Location of agricultural output and economic geography. Uruguay in the long-run (1870-2008)

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Resumen

El objetivo de este artículo es examinar la influencia de las condiciones geográficas en la distribución territorial de la producción agropecuaria de Uruguay en el largo plazo. El análisis abarca diecisiete referencias temporales (1870, 1884, 1890, 1900, 1908, 1916, 1924, 1937, 1943, 1951, 1956, 1966, 1970, 1980, 1990, 2000 y 2008), considerando el posible poder explicativo de los factores estrechamente relacionados con las características geográficas "puras" (dotación de tierras, clima y ubicación en el territorio de los departamentos) en contraste con las causas de segunda naturaleza (economías de aglomeración, infraestructura y transporte). Para ello, se utiliza una base de datos que incluye el valor agregado agropecuario a nivel departamental y un conjunto de variables posiblemente relacionadas con la localización de la producción. Se prueban las hipótesis mediante análisis de datos de panel y descomposición de R^2 a través de un método de importancia relativa, estimando la contribución de cada variable explicativa al ajuste del modelo. Los resultados muestran que los factores de primera y segunda naturaleza compiten en la explicación de la desigual distribución territorial de la producción agropecuaria y que sus efectos han cambiado a lo largo del tiempo. Durante el siglo XX, los factores de segunda naturaleza adquirieron mayor importancia a medida que el cambio tecnológico favoreció el auge de actividades intensivas (particularmente la industria lechera y los cultivos industriales). Además, se encuentra evidencia del creciente papel de los grandes mercados (ciudades del litoral uruguayo, sur del país, Montevideo y las principales regiones fronterizas de los países vecinos, como Buenos Aires, Entre Ríos y Río Grande del Sur) en la concentración de la producción agropecuaria. Las causas de segunda naturaleza se consolidaron como factores clave, con el potencial de mercado consolidándose como el factor predominante a lo largo del tiempo.

Palabras clave: agricultura, localización, factores geográficos, Uruguay

Códigos JEL: N5, N56, O33, Q16, R12.

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Abstract

The aim of this article is to examine the influence of geographical conditions on the territorial distribution of agrarian output in Uruguay in the long-run. Our analysis covers seventeen time-benchmarks (1870, 1884, 1890, 1900, 1908, 1916, 1924, 1937, 1943, 1951, 1956, 1966, 1970, 1980, 1990, 2000 and 2008) by considering the possible explicative power of those factors closely related to "pure" geographical features (land endowments, climate, places where provinces are situated in the territory) in contrast to the second nature causes (those related to agglomeration economies, infrastructure and transport). For this purpose, we used a database that includes provincial value-added of agriculture and a set of variables possibly related with the location of production, and we tested our hypotheses with panel data and R^2 decomposition through a relative importance method, estimating the contribution of each variable to the fit of the model. Our results show that first-nature and second-nature factors compete in explaining the uneven territorial distribution of agriculture and that their effects changed over time. During the 20th century, second-nature factors gained influence as technological change favoured the rise of intensive agricultural activities (particularly the dairy industry and industrial crops). Furthermore, we found evidence of the increasing role of large markets (cities in the Uruguayan littoral, the south of the country, Montevideo, and key border region in neighbouring countries such as Buenos Aires, Entre Ríos, and Río Grande do Sul) in concentrating these agrarian productions. Second-nature causes emerged as key factors, with market potential becoming the predominant factor over time.

Keywords: agriculture, location, geographical factors, Uruguay

JEL Classification: N5, N56, O33, Q16, R12.

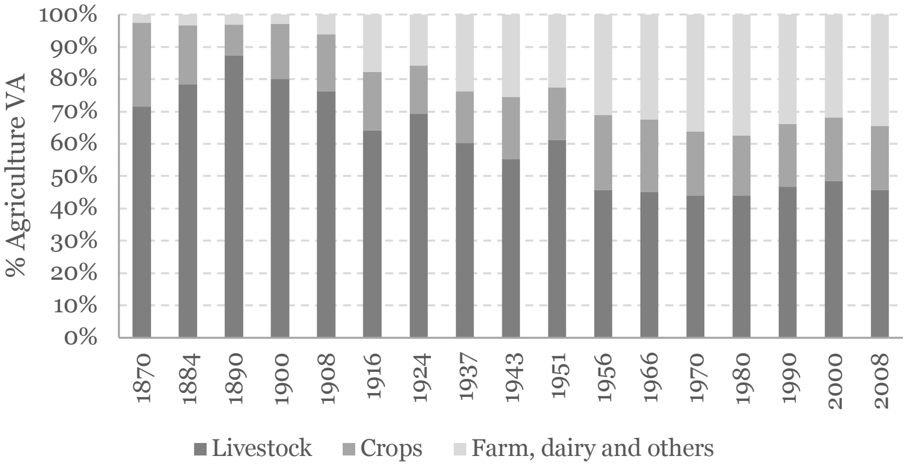
1. Motivation

Agriculture in Uruguay –as well as in other Latin American countries– has been one of the main activities of the productive structure since the constitution of the country as an independent nation in the first half of the 19th century (and even before). Agriculture represented a third of GDP (Bértola et al., 2024) and almost 50 per cent of employment (Álvarez Scanniello et al., 2024) at the beginning of the 20th century, although these percentages at the beginning of the 21st century had fallen to 9 percent and 11 per cent, respectively.

In spite of the decline in the relative economic significance of this sector in the national economic structure, agriculture maintained two relevant features. First, it sustained dynamic backward and forward linkages; on the one hand, demanding agricultural inputs (many times from abroad) and, on the other hand, providing inputs to the agro-industry sectors such as processing and preserving of meat, fruit and vegetables, manufacture of dairy products, grain mill products, beverages, textiles, leather and related products. Second, agriculture provided the majority of exports during the last century, representing 85 per cent of the total exports at the beginning of the 20th century and around 75 per cent one hundred years later.

The long-run agricultural evolution included important transformations (a true structural change within the sector). This evolution involved significant changes in the type of agrarian activities –especially the increasing share of non-perennial (cereals, rice, vegetables) and perennial crops (citrus and other tree fruits) to the detriment of animal production (rearing of cattle and sheep) (see Figure 1) and with increasing labour and land productivities –both indicators multiplied by more than 3 during the century– (Castro Scavone, 2017). These transformations were related to significant changes in the territorial location of agriculture in the long run. According to Araujo et al. (2015), the geographical location of agricultural production can be described through six stylized facts.

Figure 1. Value-Added of Agriculture by classes of agricultural activity



SOURCE: our own data.

First, production is relatively decentralised in the territory. Second, this low territorial concentration is explained, fundamentally, by animal production (cattle and sheep) while the other types of production show higher concentration (especially farming production). Third, the provinces with the most differentiated productive structures are Montevideo, Canelones, San José and Colonia, i.e. the southwest region of the country with diversified production and a significant presence of farming and dairy production. Fourth, the agricultural specialization allows us to identify provinces typically dedicated to livestock (the majority of the territory with the exception of the southwest region); the growing of cereals (the south and the Littoral regions); vegetables and fruits (provinces around Montevideo and Salto); the rearing of swine and poultry, the dairy industry (in the south) and sugar cane and sugar beets (in the north Littoral and Canelones) and, at the end of the 20th century, forestry and logging (in the centre and east of the country). Fifth, the highest labour productivity corresponded to the provinces more dedicated to cattle production. Sixth, the highest land productivity corresponded to those provinces more dedicated to growing cereals and rearing swine and poultry, and the dairy industry, which coincides with having the land with the best agronomical quality.

The aim of this article is to explain the geographical distribution of agricultural output in Uruguay –referring to the first four previous stylized facts– and, for this, we proposed to examine the role of the geographical conditions in this process in the long-run (from the last decades of the 19h century to the first decade of the 21st century).

We conducted an exploratory analysis of the determinants of the location of the regional agriculture value-added in seventeen time-benchmarks (1870, 1884, 1890, 1900, 1908, 1916, 1924, 1937, 1943, 1951, 1956, 1966, 1970, 1980, 1990, 2000 and 2008)[1], by considering the explicative power of the factors closely related to "pure" geographical features (land endowments, climate and places where provinces are situated) in contrast

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[1] The selection of years is dependent on the availability of information (agricultural census).

to the second nature causes (those related to agglomeration economies, infrastructure and transport). Additionally, we considered the effect of other factors (control variables): technological change, institutional arrangements and some relevant prices in agrarian production as those corresponding to land and commodities. For this purpose, we took advantage of a previously constructed database that includes value-added provincial agriculture (Araujo et al., 2015; Castro Scavone & Willebald, 2022; Castro Scavone, 2017[2]) and developed a set of explicative variables to test our hypotheses. One of the main challenges was to apply the New Economic Geography –a theoretical framework worked out for explaining industrial location– to understand the location of agriculture in the long-run.

