private participation, significant supported by Dirección General Forestal of the MGAP and INIA have played a very important role in the generation and application of knowledge in the forest production.

3.3 *Measure of the technological change*

In a previous work (Castro et al., 2012), we proposed a very simple representation of the technological change. From the trajectories recognized in the Uruguayan agriculture along the 20th century, we were able to identify two stylized periods for each production, considering *t* as the cutting year, where *t* represents the year from which the technical change is generalized (see Panel A in Figure 2). In this sense we call this approach as "binary approximation". Obviously this is an extreme simplification. Strictly, with this representation we miss the fundamental features of technological change in terms of accumulative process, trajectory and path-dependence. Therefore we use an alternative operationalization based on the diagram presented in Figure 2 (Panel B) that we call "Cauchy approximation".

Figure 2

THE TRAJECTORY OF TECHNICAL CHANGE: OPERATIONALIZATION



In accordance with the pattern of a trajectory characterized by the introduction of an innovation in a primitive version and, once market acceptance is achieved, it is subjected to a sequence of incremental innovations and slowly once again when maturity is reached operating decreasing returns to investment in innovation. Following Perez (2009), this changing rhythm can be represent by a Cauchy curve next to zero when the innovation is (almost) inexistent and is next to one when the process slows down and the maturity of the technical progress is reached.

[To be completed]

4. Analytical model

We consider the impact of different factors on land prices according to market, endowment, technological, institutional and public-political considerations (see Table 1). We represent this relationship linearly through the following equation:

$$LP_{i,t} = \beta_0 + \beta_1 M_{i,t} + \beta_2 E_{i,t} + \beta_3 T_{i,t} + \beta_4 I_{i,t} + \beta_5 P_{i,t} + \varepsilon_{i,t}$$

Variable definitions are the following:

$LP_{i,t}$: is the real land price; it expresses a relative price as the relationship between the land price of the province *i* in the period *t* and the consumer price index in time *t* (it is the same for all the country).

$M_{i,t}$: is a matrix of variables considered to evaluate market influence.

$E_{i,t}$: is a matrix of variables considered to evaluate endowments influence.

$T_{i,t}$: is a matrix of variables considered to evaluate the influence related to technological progress.

$I_{i,t}$: is a matrix of variables considered to evaluate institutional influence.

$P_{i,t}$: is a matrix of variables considered to evaluate the influence related to public policy.

t: represents each year between 1900 and 2010.

i: represent each province with *i*= Artigas, Canelones, Cerro Largo, Colonia, Durazno, Flores, Florida, Lavalleja, Maldonado, Montevideo, Paysandú, Rio Negro, Rivera, Rocha, Salto, San José, Soriano, Tacuarembó, and Treinta y Tres.

ε_{it}: is a white noise.

We use lagged explicative variables to reduce –at least partially– the endogeneity problems.

The model estimated contains the whole of the variables expected a priori to be significant to explain the movement of the prices of the farming land in a long run (see definitions and sources in Appendix 2). We test several specifications of the model excluding non-significant variables and obtain a reduced form considering our general model as follows:

$$lp_{i,t} = \alpha_0 + \alpha_1 hold_{i,t} + \alpha_2 size_{i,t} + \alpha_3 theil_{i,t} + \alpha_4 api_{i,t} + \alpha_5 ira_{i,t} + \alpha_6 tc_{i,t} + \alpha_7 denspop_{i,t} + \alpha_8 dist_{i,t} + \alpha_9 pci_{i,t} + \mathcal{E}_{i,t}$$

Where,

- $lp_{i,t}$: real index price of the land.
- $hold_{i,t}$: holding; number of renters/ number of owners.
- $size_{i,t}$: average farming and breeding size = farming and breeding area/ number of farms.
- $theil_{i,t}$: index of landownership concentration
- $api_{i,t,j}$: agrarian price index.
- $ira_{i,t}$: real interest rate (adjusted).
- $tc_{i,t}$: dummy or Cauchy variable of technological change.
- $denspop_{i,,t}$: density of population; population/provincial area
- $dist_{i,t}$: distance between the capital of the province and Montevideo/density of roads; density of roads = Km of roads by province/ provincial area.
- $pci_{i,t}$: index of the productive capacity of the land.