The article is ordered as follows. Initially, we characterized the agricultural concentration in Uruguay by territory during the period (1870-2008), presenting maps and considering a long run evolution of agrarian production (Section 2). Second, we present our conceptual framework considering the influence of "first-nature geography" factors (the physical geography of climate, topology and resource endowments) and the "second-nature geography" factors (the location of economic agents relative to one another in space). In accordance with the previous discussion about the stylized facts of the agricultural location and the conceptual arguments, we proposed our working hypotheses (Section 3). Then, we presented our empirical strategy based on two types of exercises: panel data analysis and R^2 decomposition using the relative importance of variables (Section 4). Our results (Section 5) show that first-nature and second-nature factors compete in explaining the unequal territorial distribution of agriculture in the long term, and the intensity of their influence changed over time.

During the 20th century, second-nature factors gained explanatory power as technological change fostered the rise of intensive agricultural activities. In addition, we found evidence of the increasing role of large markets (cities in the Uruguayan littoral, the south of the country, Montevideo, and key border region in neighbouring countries such as Buenos Aires, Entre Ríos, and Rio Grande do Sul) in concentrating these agrarian productions. While first-nature factors were relevant throughout the period, second-nature factors have historically been the principal explanatory variables, with market potential emerging as the predominant factor over time. Finally, we present some final remarks (Section 6).

2. Some stylized facts about agriculture location

Agriculture is not a homogeneous sector. It includes several types of activities with different conditions, requirements and results. In Uruguay, livestock (based on the use of the natural prairies) has historically been the country's main activity. Crop agriculture has occupied a secondary place, and more intensive activities, such as dairy and farm, have had a minor importance in the productive structure. However, activities that make

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[2] These studies offer information for particular years (each 10 years around) and this determined part of our possibilities to make statistical exercises.

intensive use of the land factor become increasingly important during the period and have been located in certain areas of the country. In accordance with DIEA-MGAP (2015) we selected three groups based on the intensive use they make of the land.

- Livestock: cattle (for beef), sheep (for lamb, mutton and wool).
- Crop: cereals, fodder, leguminous crops and oil seeds
- Dairy and farm: production of milk, rearing of swine/pigs and poultry, growing of vegetables and melons, roots and tubers, grapes, citrus fruits and other fruits.

One of the more classical characterizations of Uruguay corresponds to Reyes Abadie et al. (1966) who describes it as the combination of "prairies, border and harbour". In other words, Uruguay –usually referred to as Banda Oriental in colonial times– was a region with abundant natural resources suitable for cattle production, with one of the better ports of South America (which was the main "exit door" for commodities from the River Plate to the international markets until the end of the 19th century) and was the frontier between the two empires that conquered Latin America: Spain and Portugal. This feature continued even after the independence from other protagonists –Argentina and Brazil– but with similar consequences: Uruguay constituted a buffer state between two immense countries that productively, institutionally and culturally moulded the society, leading to differences within the country that have persisted until today (see Martínez-Galarraga et al., 2020).

The current provincial division of Uruguay has been in force since 1884-1885 including 19 "*departamentos*" (provinces) that, as shown in Figure 2, have very diverse dimensions.

Figure 2. Provinces of Uruguay

Source: our data based on Instituto Nacional de Estadística (INE).

The largest province (Tacuarembó) is 30 times the size of the smallest (Montevideo), and the most populated in the mid-20th century (Montevideo) was 28 times more populous than the least populated (Flores). We consider this administrative division as a reference due to the availability of the information.

The sector concentration between regions can be addressed by estimating the density of the agriculture value-added (VA). If the regions concerned were the same size, regional VA could be used as a simple indicator of the spatial distribution of the total economic activity of the country. However, as provinces have different surface areas, the density of the value-added (VA per km^2) controls the differences between administrative divisions (equation 1). Such indicators are commonly used as a measure of economic concentration, and they are useful to rely on the New Economic Geography (NEG) theoretical framework for studying industrial concentration (Novel & Tirado, 2008). The use of this indicator to study the concentration of agricultural VA is justified in the growing importance that intensive agricultural activities in land use and labor acquired in the 20th century in the provinces with the highest access to regional markets.

$$density_{i,t} = \frac{VA_{i,t}}{area_i} \tag{1}$$

We analyze the evolution of VA –average values– between 1870-2008 but considering three sub-periods that guided the trajectories of the Uruguayan economy in the long term (Román & Willebald, 2021).

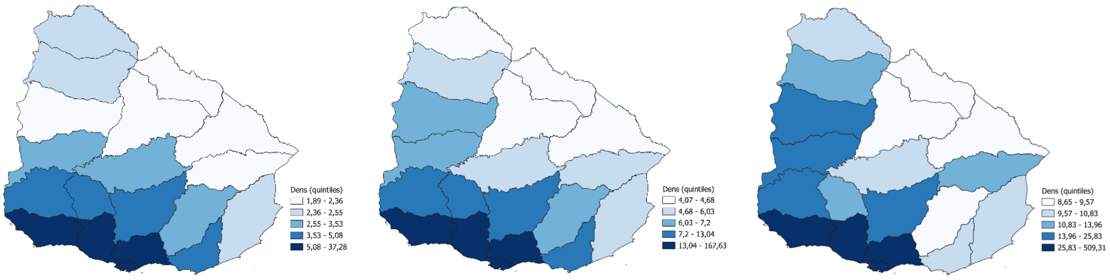
The first period covers the last three decades of the 19th century and the first two of the 20th century and contains seven benchmarks: 1870, 1884, 1890, 1900, 1908, 1916 and 1924. The results of this period reflect the reality of an agro-export economy inserted in the dynamics of the First Globalization. The last benchmark could capture the effects of the transition period in the 1920s and is included in the following period as well. So, the second period contains the years 1924, 1937, 1943, 1951, 1956 and 1966. These benchmarks cover the period of import-substitution industrialization (ISI) (or state-led industrialization), from the transition in the 1920s to its decline in the 1950s. The third period –including the benchmark of the transition in 1966– covers the last three decades of the 20th century (1966, 1970, 1980, 1990, 2000) and ends in 2008. It is a period characterized by growing financial liberalization and promotion of non-traditional exports in the 1970s, and once the "lost decade" of the 1980s was over, the liberalizing that had begun in the 1970s resumed, until the economic and social debacle that culminated in the crisis of 2002 occurred. The last year of the period coincides with the first official regional VA estimates (OPP-INE, 2012) and represents the first years of the new agro-export cycle and transformations in agriculture, which are still underway (Bértola et al., 2014).

As our interest is focusing the analysis on the 19th and 20th centuries, we decided not to advance beyond 2008. With the information referring to 2008, we “closed” the 20th century. Additionally, it is true that agriculture, from the second decade of the 21st century, experienced a new context that led to deep and significant changes. The region combined a favorable macroeconomic context, high international prices, and auspicious public policies, which encouraged important transformations in Uruguay's agriculture, and which were expressed in a growing intensification of agricultural production with a marked expansion of crop agriculture and forestry. This process cannot be analyzed without addressing a set of factors, within which the presence of new business actors (with a strong presence of transnational capital) and very profound changes in the models of management, production, financing, and use of modern technology stand out (Arbeletche, 2020). In future stages of our research, we will go into these topics in depth (for this, it would be essential to have the census information from 2024, which is currently being processed).

Historically, the south and littoral[3] of the country (see Figure 3) was the leading location of agricultural production. The provinces that occupied the first places in the ranking were Montevideo, Canelones, San José, Colonia and Soriano, with the provinces of Río Negro, Flores, Florida, and Maldonado a few steps below. In addition, in a previous study, we found evidence that these provinces are characterized by a high specialization in intensive activities (such as farming involving dairy, poultry, pigs, fruit, vegetables and industrial crops) and show a higher degree of productive diversification (Castro Scavone, 2017).

Those regions would have taken advantage of their natural benefits in terms of land quality but also would have benefited from their better access to the Montevideo market, and, consequently, to the port to participate in international trade. It is possible that these factors, together with the incorporation of technology, contributed to a higher diversification of their productive structures and allowed them to incorporate increasingly intensive activities, such as dairy and farming (Castro Scavone, 2017).

Figure 3. Density of value-added in provinces of Uruguay



1870-1924[4] 1924-1966 1966-2008

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[3] In Uruguay, the zone in the border with Argentina corresponding to the Uruguay river is identify as the littoral.

[4] The current administrative division of Uruguay composed of 19 provinces corresponds from 1885 onwards; the consideration of the map for the period 1870-1924 has an instrumental purpose. See an explanation in Castro Scavone & Willebald (2022).

SOURCE: our own data.

3. Conceptual framework and hypotheses

Over the last 25 years, the uneven distribution of economic activity across the territory has received renewed attention with the emergence of the NEG (Krugman, 1991a; Fujita et al., 2001). Whereas traditional neoclassical explanations of the distribution of economic activity across the territory emphasize "first-nature geography" –the physical geography of climate, topology and resource endowments– (Gallup et al., 1998; Sachs, 2000), this new body of research stresses the role of "second nature geography" (the location of economic agents relative to one another). NEG models introduce product differentiation, increasing returns to scale and transport costs as essential components of the analysis, which together create pecuniary externalities that explain the agents' location choices (Redding, 2010). Combined with either factor mobility or intermediate inputs, these three components have given rise to forces of cumulative causation and agglomeration.

As workers tend to concentrate their location in specific areas, the resulting shift in expenditure encourages the firms to locate production in those areas (the so-called "home market effect"). Likewise, as firms concentrate production in a location, the resulting reduction in the consumer price index –as a consequence of a higher supply– increases workers' incentives to concentrate in that location (the so-called "price index effect").

In NEG models, the tension between these agglomeration and dispersion forces in the form of immobile factors of production (Krugman, 1991a, b) and non-traded amenities (Helpman, 1998) determines the spatial distribution of economic activity. A central implication of these models is that for a range of parameters this distribution is not uniquely determined by locational fundamentals, but exhibits multiple equilibria (Redding, 2009).

Some authors have argued that embedding endowment-based comparative advantages within a standard NEG framework helps solve the indeterminacy due to multiple equilibria and the ambiguity concerning the relation between integration and specialisation (Epifani, 2005). In other words, the interplay between factor abundance and agglomeration forces can offer a better explanation about the location of economic activity than considering both arguments as alternative hypotheses.

The use of these economic geography models in addressing historical questions is relatively recent. Nonetheless, the increasing interest of economic historians in economic geography has been mainly focused on the manufacturing sector (Kim, 1995; Wolf, 2007; Martínez-Galarraga, 2012, Klein & Crafts, 2012). Agriculture is rarely considered and is involved as an exogenous determinant of income (Rosés et al., 2010; Combes, 2011).

This lack of interest in economic geography models in the agricultural sector seems, at the very least, contradictory when we take into account that the first model of spatial distribution of economic activity specifically focused on agriculture (Martinelli, 2014). In effect, von Thünen (1826) was interested in the pattern of agricultural production around a central town in an isolated state, in a homogeneous featureless plain of equal fertility.

He developed a system of concentric circles, in which bulky or perishable goods are produced closer to the city and valuable or durable goods are imported from a greater distance. In this central town the price of a product like grain is determined by the production and transportation costs from the most distant farms whose production is required to satisfy the town's demand. Since grain must sell at the same price irrespective of its location of production, land rent is highest in the first concentric ring and decreases with distance (Blaug, 1997). However, the von Thünen model was rather neglected for decades, at least outside the specific field of urban economics (Krugman, 1991a). In the second half of the 20th century, the model was refined with mathematically rigorous formulation within the neoclassical framework (Beckman, 1972; Samuelson, 1983), but its empirical applications have still been scarce or marginal.[5] The recent contribution of Kopsidis & Wolf (2012) (for Prussia) and Martinelli (2014) (for Italy) represent important contributions in the line of research inspired in a Thünen framework, in a historical economic analysis, referring to agriculture in a main role.

Our research shares the same intellectual inquisitiveness as the previous papers, i.e. the explanatory factors of the geographical location of agriculture in the long run. We take into account the conceptual proposal of Epifani (2005) and consider the simultaneous influence of the first and second nature factors and the combined incidence of both aspects on location. Our working hypotheses are the following: agricultural production in Uruguay is highly decentralized with a strong persistence along the 20th century. Natural resources in Uruguay are suitable for agrarian production. More than 95 percent of total territory corresponds to grassland, steppe, and open shrub land (Willebald & Juambeltz, 2018) and, in fact, (almost) all the territory is apt for rearing livestock and crops. Only in the second half of the century was it feasible to expect some regions with an increasing specialization in the dairy industry (Bertino & Tajam, 2000) and cereal growing regions (Bertino & Bucheli, 2000). Our argument posits that the spatial distribution of economic activity is determined by a combination of competing factors. The existence of comparative advantages related to factor endowments (first-nature factors) is only part of the explanation. As more intensive agricultural activities increased their share of total value-added and concentrated on the best lands, second-nature factors, such as market access, would have solidified their importance, ultimately becoming, from a long-term perspective, the main factor explaining regional differences in Uruguay's agriculture.

4. Empirical strategy

The first and second nature factors "compete" in the explanation of the location of agriculture across the area and, presumably, it is possible to find interactions that also influence the process (Beltrán 1999; Rosés, 2003; Tirado et al., 2008; Ayuda et al., 2010). With the aim of obtaining a measure of the importance of these factors to explain the location of agricultural production we propose two complementary exercises.

First, we built and analyzed a panel data set to take advantage of the spatial and temporal variability of the variables. This allowed us to obtain information about the

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[5] Curiously enough, one of these scarce empirical exercises was applied to Uruguay in the beginning of the 1970s (Griffin, 1973)

signs and significance levels of these variables as explanatory factors of agricultural location. Second, we performed a decomposition of the R^2 to measure the relative contribution of both types of factors—first-nature geographical factors, such as soil quality, and second-nature geographical factors, such as proximity to markets—to explain the location of agricultural output.

4.1 Panel data analysis

We faced the double challenge of analysing the agricultural location for different areas and for long periods. Therefore, we considered benchmarks during the last three decades of the 19th century, the entire 20th century and first decade of the 21st century (1870, 1884, 1890, 1900, 1908, 1916, 1924, 1937, 1943, 1951, 1956, 1966, 1970, 1980, 1990, 2000 and 2008) and distinguished several regions of Uruguay that we identified with local administrations (*departamentos* or provinces).

We consider panel data (or cross-sectional time series data) to be a good technique to approach our problem because it allows us 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 (18 *departamentos*), and the time-series or within-subject information reflected in the changes within subjects over time (139 years covered with 17 benchmarks). Panel data regression techniques allow us to take advantage of these different types of information.

We used a model to represent the influence of each factor on the density ($dens_{i,t}$) of the agricultural VA assuming additive and linear relationships (data in Appendix A). We considered the impact of different first and second nature factors on agricultural location (see equation 2), and we detailed the explanatory variables in Table 1. Full information on the variables is presented in the end of the document; we made a complete description of the variables and their operationalization in Appendix B and we detailed the sources of information in Appendix C, Table C.1.

We used a random effects model for the exploratory analysis based, first, on its ability to test the importance of first-nature factors, which are assumed to be fixed (endowments and location), and second, on the fact that the variable $dens_{i,t}$ is relatively stable within the provinces during the analyzed period, but changes significantly between provinces (see descriptive statistics in Appendix D). The consideration of a fixed effects model is not appropriate, since it has the limitation of not taking into account the variation between agents (provinces in our case) and imposes too many restrictions (Baltagi, 2013).

The structure of the model in matrix notation is as follows:

$$\mathrm{Y} = \mathrm{F}\beta + \mathrm{S}\gamma + \mathrm{X}\delta + \varepsilon \tag{2}$$

Where: The dependent variable Y corresponds to the natural logarithm of agricultural value-added density, denoted as $\ln(dens_{i,t})$; F is the matrix of natural-first variables; S is the matrix of second-nature variables; X is the matrix of control variables (see Table 1); β, γ and δ are the parameters to be estimated; ε is the error term.

t: represents each year 1870, 1884, 1890, 1900, 1908, 1916, 1924, 1937, 1943, 1951, 1956, 1966, 1970, 1980, 1990, 2000 and 2008.

i: represents each province, with i= Artigas, Canelones, Cerro Largo, Colonia, Durazno, Flores, Florida, Lavalleja, Maldonado, Paysandú, Río Negro, Rivera, Rocha, Salto, San José, Soriano, Tacuarembó, and Treinta y Tres.[6]

Table 1. Explicative variables

Related to:		**Variable:**	**Concept:**
First nature geography	Endowments	landq	Land quality: indicator of aptitude of soils for agriculture.
		distcap	Distance (linear) of each province to national capital (Montevideo).
		rain	Rainfall: average annual rainfall (litres/ha).
Second nature geography	Market forces	markpot	Market potential: measure of economic activity that each province has access after having deducted cost transportation.
	Infrastructure and transport	connect	Connectivity: global measure that considers the national transport network.
Control variables	Agrarian prices	commp	Commodities prices: commodities price index that considers the main products (meat, wool., and wheat).
		landp	Land price: real land price index.
	Technological change	tech	Technological change: global indicator of technological change that considers the main technical transformations of the period.
	Institutional arrangements	size	Farm size: average size of the agricultural plots.
		hold	Tenure: ratio between numbers of tenant farmers and landowners.
		inia	Governmental support for researching in agriculture: indicator that measures the impact of being close to an experimental station.

SOURCE: developed by the authors.

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[6] We excluded Montevideo for two reasons: (i) it represents only 1 per cent of the total territory; (ii) Montevideo has presented, historically, a marked urban profile inducing other conditions to the location of economic activities (see Martinez-Galarraga et al., 2020). Given that the field of study of this research is the agricultural sector and proposes a methodology based on econometric exercises, including Montevideo would lead to problems, often attributed to atypical data.