Our econometric analysis aims to look at both spatial (our comparative approach) and temporal (our long-run analysis) dimensions. We consider therefore that panel data analysis provides the best methodology to test our main hypotheses. The spatial dimension pertains to a set of cross-sectional units of observation (provinces) and the temporal dimension corresponds to annual observations of a set of variables characterizing these cross-sectional units over the 20th century and the first decade of the 21st century. We consider the most suitable model for each case among fixed effects (FE) and random effects (RE). As it is usual in the literature, we initially tested the correlation between the individual effects and other regressors with the Hausman test to confirm whether the results allow us to reject the null hypothesis of no correlation and to use fixed effects model. Otherwise, if we cannot reject it, we estimate the model using random effects. In addition, we tested the significance of the individual effects computing the Breush-Pagan for random effects, and the use of the F statistic for fixed effects. To control for heteroscedasticity we always use robust standard errors.

5. Results

In Table 2 we present our econometric results considering market, endowment, institutional and technological factors. In general, we obtain the expected signs of the coefficients.

In accord with our hypothesis, the positive impact of the agricultural prices (*lnapi*) on land prices demonstrates that the valuation of the agricultural production improves the producer expectations and, in consequence, they are able to support higher land prices. However, higher interest rates signify an increased cost of opportunity of the investment in land and the influence results negative.

Considering institutional factors, we obtain positive signs for the influence of our indicator of holding regime (*lnhold*) on land prices. By construction, this result signifies that higher proportion of land lessees on landowners implies higher land prices, and it is evidence of greater dynamism of land market. In a similar way, those provinces with higher concentration of land ownership (*theil*) and average size of the holding (*size*) are related with lower land prices probably because both factors are associated with narrow markets and low volume of transactions.

Table 2
ECONOMETRIC RESULTS

Dependent Variable:

Real index of the land price (ratio between land price and consumption price)

		Model 1 FE	Model 2 FE	Model 3 RE	Model 4 FE
	Constant	**45.440** (1,9)***	**46.082** (1,94)***	**83.216** (4,43)*	**61.503** (2,48)**
Market	**lnapi**	**14.183** (7.98)*	**14.444** (8.28)*	**11.565** (6.76)*	**12.010** (6.44)*
	lnria	**-3.581** (-17.26)*	**-3.509** (-16.16)*	**3.620** (-16.91)*	**-3.606** (-15.28)*
Institutions	**lnhold**	**35.732** (10.18)*	**35.207** (11.06)***	**34.827** (11.84)*	**35.807** (12.13)*
	theil	**-23.877** (-2.64)**	**-23.820** (-2.54)**	**-25.236** (-3.09)*	**-27.240** (-2.83)**
	size	**-0.014** (-2.53)**	**-0.014** (-2.5)**	**-0.148** (-3.45)*	**-0.0134** (-2.67)**
Endowment	**lnpcl**	**0.456** (2.49)**	**0.4413** (2.39)**	**0.231** (1.96)**	**0.449** (2.35)**
	denspop	**1.919** -0.18		**-0.379** (-0.04)	
	dist	**0.000** (3.35)*		**0.000** (3.69)*	
Technological change	**tccauchy**			**24.351** (5.18)*	**23.711** (5.13)*
	tcdumm	**23.875** (6.66)*	**23.535** (6.73)*		
	Within	0.4441	0.4422	0.4282	0.4293
	Between	0.1313	0.1358	0.1698	0.1356
	Overall	0.2717	0.2726	0.3422	0.2652
	F	62.97	78.62		73.03
	(Prob)	0	0		0
	F all u_i=0				
	(Prob)				
	Wald chi2			637	
	(Prob)			0	
	Observations	1978	1978	1978	1978

All coefficients were estimated with robust standard error (p-value in italic).
Significance level: *** (1%), ** (5%), * (10%).