4.2 Decomposition of R^2

We employed the R^2 decomposition method to evaluate the relative importance of the explanatory variables in explaining the variance of the dependent variable. This approach quantifies the contribution of each variable to the overall explanatory power of the model, identifying first and second nature factors. We measure the marginal contribution of each variable to the explained variance using the Lindeman, Merenda, and Gold (LMG) method, which accounts for the order in which variables enter into the model. This method provides an additive measure of each variable's contribution to the total R^2, offering clear interpretability and enabling comparisons across variables and time periods.

The R^2 decomposition is implemented in two steps:

i. A random-effects panel model is estimated to capture spatial and temporal variability.

ii. The panel structure is then re-estimated as a linear model to calculate the R^2 decomposition using the LMG method.

By applying this decomposition across moving time windows, we analyse how the relative importance of first and second nature factors evolves over time. We present the results graphically, which illustrate the dynamics of variable importance across periods. Detailed calculations are presented in Appendix E.

5. Results

5.1 Panel data analysis

The general approach was to estimate a base model and so add explanatory variables in two additional specifications. Firstly, we estimated a model only with geographical factors of the first nature –$landq_i$, $distcap_i$ and $rain_{i,t}$– (model 1). Second, we included those factors that the NEG considers key in the explanation of the unequal distribution of economic activity in the territory –internal market forces ($markpot_{i,t,}$) and transport network ($connetc_{i,t}$)– and variables associated with factors which were particularly relevant from a historical perspective, but are not usually considered in the NEG framework. For this, we included technical change ($tech_{i,t}$), institutional variables related to some relevant aspects of the agrarian structure –average size of establishments ($size_{i,t}$), land tenure ($hold_{i,t}$)–, sectoral policies for the promotion of research and development ($inia_{i,t}$) and, finally, variables associated with the relevant prices in agriculture –land prices ($landp_i$) and commodity prices ($commp_{i,t}$)– (model 2). The results are presented in Table 2.

The first noteworthy result is the high relevance of first-nature geographical factors in explaining the territorial distribution of agricultural output. In particular, the allocation of resources, measured through the CONEAT index ($landq_i$), is significant and positive throughout the analyzed period. On the other hand, location ($distcap_i$) is negative and significant in the initial specifications, suggesting that regions close to Montevideo enjoyed a privileged position that allowed them to benefit from their proximity to the country's capital and main national port. Finally, model 1 includes a variable that measures rainfall volume ($\text{rain}_{i,t}$) as a proxy for climatic conditions. Similar to resource endowments and location, the estimates provide evidence of its importance in explaining the long-term spatial distribution of agricultural production in Uruguay.

From the estimation of model 2, in addition to the importance of the resource endowments, geographical location, and climate, we found evidence about the importance of second nature geographical factors; i.e. variables associated with market forces and transport infrastructure. The significance and the positive sign obtained in the estimation of transport infrastructure indicator ($\text{connect}_{i,t}$) suggests that connectivity and the development of the transport network, together with the importance of regional markets ($\text{markpot}_{i,t}$), in particular those close to the country's port cities –Paysandú and especially Montevideo– had an influence on the regional location of agricultural output. The inclusion in model 2 of an infrastructure indicator that incorporates information on the distance to the capital is the reason why the variable distcap_i is excluded from this analysis.

Table 2. Econometric results

Dependent variable: natural logarithm of agricultural VA density (ln(dens))

Variables	Model 1	Model 2
distcap	-0.0015***	
	(0.0005)	
landq	0.0142***	0.0044***
	(0.0025)	(0.0039)
rain	0.0005***	0.0003***
	(0.0005)	(0.0001)
markpot		0.0044***
		(0.0008)
connect		0.0753***
		(0.0167)
size		-0.0005***
		(0.0001)
hold		-0.1085*
		(0.0626)
inia		0.3892***
		(0.0933)
tech		0.1041***
		(0.0193)
commp		-0.0003
		(0.0006)
landp		0.0048***

		(0.0007)
overall	0.2680	0.8494
observation	306	306

Coefficients estimated with robust standard error (p-value in brackets)
Significance levels: *** (1%); ** (5%); * (10%)
All the models were estimated including constant (not shown).

The third key finding is that we found evidence of the impact of certain control variables. First, technology, measured through the adoption and diffusion of innovation curves —crossbreeding, mechanization, improved pastures, and fertilization— was significant and positive in explaining the concentration of production in the provinces of Uruguay. Additionally, we found evidence about that in those provinces near to state research centers ($inia_{i,t}$), producers may have leveraged the advantages of knowledge transfer and rural extension programs to improve their production practices and achieve higher productivity levels. Second, the estimation of institutional factors reflecting the agrarian structure, such as the scale of production, was significant and negative, which could indicate that Uruguay's historical latifundia problem posed a long-term limitation for agricultural development. Similarly, the negative sign of the variable capturing the dynamics of land tenure in the country's provinces suggests that land leasing, historically high in Uruguay, was associated with lower levels of output per hectare.

Finally, as expected, we found that higher land prices in certain areas could be associated with higher levels of output per hectare. Conversely, no evidence was found that international commodity prices influenced the unequal distribution of production across Uruguayan provinces.

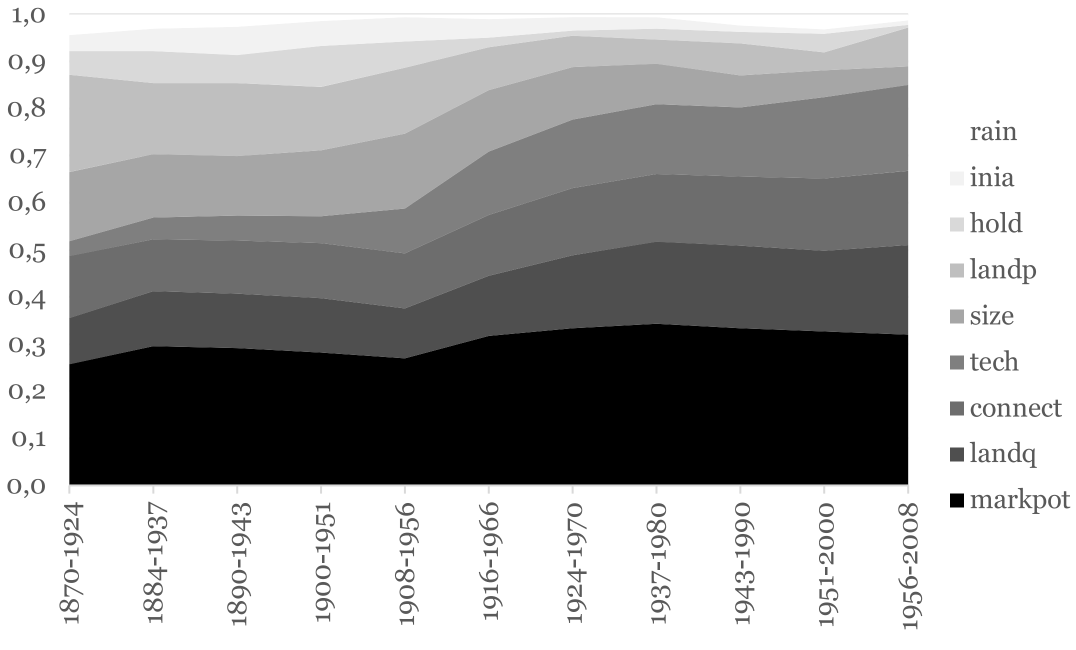
5.2 Decomposition of R^2

The aim of this exercise is to assess the relative importance of the variables competing to explain the distribution of regional agricultural VA over the long run (1870–2008). Conducting an intertemporal comparison requires a model that can be evaluated at different points in time. To achieve this, we adopted the following procedure. First, we used the specifications of Model 2 (the complete model) presented in the previous section. Then, we applied a moving-window approach to different time periods: 1870–1924, 1884–1937, 1890–1943, 1900–1951, 1908–1956, 1916–1966, 1924–1970, 1937–1980, 1943–1990, 1951–2000, and 1956–2008. The selection of these moving windows follows an instrumental criterion, ensuring that a sufficient amount of data is available for reliable model estimation.

From the comparative analysis, several noteworthy results can be identified (Figure 4). A first result is the significant prominence of market potential. Market potential is the factor that provides the greatest explanatory power in the model. The evidence shows growing dynamism during the period identified in Uruguayan literature as the era of import substitution industrialization. The strengthening of the domestic market in the context of state-led industrialization could have generated spillover effects into the agricultural sector, explaining its distribution across the territory. While a reduction in the importance of the domestic market is observed after the industrialization period, its values remain relatively high. Secondly, first-nature geography plays an important role as a determinant of the distribution of agricultural production in Uruguay from a long-term perspective. A third significant result is the decreasing influence of factors associated with institutional arrangements, reflected in changes in the agrarian structure. In particular, the extensive nature of production and, to a lesser extent, land leasing as a tenure system were more relevant during the 19th century, but throughout the 20th century, both factors lost importance, ending the period with low values.

While market potential is the factor that provides the greatest explanatory power throughout the entire period, it becomes particularly relevant as the 20th century progresses, coinciding with the development of the road transport network. The combined transport indicator considers the three main transport networks of the period (railways, roads, and inland navigation), but the limited explanatory capacity of the transport indicator ($connect_{i,t}$) contradicts our initial expectations regarding the importance of the railroad, which has been documented in previous studies (Barrán & Nahum, 1978; Díaz, 2017; Herranz-Loncán, 2011).

Figure 4. Evolution of the explanatory power of geographic factors (1870-2008 moving windows)



SOURCE: our own data.

Although the railway network was essential for the formation of a national urban network, it did not achieve the same success in developing integrated internal markets.

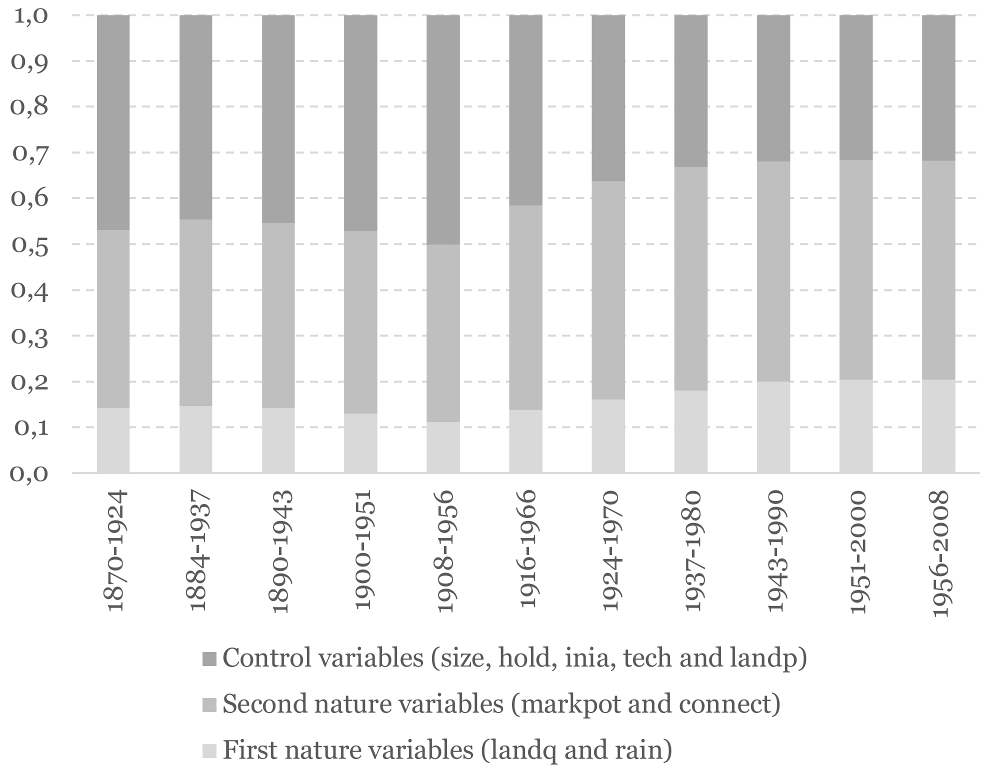
On the contrary, it was only recently, with the influence of automotive transport, that the process of urbanization was strengthened, and the integration of distant economic spaces was promoted (Klaczco & Rial, 1981).

A fourth important result relates to the pattern of technological change as a determinant of the regional distribution of production. The combination of different technological paths used to construct the indicator highlights the importance of crossbreeding during the 19th century and the introduction and diffusion of the tractor, which reached its greatest dynamism in the mid-20th century. The increased explanatory power of this variable from the second half of the 20th century likely stems from the introduction of a technological package that combines a set of technologies already proven in other countries, with the mechanical technology of the tractor and the chemical technology of fertilization as key components (Moraes, 2001; Álvarez Scaniello, 2018; Álvarez Scaniello and Bortagaray, 2007).

Another result concerns the importance of land prices ($landp_{i,t}$). This indicator was significant from the late 19th century to the mid-20th century and is associated with the development of the land market. This variable has reflected, at a regional level, the movement of productive activities whose profitability was affected by the increase in land value close to the major markets.

Finally, we observe that both types of determinants —first-nature and second-nature geography— compete in explaining the distribution of agricultural production in the long run. On the one hand, the evidence shows the historical relevance of first-nature geography (represented by the endowment factor), explaining one-fifth of the variance in the dependent variable (Figure 5). On the other hand, the importance of second-nature geographical determinants has been the most prominent throughout the entire period. The relevance of these factors increases, primarily due to the evolution of factors highlighted by the NEG: market potential and transportation costs, but since the second half of the 20th century, this evolution is further complemented by the growing importance of technological change. This demonstrates how complementary factors can enhance the explanatory power of the standard factors derived from the NEG framework.

Figure 5. Evolution of the explanatory power of first and second nature geogaphy and control variables (1870-2008 moving windows)



SOURCE: our own data.

6. Conclusion

We examined the influence of geographical conditions on the location of agriculture in Uruguay from the last decades of the 19th century to the first decade of the 21st century (1870-2008). We conducted an exploratory analysis of the determinants of this process at seventeen temporal benchmarks (1870, 1884, 1890, 1900, 1908, 1916, 1924, 1937, 1943, 1951, 1956, 1966, 1970, 1980, 1990, 2000, and 2008), considering the explanatory power of first- and second-nature factors. For this purpose, we built a database that includes the provincial-level agricultural VA and a set of explanatory variables, testing our hypotheses through two complementary exercises: panel data analysis and R^2 decomposition techniques.

We proposed empirical tests of some central postulates of the NEG for the case of agriculture in Uruguay in the long term, obtaining two main results. First, the evidence found allows us to assert that first- and second-nature geographic factors compete to explain the unequal regional distribution of agriculture in Uruguay over the long term (1870-2008). Second, it is possible to affirm that the influence of both sets of factors has changed over time. Second-nature geography gained explanatory power throughout the period. Indeed, the evidence indicates that the increasing importance of market integration, market access (mainly to Montevideo), the advantages associated with infrastructure, and the use of transportation means complemented the historical influence of resource endowments. At the same time, we found evidence of a growing role for agricultural technology and, in contrast, a declining relevance of the agrarian institutional structure, as reflected by the average size of farm plots. Lastly, land prices showed a decreasing influence over the period.

In summary, the combined effect of the internal market potential, the transportation network, and technology appears to have played a substantial role in regional location of agriculture. These findings show that the discussion on location of production go beyond the industrial activities and can be applied to other sectors where scale economies, diversification, specialization and cost of transport are relevant factors. In other words, our results confirm that, even in the long run, agricultural location continues to align with Von Thünen's original framework from nearly two centuries ago, where market access and transportation costs remain key factors in explaining the spatial distribution of agricultural production

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Appendix A

Table A.1 Density of the provincial agriculture VA in Uruguay 1870-2008

Año	1870	1884	1890	1900	1908	1916	1924	1937	1943	1951	1956	1966	1970	1980	1990	2000	2008
Artigas	1,20	2,10	2,28	2,53	2,44	2,71	3,50	3,27	4,34	4,78	5,61	5,56	7,23	10,65	14,58	9,28	13,15
Canelones	9,53	17,46	7,69	19,28	22,70	15,62	19,45	20,37	27,37	39,55	44,40	57,67	73,97	74,90	107,88	64,13	87,21
Cerro Largo	1,10	2,37	2,70	2,45	2,35	2,68	2,86	3,89	4,13	5,87	5,95	5,22	5,99	8,73	9,41	9,74	13,32
Colonia	2,06	3,58	5,47	7,17	10,58	5,14	8,87	12,71	15,07	16,39	19,44	19,65	20,45	27,91	35,63	35,24	46,28
Durazno	1,10	2,11	2,86	3,00	3,95	3,74	4,90	5,11	5,82	5,85	6,90	7,11	7,24	8,51	9,83	10,87	13,92
Flores	1,37	2,77	3,89	4,16	5,15	6,11	6,10	6,64	7,60	8,99	8,38	9,50	9,37	11,34	12,49	16,61	22,62
Florida	1,03	1,81	2,47	3,46	4,54	5,15	6,39	6,69	7,41	8,75	10,62	12,55	13,64	15,17	16,77	18,65	23,57
Lavalleja	1,33	2,05	2,03	2,77	4,64	5,42	5,82	6,21	6,42	7,06	7,19	7,13	7,67	8,50	9,77	11,11	13,15
Maldonado	4,54	3,63	1,74	4,26	4,29	5,38	7,05	6,25	7,13	7,75	8,01	7,18	8,54	11,93	10,96	9,26	11,43
Paysandú	1,07	2,21	2,44	2,56	2,56	1,96	3,11	4,33	4,81	6,97	9,79	9,12	9,46	12,43	15,54	15,28	22,39
Río Negro	1,09	2,38	3,00	3,23	2,57	2,83	3,47	5,20	6,91	7,24	9,85	9,94	10,24	13,11	16,70	21,43	33,65
Rivera	1,27	1,86	1,81	1,89	1,91	1,77	2,73	3,03	3,71	4,75	5,25	4,98	5,90	8,81	9,87	11,31	15,19
Rocha	0,94	1,79	1,86	2,64	3,23	2,88	4,37	4,63	5,23	5,50	6,09	5,63	6,70	10,57	12,74	12,78	15,63
Salto	1,25	2,24	2,59	2,77	2,05	2,66	3,90	3,40	5,15	6,04	6,71	6,84	8,94	11,13	12,75	12,41	16,73
San José	2,92	6,23	5,03	7,70	6,26	5,53	8,94	12,69	13,96	16,78	22,01	30,52	31,05	34,82	38,76	44,75	55,34
Soriano	2,06	3,52	3,52	4,48	5,22	5,43	6,32	9,03	12,83	12,53	13,89	14,41	14,38	18,08	24,20	29,20	34,59
Tacuarembó	1,41	2,46	2,70	2,46	2,24	2,34	2,89	3,59	4,21	4,89	5,75	5,35	6,50	8,49	9,40	9,41	12,76
Treinta y Tres	0,95	1,87	2,27	2,43	2,60	2,42	3,31	4,25	5,15	4,88	5,00	5,61	6,76	9,93	13,05	16,25	22,24