Taking into account the productive endowments we obtain a couple of unexpected results. On the one hand, and in accord with our hypothesis, higher land quality (*lnpcl*) influences positively on land prices. However, on the other hand, the population density (*denspop*) is not significant to explain the land prices and the distance to Montevideo (*dist*) has a positive influence. We have two reasons to explain these unexpected results. The increasing in the density of population in Uruguay in places different than the capital of the country never was a problem. Uruguay is one of the typical cases of urban macrocephalia in Latin America and it has concentrated around the half of the (small) population in Montevideo along the 20th century. The distance to Montevideo is not a factor that reduces land prices but it is related to higher values. Uruguay is a small country, without geographical accidents than impede dramatically the communication among the different points of the territory and where, probably, the relative simplicity to connect people and production with the neighbour countries diminish the relevance of the proximity to Montevideo.

Finally, our indicators of technological change offer very interesting results. According to our hypothesis, the technological change in the agriculture would improve the expectations about the future of the production. The significant and positive coefficients obtained in all the models show this favourable influence of the agricultural technification on land prices.

6. Conclusions

Technological change is a determinant of the long-run evolution of land prices in the agriculture. We demonstrate that the dynamics of the technological change determines the trajectory of the prices of the land used for agricultural activities even when we control with other explicative variables related to the agrarian market (prices of agricultural commodities and interest rate), institutions (holding regime, size of the holding and landownership concentration) and endowments (land quality and distance).

We propose a Neo-schumpeterian approach of technological change in the agriculture to understand the process and admit that the formation of land prices incorporate, at least, two analytical dimensions. On the one hand, we need to incorporate a temporal dimension because the land prices are subject to long-run forces. On the other hand, the formation of prices in agriculture is intensively related to geographical localization of the farms that produce on soil of different quality. Therefore we propose empirical exercises applying a panel data analysis for a very long run period (annual figures for 1900-2010) and provincial data (18 administrative jurisdictions excluding Montevideo).

The literature about technological change does not offer suitable indicators for representing the improvements in the technical conditions of the agriculture in the long run. Our empirical strategy presents two steps to solve this problem. First, we review an extensive literature about the agriculture in Uruguay and interview qualified informers considering the main types of production (cattle, crops, dairy industry and forest) to obtain a description of the activity along the 20th century. Second, we represent numerically this qualitative description using a dummy variable and a functional approximation according to a Cauchy function. We construct a dummy variable that values 0 until that year when is evident that some specific technological changes are generalized and so the variable adopts the value 1. However, this depiction of a sudden break is not representative of a process that, by definition, is progressive and accumulative. Therefore, we use a Cauchy function to link both moments by means of a smoother trajectory from those years when evidently the technological change had not been generated to that period when the process just was generalized.

Our indicators offer good results and show that the technological change explains the evolution of the prices of the land in the long run even when we consider institutional, market, endowments and localization factors.

Appendix 1: qualified informers

Name	Institutional filiation
PhD. Maria Ines Moraes	Faculta de Ciencia Sociales (FCS)
Ec. Verónica Duran	Ministerio de Ganadería Agricultura y Pesca (MGAP - OPYPA)
Ing. Agr. José E. Bervejillo	MGAP
Ing. Agr. Carlos Tessore	Oficina de Planeamiento y Presupuesto(OPP)
Ing. Agr. Silvia Becoña	Oficina de Planeamiento y Presupuesto(OPP)

Appendix 2: statistics, definitions and sources

In order to follow with the objective of the research, to study the determinants of land prices in Uruguay, it was necessary to have a set of variables that assess the causal relationships expressed in the theoretical framework. The difficult of a departmental, by sectors and a long term analysis, in terms of the availability of information, forced us to use various estimation techniques to complete the series, the basic input of the models showed in the empirical strategy.

When data sources do not cover the whole period, linear interpolations are performed (provided that no such periods of absence of information too extensive). We believe that the nature of the variables used and the motivation of the analysis do not invalidate this technique, which offers the possibility of having annual series data. It is generally followed the following criteria:

$$X_t = X_{t-1}(\frac{X_{newer}}{X_{older}})^{1/n}$$

Where *t* is a temporal variable, X_{newer} represents the last data; X_{older} represents the first real figure; n is the time (in years) from X_{newe} and $X_{older.}$

An additional difficulty in this type of analysis is related to the heterogeneity in the presented information. In order to solve this problem it was decided to refer the current criteria used in the revised documents and gather information seeking as uniform as possible as we go to more remote periods. Below are the variables used, estimation techniques that enable it to cover the whole period of study and the literature reviewed. These are in a summary table at the end of the Appendix 2 and its corresponding full citation in the bibliography.