SOURCE: our own data.

Appendix B. Description and operationalization of variables

First nature geography

We consider land quality, measures of distances (both are constant in time) and climatic conditions.

First, we used a variable that reflects the natural condition of the soil and offers an idea of the quality of the land. This variable, which we call index of quality of the soil ($landq_i$), takes the provincial CONEAT index (widely used in Uruguay) as a reference. The CONEAT index is used as a measure of land quality because it attempts to express the production capacity of the soils in terms of meat and wool (CONEAT, 1979; Lanfranco & Sapriza, 2011).

Second, given the historical importance of the capital city for agricultural production as the main market –for internal consumption and exports–, we constructed a variable that measures the Euclidean distance between each provincial capital and Montevideo ($distcap_i$).

Finally, we represent the climatic differences between provinces through a measure of annual rainfall (litres/ha^2) ($rain_{i,t}$). Institutions responsible for measuring and systematizing information on rainfall in Uruguay integrate several weather stations located in the major basins of the country corresponding to significant rivers: *Negro, Uruguay, Santa Lucía, de la Plata* and *Merín* lagoon. From this information, the institutions report the rainfall activity by province (or by cities as is the case of the data corresponding to 1902-1908). Although the importance of climate as a determinant of the distribution of the production is a combination of factors, of which rainfall is only one –temperature, sunlight, etc. could also be considered–, rainfall constitutes a main determinant of agriculture and turns out to be a good proxy for our analysis.

Second nature geography

As second nature factors we consider market forces, infrastructure and transport.

First, access to markets and its importance in the distribution of economic activity has been highlighted in several studies of economic history (Crafts, 2005; Martinez-Galarraga, 2013). Our indicator of market access in a historical perspective is inspired by the equation of market potential, originally presented by Harris (1954). The original idea put forward by the author can be represented by the following equation:

$$P_i = \sum \frac{M_j}{d_{i,j}} \qquad \text{(B.1)}$$

P_i is the market potential of the region *i*, M_j is a measure of economic activity in the rest of the regions *j* and $d_{i,j}$ the distance between the *i* and the *j* regions.

This indicator can be interpreted as the volume of economic activity that has access to region *i* after having deducted transportation costs to cover the distances needed to reach the rest of regions *j*.

The information used to calculate the domestic market potential included, on the one hand, the total VA of Uruguay's provinces and the main border markets, considering the centroids of Buenos Aires (province and metropolitan area) to the south, the province of Entre Ríos towards the Littoral region, and Rio Grande do Sul to the north as well as the distances between provincial capitals. On the other hand, to obtain the market potential within each province, we calculated the intra-provincial distance following the proposal by Keeble et al. (1982), who calculated intra-provincial distance using a measure equivalent to one-third of the radius of a circle with an area similar to that of the region.[7] To obtain a comparable measure of the total VA of Uruguay's provinces and its neighboring regions, we used the aggregated data reported in Badía-Miró et al. (2020) expressed in 2011 dollars PPP (see Aráoz et al., 2020, for Argentina; Bucciferro & Ferreira de Souza, 2020, for Brazil; and Martínez-Galarraga et al., 2020, for Uruguay).

Second, plots located close to the points of sale or with access to better transport infrastructure or logistic systems will have, probably, a better performance because the costs of transporting the products to the markets are lower. This situation determines the location of the production and we need indicators that capture these differences in the connectivity of the regions. This indicator reflects one of the main contributions of Von Thünen (1826), which was the introduction of the concept of location rent, where transportation costs play a central role in explaining the relationship between different types of production, their intensity, and the available markets. In Uruguay, since the colonial times, Montevideo has been the main port and the capital, so we considered it as a reference point. However, the lineal distance is not enough to represent the economic distance between provinces and Montevideo.

The transport and communications system in Uruguay, which connects various provinces and, through its main ports, the country with the rest of the world, consists of rivers, railways and roads. Both the railways and inland waterway networks were important means of transport, but since the 20th century the continual construction of highways and roads gained prominence as a way of connecting the different regions of Uruguay (Baracchini, 1981).

The scarcity of transport infrastructure can invalidate any considerations regarding distance. We constructed indicators of connectivity for three networks and then proposed a combination that would allow us to obtain a global measure of the transport network in the period 1870-2008 ($connect_{i,t}$). The general equation is as follows:

$$\begin{matrix} transport \\ network_{\ j,i,t} \end{matrix} = \frac{Use\ of\ the\ network_{j,i,t}}{distance\ to\ capital \Big/ network\ density_{j,i,t}} \qquad \text{(B.2)}$$

With j: railway, road and inland navigation, i: Artigas, ..., Treinta y Tres and t: 1870, ..., 2008

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[7] Calculation is as follows: $d_{rr} = \frac{1}{3}\sqrt{\frac{size\ of\ the\ province}{\pi}}$, d_{rr} is the intraregional distance.

For the railway network, we used the amount of cargo transported per department, adjusted for the distance to Montevideo and the density of railway tracks. This reflects the railway's capacity to integrate regions into national and international trade. The river network is constructed based on the cargo transported through ports, considering the river distance to Montevideo's port and the number of ports in each department. Inland navigation was crucial until the early 20th century, when it lost prominence to the railway. Finally, the road network indicator is built using road density and the number of trucks per department as a measure of road transport usage for goods mobility. This mode of transport began to replace the railway starting in the 1930s (see details in Castro Scavone, 2017).

The lower the distance to the main port of the country (Montevideo), the higher the density of roads and railways, the larger the number of ports, the greater the cargo or load transported as well as a greater use by the number of trucks to transport by road, better connectivity of the province and, therefore, greater access to the market.

The calculation of the global transport connectivity indicator is based on a weighted combination of Uruguay's three main transport networks: railway, river, and road. Dynamic weights ($\lambda_{i,t}$) are assigned to reflect the changing relative importance of each transport mode over time. First, river transport is considered to lose relevance after 1916 due to the expansion of the railway network, leading to a reduction in its weight in the indicator from that year onward. Second, the transition from rail to road transport between 1924 and 2008 is incorporated, using Gross Production Value data for freight transport, which show that the railway sector declined from nearly 100% in 1920 to around 0% in 1955, while the road network expanded with the construction of highways and the increase in the truck fleet. Finally, for the 1870-1916 period, an inverse relationship is established between river and rail transport, assuming that the importance of the former decreased at the same rate as the latter increased. To ensure comparability across time series, the indicator values are standardized between 0 and 1 before applying the weighting scheme (see details in Castro Scavone, 2017).

The construction of the connectivity indicator is similar in each modality of transport j (railway, road, navigation) and combines transport networks ($\text{connect}_{i,t}$) calculated as follows:

$$\begin{aligned} connect_{i,t} = {} & \lambda_{1,t} E\left(transport\ network\ railway_{i,t}\right) \\ & + \lambda_{2,t} E\left(transport\ network\ road_{i,t}\right) \\ & + \lambda_{3,t} E(transport\ networknavigation_{i,t}) \end{aligned} \tag{B.3}$$

With E a function that standardizes values between 0 and 1, i=Artigas, ..., Treinta y Tres, $\lambda_{i,t}$: weights of each network and t = 1870, 1884, 1890, 1900, 1908, 1916, 1924 and 1937, 1943, 1951, 1956, 1966, 1970, 1980, 1990, 2000, 2008.

Control variables

We consider institutional arrangements, technological change and some relevant prices in agrarian production (land prices and commodities prices).

- Institutional arrangements

We considered two types of institutional arrangements. On the one hand, we represented the institutions most associated with modalities of ownership and concentration of land and, on the other hand, a variable that represents the agricultural technological policy.