The explanatory variables that make up the empirical model can be classified according to their characteristics: technical change, institutional arrangements, market, and resource endowments.

We think that is convenient to use qualitative variables that tell us the periods for which there is a significant technological change. The idea is not new and has been proposed in other studies of innovation and technical change. Baltagi and Griffin (1988) create a general index of technical change through the combination of a specific set of time dummies in panel data model. The authors Piva and Vivarelli (2002) included dummy variables to represent technology (R&D), organizational changes and globalization. From the literature review and interviews with qualified informants summarizes the major technical and its location in time.

As usual in this type of effort, our proposal is not absolute rigor when determining a given year where technical change is introduced, but only seeks to capture the relevant period in which technical change spreads on the farms and can be considered as a generalized practice. In this sense the approach used was to identify technical change and, from the information available, propose a long enough periods where relevant technical change resulted.

In order to illustrate institutional arrangements relating to land, we tend to represent those most associated with modalities of ownership and concentration. We consider the modality of tenure or holding, the average size of the farm and the landownership Theil indicator.

$$size_{i,t} = \frac{\text{farming and breeding area}}{\text{number of farms}}$$

Agricultural censuses provide data for: 1900, 1908, 1916, 1937, 1943, 1951, 1980, 1990, 2000, 2005 and 2010.

The calculation of the Theil index included the number of establishments by size range. Since the stratification differs between census was necessary to standardize this variable. To perform the calculation, class mark was adjusted for the number of establishments per hectare.

The third variable which contains the institutional dimension is the land tenure.

$$hold_{i,t} = \frac{\text{number of renters}}{\text{number of owners}}$$

Given the lack of data from 1900 to 1915, the departmental structure corresponding to 1916 was considered for all the period. Then interpolations were performed to complete the series.

1943 Census had underestimated data and the censuses of 1937 and 1951 were used as reference. In the cases in which the 1943 census data was moving away from fair values (variations of more than 15% with respect to the Census of 1937), estimated new values while maintaining the existing structure in 1937.

The variables associated with the market conditions considered are: the dependent variable (or endogenous), which is called real index of the price of agricultural land ($lp_{i,t}$), the real price index for weighted production ($api_{i,t,j}$) and the adjusted real interest rate ($ria_{i,t}$).

For the calculation of the $lp_{i,t}$, first of all, data were expressed in Uruguayan currents pesos, using the series of exchange rate when the data in the source was expressed in dollars.

The series was completed with the aim of capturing long-term trends, following, alternatively, any of the following criteria:

i) $\mathrm{X_t = X_{t-1}(\frac{X_{newer}}{X_{older}})^{1/n}}$

ii) $\mathrm{X_t = X_{t-1} \times \pi}$

Where is π the rate of annual growth in GDP prices.

iii) $\mathrm{X_{i,t} = \overline{X}_t(\frac{X_{i,t-n}}{\overline{X}_{t-n}})}$

Being: $\mathrm{\overline{X}_t}$ the average of the price of land in the year *t* (for departments where there is data), $\mathrm{\overline{X}_{t-n}}$: the *t-n* average considering the same departments that *t*

iv) $\mathrm{X_t = X_{t-1}}$

Thirdly, we construct departmental price indices considering 2005 as the base year. Finally, the index of the price of land ($lp_{i,t}$) was deflated by the CPI (consumer price index) to obtain a relative price (that we call "real" price).