First, we considered the type of land tenure and the average size of the agricultural plots. Considering modalities of landownership, we calculated the ratio between the leased area and the area owned by the proprietors.

$$\mathrm{hold}_{\mathrm{i,t}} = \frac{\text{area of leased land}_{\mathrm{i,t}}}{\text{area of owned land}_{\mathrm{i,t}}} \tag{B.4}$$

A second variable corresponds to the average farm size.

$$\mathrm{size}_{\mathrm{i,t}} = \frac{\text{total agricultural area}_{i,t}}{\text{number of agricultural plots}_{i,t}} \tag{B.5}$$

Both variables are particularly important for Latin American countries because the latifundia has been a structural feature of the land ownership systems and leases have been, mostly, short-time contracts (Álvarez Scanniello & Willebald, 2013).

Lastly, the public policy has a broad and varied field of action to influence agricultural location. We considered the support of agricultural production with soil preservation programmes, technical advice and assistance, and knowledge diffusion to improve land productivity. In Uruguay, the creation of agricultural experimental stations has a long history from the first decades of the 20th century (Baptista, 2016) and we considered the existence of a station in a province as an indicator of those types of programmes. Nowadays, these stations are part of a research network in agricultural matters and constitute the *Instituto Nacional de Investigación Agropecuaria (INIA)*; so, we referred to this variable as $\mathrm{inia}_{\mathrm{it}}$. We proxied this type of government support through a dummy variable that takes the value 1 in the province where an experimental station is installed, 0.5 in the border provinces and 0.25 in the provinces adjacent to the latter.

- Technological progress

Historically, technological progress opened possibilities of production in different territories. Many times, unsuitable soils for growing certain crops or raising determined animal species became useful because of the application of new techniques.

The diffusion of technology does not occur instantaneously in the economic and social structure (Mansfield, 1961; Rogers, 2003/1962), rather it is a process in which the information and the reduction of uncertainty are key factors in the early stages, in which individuals interact and learn a new way of doing things on the basis of experimentation.

The process of learning is subject to a lot of trial and error until, progressively, the learning capacity is reached. In a social system, transmission plays a central role, in which each individual –or adopter– accepts or rejects the innovation; ultimately, the acceptance of a new idea is the result of human interaction. Jarvis (1981) argues that the first adopters are producers with less aversion to risk and after that the new technologies are incorporated by the other producers gradually. However, once the information circulates faster diffusion accelerates and increases the number of adopters. Finally, the transmission slows down until, gradually, the benefits of the technology declines and its maturity is reached. Using this approach, the technology diffusion can be modelled through a normal distribution which, if assessed in accumulated terms, takes a S-shape. Similarly, Neo-shumpeterian authors emphasize that innovation and diffusion are not processes that can be separated into watertight compartments, but are integrated and mutually reinforcing (Rosenberg, 1976; Metcalfe, 1981; Pérez, 2009).

Given these considerations, technology follows a pattern of dissemination in an S-shape that can be represented by a logistic function with respect to time. Background on the use of this methodology can be found at Griliches (1960), who identified the S-shape in the pattern of diffusion of maize hybrid and agricultural machinery of the United States in the period (1933-1958) and Jarvis (1981) who analyzed the pattern of transmission in the improvement of pastures in Uruguay in the period (1960-1978).

We followed this type of analysis and estimated the patterns of diffusion of relevant technological changes in agricultural production over the long term, considering the mature period of each technological paradigm. First, we analyzed the crossbreeding of livestock (cattle and sheep) during the period 1870-1937, using the ratio between the stock of crossbred livestock and the total livestock stock. Second, we examined an indicator of agricultural mechanization from 1908 to 2008, based on tractor horsepower. Third, we considered pasture improvement, measured as the ratio of improved pastures to total pastures, for the period 1951-2008. Finally, we calculated the intensity of fertilizer consumption between 1970 and 2008. Fertilizer consumption for Uruguay was used, and the provincial distribution was determined based on the number of fertilized hectares (1970, 1980, and 1990) and agricultural land area (2000 and 2010) —see details in Castro Scavone (2017)—.

Analytically, we apply the following expression:

$$P_t = \frac{S}{1 + ke^{-bt}} \text{, with S, b, k} > 0. \tag{B.6}$$

Where,

S: represent the theoretical maximum of logistic function.

b: represents a diffusion coefficient of the technology.

k: is a constant.

Initially, we apply a mathematical linearization of equation (B.6) and then we estimate the parameters b and k with the OLS method using the available data. S is chosen in accordance with the available evidence (see Castro Scavone, 2018, for an application to the Uruguayan case).

In order to illustrate this point, in Figure B.1, we present estimates of the four technological paths in the case of Uruguay; the same procedure is followed for the 18 provinces.

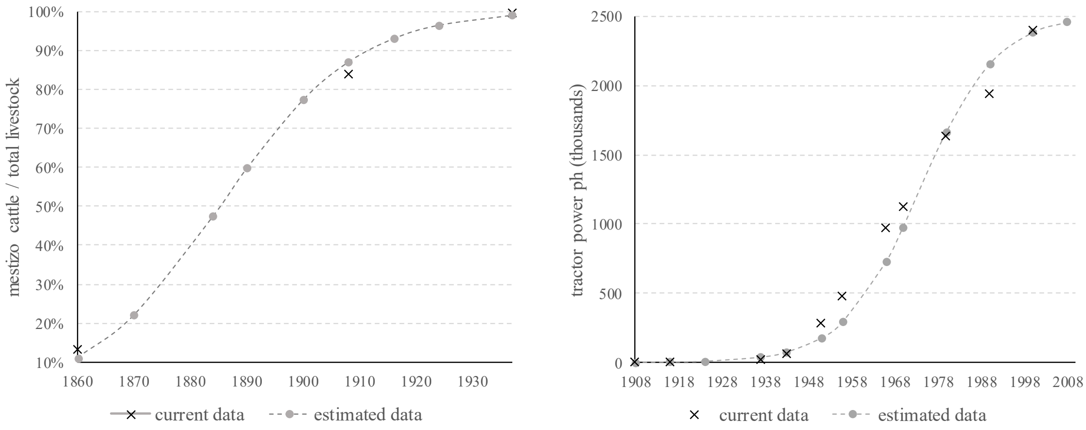
Finally, we calculated a global indicator of technological change, and with the objective of evaluating different paths altogether, we propose a standardization between 0 and 1 of the data obtained in the four trajectories. It is assumed that when a path declines, as is the case with genetic improvements (based on the crossbreeding of cattle) towards the end of the 1930s, the effect remains stable in the maximum value until the end of the period.

From the previous considerations, the indicator of technological change ($tech_{i,t}$) is calculated by adding the normalized values of estimated technological trajectories: crossbreeding of livestock ($tcgenetic_{i,t}$) between 1900 and 1937, mechanization (tcmeci,t) between 1908 and 2008, pasture improvement ($tcpast_{i,t}$) between 1951-2008 and consumption of fertilizers ($tcfert_{i,t}$) between 1970 and 2008. As we mentioned, the only trajectory which is considered exhausted is that referring to the genetic improvement of the cattle, while mechanization and the pastures in 2008 are close to decline, and consumption of fertilizers seems to even have potential to increase.

$$\mathrm{tech}_{i,t} = E\left(tcgenetic_{i,t}\right) + E\left(tcmec_{i,t}\right) + E\left(tcpast_{i,t}\right) + E\left(tcfert_{i,t}\right) \qquad \text{(B.7)}$$

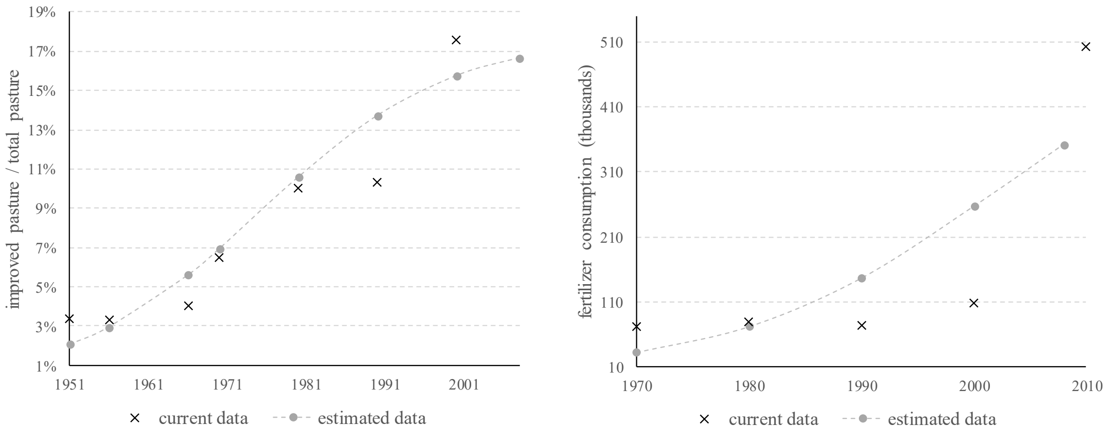
Where E is a function that standardizes values in the period of duration of the path between 0 and 1, i = Artigas, ..., Treinta y Tres and t = 1870, 1884,..., 2008.

Figure B.1 Logistic model estimation (Uruguay)



Panel a) Crossbreeding

Panel b) Mechanization



Panel c) Pasture improvement

Panel d) Fertilizer consumption

SOURCE: our own data.

- Relevant prices in agrarian production

Firstly, we consider a commodity price index. The information used to calculate the weighted index is as follows: international prices of three products (expressed in dollars), an exchange rate index which allows the conversion from dollars to pesos, the implicit price of Uruguayan agricultural value-added and a weight index of relative GDP of each product –meat, wool and wheat– in the 18 provinces. We calculated the index with the prices presented in Ocampo & Parra (2010) weighed according to the shares of those three activities in the productive structure of the provinces (Araujo et al., 2015; Castro Scavone, 2017), and the conversion to local currency allows us to capture the effect of devaluation on the dynamics of production and location. This index is divided by an implicit prices index of agricultural production (see Table C.1) In analytical terms the weighted index of prices of commodities ($\text{commp}_{i,t}$) is expressed as follows:

$$commp_{i,t} = \sum_{j} (p_{j,t}.er_t)/\,(ipi_t) x \frac{VA_{i,j,t}}{VA_{i,t}} \tag{B.8}$$

Where $p_{j,t}$: prices index in dollars for the product j (with j=meat, wool and wheat) in the period t (1870-2008)

er_t: (*pesos*/usd) exchange rate index.

ipi_i: implicit deflator of agriculture output.

$VA_{i,j,t}$: VA of the province i (Artigas, ,..., Treinta y Tres), in the period t (1870-2008) for the category j (meat, wool and wheat).

$VA_{i,t}$: total VA of the three products (meat, wool and wheat).

Finally, a variable that measures the evolution of land prices ($landp_{i,t}$) is included. It expresses a relative price as the ratio between the land price of each province i in the period t and the consumer price index in time t (this index is the same for the whole country) —see details in Castro Scavone, 2017—. This variable is considered because land has historically been the main production factor in agricultural activities in Uruguay. Land is a durable, non-reproducible, and immobile factor that influences market dynamics.

Appendix C. Statistical sources

Table C.1

Variable:		Observation year	Source and publication year
landq		1979	MGAP-CONEAT (1979)
distcap		2017	Web tourism services
rain		1884 -1890, 1902-1904 (average of the period), 1907, 1916, 1917, 1936, 1937, 1951, 1954, 1966, 1979, 1980, 1990, 2000 and 2008	Anuario Estadístico (1890, 1905, 1908, 1916, 1917, 1938, 1955, 1964-1966, 1983) and INUMET (2016)
markpot		1870, 1884, 1890, 1900, 1908, 1916, 1936, 1955, 1961, 1966, 1978, 1993 and 2008	Araóz et. al. 2020 from Argentina; Bucciferro & Ferreira de Souza, 2020 for Brazil; and Martínez-Galarraga et al. 2020 for Uruguay
commp		1870, 1884, 1890, 1900, 1908, 1916, 1936, 1955, 1961, 1966, 1978, 1993 and 2008	Ocampo & Parra (2010) e HISTECO-IECON
connect	railway	1869-1939, 1910	AE (1940) and Travieso (2017)
	Inland navigation	1884, 1890, 1900, 1909, 1916 and 1937	AE (1884, 1890, 1900, 1909, 1916 and 1937)
	Road	1924, 1957, 1965, 1975, 1989 and 2000-2008	Guardia et al. (2016), Anuario Estadístico (1974) CIDE (1965), MTOP (1989), MTOP (web) and SUCIVE (web)
tech	crossbreeding	1852, 1860, 1908, 1930 and 1937	AE (1905, 1938), Estadística Agrícola (1916), Censo General Agropecuario (CGA) (1930, 1937), Anuario Estadístico (AE) (1975)
	mechanization	1870, 1884, 1890, 1900, 1908, 1916, 1936, 1955, 1961, 1966, 1978, 1993 and 2008	AE (1908), EA (1916), CGA (1937, 1943, 1951, 1966, 1970, 1980, 1990, 2000, 2010)
	pasture improvement	1955, 1961, 1966, 1978, 1993 and 2008	CGA (1951, 1966, 1970, 1980, 1990, 2000, 2010)
	fertilization	1970, 1980, 1990, 2000 y 2010	FAO (web), INE (web), CGA (2000, 2010)
size		1870, 1884, 1890, 1900, 1908, 1916, 1936, 1955, 1961, 1966, 1978, 1993 and 2008	CGA (1908, 1916, 1924, 1937, 1943, 1951, 1966, 1970, 1980, 1990, 2000 and 2010)
hold		1870, 1884, 1890, 1900, 1908, 1916, 1936, 1955, 1961, 1966, 1978, 1993, 2008 and 2010	CGA (1908, 1916, 1924, 1937, 1943, 1951, 1966, 1970, 1980, 1990, 2000 and 2010)
inia		1914, 1947, 1964, 1970 and 1972.	INIA (2010)
landp		1870, 1884, 1890, 1900, 1908, 1916, 1936, 1955, 1961, 1966, 1978, 1993 and 2008	Castro Scavone (2017) based on: Barran & Nahum (1977), Balbis (1994), Reig & Vigorito (1986), MGAP (1988), Piriz (1987), Bértola et al. (1999) and MGAP-DIEA (2010).

SOURCE: our own data. See explanation and details of the sources in Castro Scavone (2017).

Appendix D

Table D.1 Descriptive statistics

Variable	SSSS	Mean	SD	Min	Max	Observations
ln (dens)	overall	1.88	0.91	-0.07	4.68	N = 306
	between		0.54	1.35	3.45	n = 18
	within		0.74	-0.03	3.58	T = 17
markpot	overall	0.66	0.42	0.21	2.32	N = 306
	between		0.43	0.27	2.09	n = 18
	within		0.07	0.39	0.94	T = 17
connect	overall	0.03	0.09	0.00	1.00	N = 297
	between		0.05	0.00	0.19	n = 18
	within		0.08	-0.17	0.83	T-bar = 16.5
landq	overall	97.56	23.67	68.00	138.00	N = 306
	between		24.31	68.00	138.00	n = 18
	within		0.00	97.56	97.56	T = 17
rain	overall	1070.82	337.38	337.20	2381.82	N = 306
	between		135.78	929.59	1335.90	n = 18
	within		310.41	413.80	2116.74	T = 17
size	overall	484.78	407.20	20.20	2084.50	N = 306
	between		272.26	33.04	1037.66	n = 18
	within		309.15	-24.80	1666.30	T = 17
tech	overall	1.70	1.36	0.03	6.82	N = 306
	between		0.79	0.90	3.65	n = 18
	within		1.12	-0.99	5.23	T = 17
landp	overall	62.44	45.21	0.00	322.17	N = 306
	between		16.53	30.01	89.45	n = 18
	within		42.25	3.52	310.92	T = 17
hold	overall	0.61	0.41	0.13	3.01	N = 306
	between		0.21	0.39	1.21	n = 18
	within		0.35	-0.36	2.41	T = 17
inia	overall	0.29	0.33	0.00	1.00	N = 306
	between		0.12	0.03	0.54	n = 18
	within		0.31	-0.26	1.17	T = 17
commp	overall	120.32	52.25	29.70	269.89	N = 306
	between		5.76	111.18	130.08	n = 18
	within		51.94	24.60	267.02	T = 17

Appendix E. Decomposition of R^2

Table E.1

LMG (Lindeman, Merenda, and Gold)

years	*markpot*	*connect*	*landq*	*rain*	*size*	*tech*	*landp*	*hold*	*inia*
1870-1924	0.24	0.02	0.15	0.04	0.17	0.05	0.22	0.05	0.06
1884-1937	0.23	0.02	0.16	0.03	0.15	0.07	0.18	0.07	0.09
1890-1943	0.21	0.01	0.15	0.03	0.14	0.08	0.21	0.06	0.11
1900-1951	0.24	0.01	0.13	0.01	0.15	0.1	0.18	0.09	0.09
1908-1956	0.21	0.01	0.12	0.01	0.17	0.16	0.18	0.05	0.08
1916-1966	0.27	0.02	0.15	0.02	0.14	0.22	0.11	0.02	0.05
1924-1970	0.32	0.02	0.18	0.01	0.12	0.22	0.08	0.01	0.04
1937-1980	0.31	0.04	0.21	0.01	0.1	0.21	0.06	0.03	0.04
1943-1990	0.26	0.12	0.2	0.03	0.07	0.19	0.07	0.03	0.02
1951-2000	0.29	0.06	0.21	0.04	0.07	0.23	0.04	0.05	0.01
1956-2008	0.27	0.08	0.22	0.01	0.06	0.24	0.1	0.01	0.01