The price of the products is a highly relevant variable to explain the movement of prices of agricultural land. In order to capture the presence of heterogeneity in departmental productions, we elaborate a real price index of production that reflects the relative weight of each production (livestock for meat and wool, dairy, agricultural and forestry). In these terms, in the case of a province specialized in livestock (according to the proportion of total land used for this productive proposal), meat and wool prices should have a strong influence in the local prices, and more intensive than in provinces specialized in other products. To represent this different influence, we consider the respective weights according to the area dedicated to each heading (cattle, crops, dairy and forest). The real weighted price of production ($ria_{i,t}$) index is calculates as follows.

$$\text{Price weighted} = \sum_{i,j}^{i,j} a_{it} \times \text{ real implicit price index}_{jt}$$

$$\alpha_i = \frac{activity\ area_i}{\text{total aera}_i}$$

i=1 corresponds to the meat cattle, *i=2* corresponds to agriculture, *i=3* corresponds to dairy, *i=4* corresponds to the forest production.

j=1 corresponds to the price of the livestock activity, *j=2* corresponds to the price of the activity of agriculture, *j=3* corresponds to the activity of dairy, *j=4* corresponds to the price of forest.

We need indicators of prices for each of the productions, which are represented by the corresponding implicit deflators of gross production values.

$$\text{implicit price index } (\text{IPI}_{t,o}) = \frac{\text{GVP}_{t,t}}{\text{GVP}_{t,0}} \times 100$$

Where: *t* is the current year and *0* represents the year taken as base (2005).

Given the difficulties in obtaining data for the period 2004-2010 it was assumed the same growth of prices of the livestock for dairy, exercise that was carried out based on information obtained from the systems of national accounts of the BCU. Changes of base on implicit price indices splicing series with the usual method (proportional change) had made. The current rate of weighted prices ($ria_{i,t}$) was obtained finally deflating prices weighted by the API (agricultural price index). We replicate the exercises with the CPI and the results were similar.

The interest rate is a measure of the opportunity cost in the model. Given that our aim is to have a real rate of interest that includes departmental differences, we elaborate a deflator ($def_{i,t}$) which is calculated as follows:

$$def_{i,t} = IPC_t \times \frac{\text{pwpi}_{i,t}}{\text{cpi}_t}$$

Where $pwpi_{i,t}$ is the production weighted price index; pia_t is the price agricultural index, and cpi_t consumer price index.

To obtain the adjusted real interest rate ($ria_{i,t}$) we deflate the rate of nominal passive interest (npi_t) by this deflator.

$$\mathrm{ria}_{i,t} = \frac{\mathrm{npi}_t}{def_{i,t}}$$

In terms of the provision of resources, we consider three explanatory variables of the price of the land. First, we consider the distance (dist), which allows to measure the effort to access to “the market", and gives an idea of the allocation of resources in the economy (in this case in terms of transport infrastructure).

$$\mathrm{Dist}_{\mathrm{i,t}} = \frac{\text{Distance from the provincial capital to Montevideo (km)}}{\text{Density of roads}_{\mathrm{i,t}}}$$

$$\text{Density of roads}_{\mathrm{i,t}} = \frac{km\ of\ roads\ in\ the\ province}{\text{total area}_{\mathrm{i}}(\mathrm{km}^2)}$$

The series was completed with linear interpolations.

Second, we use a variable that reflects the natural conditions of the soil, and offer an idea of the quality of the land as the productive resource of the agriculture. This variable we call index of productivity or capacity of the soil ($pci_{i,t}$), takes as reference the departmental CONEAT index (widely used in Uruguay) which is adjusted by the weight which each productive activity uses the soil of the province (as an indirect measure of sectorial productivity).

"The CONEAT index is used as a measure of the productivity of an area because it tries to express the ratio of its production capacity, in terms of meat and wool, with ground units that comprise"(Capurro, 1977; CONEAT, 1979; Lanfranco and Sapriza, 2010).

$$\mathrm{pci}_{\mathrm{i,t}} = \sum_{\mathrm{i=Artigas,\ t=1900,\ j=1}}^{\mathrm{i=Treinta\ y\ Tres,\ t=2010,\ j=4}} \text{coneat index}_{\mathrm{i}} \times \frac{\mathrm{hectares}_{\mathrm{ij,t}}}{\text{total hectares}_{\mathrm{i,t}}} \times (1 + (\frac{\mathrm{GVP}_{\mathrm{J,t}} / \mathrm{hectares}_{\mathrm{i,j,t}}}{\sum_{\mathrm{j=1,\ t=1900}}^{\mathrm{j=4,\ t=2010}} \frac{\mathrm{GVP}_{\mathrm{J,t}}}{\mathrm{hectares}_{\mathrm{j,t}}}})$$

t: represents each year between 1900 and 2010.

i: represents each province with *i*=Artigas, Canelones, Cerro Largo, Colonia, Durazno, Flores, Florida, Lavalleja, Maldonado, Montevideo, Paysandú, Rio Negro, Rivera, Rocha, Salto, San José, Soriano, Tacuarembó, and Treinta y Tres.

j: represents each activity sector with *j*=livestock for meat and wool, crops, dairy and forestry. Finally, we add a variable to measure the demographic pressure on the demand for land ($denspop_{i,,t}$).

$$\mathrm{denspop}_{\mathrm{i,t}} = \frac{\mathrm{Population}_{\mathrm{i,t}}}{\mathrm{total\ area}_{\ \mathrm{i}}(\mathrm{km}^2)}$$

Table 3

INDICATORS AND SOURCES

Variable	year	Abbreviated source and year of publication
Hectares dedicated to livestock	1908, 1916, 1937, 1943, 1961, 1970, 1980, 1990, 2000, 2005, 2010.	MGAP (Censos generales agropecuarios)
Hectares dedicated to agriculture	1908, 1916, 1937, 1943, 1961, 1970, 1980, 1990, 2000	MGAP (Censos generales agropecuarios)
Hectares dedicated to dairy	1937, 1956, 1980, , 2000, 2003, 2007, 2008, 2009, 2010	CIDE (1967) MGAP, Censos generales agropecuario (**) MGAP (DICOSE) (*)
Hectares dedicated to forestry	1951, 1966, 1970, 1980, 1990, 2000, 2005, 2010.	MGAP (Censos generales agropecuarios)
Land prices	1900-1913, 1911-1924, 1940-1966, 1977-1985, 2000-2010	Barran y Nahum (1977) Jorge Balbis (2005) Reig y Vigorito, MGAP (1988) Piriz (1987) MGAP-DIEA (2010)
Gross sectorial production value	1979	MGAP-CONEAT (1979)
Coneat index	1900-1955 1955-1982 1983-2010	Bertino y Tajam (1999) (El PIB de Uruguay 1900-1955) BCU (Producto e Ingreso Nacional, varios números) MGAP (Web)
(api) agricultural price index	1900-2010	Área de Historia Económica, IECON. Bonino et. al. (2011) Bértola et al. (1998) Bertino y Tajam (1999). ÁLVAREZ y WILLEBALD (2011)
Total number of farms	1916,1937, 1943, 1951, 1980, 1990, 2000, 2005, 2010.	MGAP (Censos generales agropecuarios) (*)
Number of establishments by stratum area	1916, 1922, 1937, 1943, 1951, 1980, 1990, 2000	MGAP (Censos generales agropecuarios) (*)
Number of lease	1916, 1937, 1943, 1951, 1966, 1970, 1980, 1990, 2000, 2005,2010	MGAP (Censos generales agropecuarios) (*) MGAP (DICOSE) (*)
Number owners	1916, 1937, 1943, 1951, 1966, 1970, 1980, 1990, 2000, 2005,2010	MGAP (Censos generales agropecuarios) MGAP (DICOSE) (*)
IPC	1900-2010	INE (2011)
Km of road	1965, 1989, 2000-2010	CIDE (1965) MTOP (1989), MTOP (Web)
Surface total by province	Todo el período	INE (2011) Censos (Web)
Type of change	1977-1988 2000-2010	INE (2011)
GDP deflator	1980-2000	Area de Historia Económica, IECON, Bonino et al. (2011), Bértola et. Al (1998), Bertino y Tajam (1999), Bonino y Willebald (2011)
Rate nominal interest	1900-2010	IECON
Population by province	1900, 1910, 1920 y 1930 - 1908, 1963, 1975, 1985, 1996, 2044, 2011	Instituto Nacional de Estadística (INE) Juan Rial. "Estadísticas Históricas del Uruguay 1850-1930."
(*) The years of the publication correspond to the observed year column		

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