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Agrarian mechanization in the settler economies. The diffusion of tractor in New Zealand and Uruguay in the 20th century

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Resumen

El objetivo de este artículo es estudiar el proceso de mecanización agrícola en las economías templadas de nuevo asentamiento europeo (*settler economies*) desde una perspectiva histórica y comparada. La relevancia histórica de la actividad agropecuaria en estos países se hace evidente en las características de su especialización productiva y en sus modos de inserción internacional. En primer lugar, el artículo propone la construcción de un indicador de mecanización agrícola en Uruguay y Nueva Zelanda para un período prolongado (todo el siglo XX). En segundo lugar, ofrece un análisis exploratorio de los factores que influyeron en la difusión y la adopción del tractor en ambos países. La perspectiva evolucionista y neo-schumpeteriana del cambio técnico y la innovación proporciona un marco conceptual que aborda la complejidad de la transformación tecnológica y permite estudiar su evolución en el tiempo, destacando su naturaleza tácita, acumulativa y dependiente del pasado. A partir de una caracterización integral del parque de tractores y su comportamiento en el tiempo, se aplica un modelo logístico para determinar la dinámica de adopción y difusión de esta tecnología. En términos generales, la introducción del tractor marcó un hito en el proceso de mecanización y reveló una dinámica con particularidades asociadas a la naturaleza y evolución del cambio tecnológico. En sus inicios, la introducción del tractor en las actividades agropecuarias respondió a un proceso de adopción lento —y de sustitución de otras técnicas— que constituyó una etapa temprana de aprendizaje; posteriormente, se difundió con rapidez en la estructura productiva de los países analizados. Finalmente, el proceso alcanzó un punto de saturación que coincidió con la emergencia de nuevas técnicas de producción que han ido sustituyendo de manera progresiva a las previamente dominantes. Por otra parte, se observa que la dinámica tecnológica difirió entre los países, con Uruguay rezagándose constantemente respecto a Nueva Zelanda. Por último, la exploración de los determinantes de las distintas tasas de adopción y difusión del tractor en ambos países revela que las condiciones enfrentadas por los productores neozelandeses fueron significativamente más favorables en términos de costos de combustibles mas bajos y mayores salarios que favorecieron una tecnología ahorradora de trabajo como lo es el tractor, así cómo mayores fuentes de financiamiento, menores precios del tractor y una estructura agraria más propicia para la mecanización, lo que permitió una adopción mas rápida y sostenida de la tecnología en comparación con Uruguay.

Palabras clave: agricultura, tractor, modelo logístico, adopción y difusión tecnológica.

Códigos JEL: N56, N57, O13, O33

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Abstract

The objective of this article is to study the process of agricultural mechanization in the temperate economies of new European settlements (settler economies) from a historical and comparative perspective. The historical significance of agricultural activity in these countries is evident in the characteristics of their productive specialization and the modes of their international integration. First, the article proposes constructing an indicator of agricultural mechanization in Uruguay and New Zealand for an extended period (the entire 20th century). Second, it offers an exploratory analysis of the factors that influenced the diffusion and adoption of the tractor in both countries. The evolutionary and neo-Schumpeterian perspective on technical change and innovation provides a conceptual framework that addresses the complex nature of technological change and allows for the study of its evolution over time, emphasizing its tacit, cumulative, and path-dependent nature. Based on a comprehensive characterization of the tractor fleet and its evolution, a logistic model is applied to determine the dynamics of adoption and diffusion of this technology. In general terms, the introduction of the tractor marked a milestone in the process of mechanization and revealed a dynamic that exhibited particularities associated with the nature and evolution of technological change. Initially, the introduction of the tractor in agricultural activities responded to a slow adoption process—and replacement of other techniques—that constituted an early stage of learning, after which it spread rapidly across the productive structure of the analyzed countries. Ultimately, the process reached a saturation point that coincided with the emergence of new production techniques that have progressively replaced the previously dominant ones. Secondly, it is observed that the technological dynamics differed between the countries, with Uruguay consistently lagging behind New Zealand. Finally, the analysis of the determinants of the different rates of tractor adoption and diffusion in both countries reveal that New Zealand producers faced significantly more favorable conditions in terms of lower fuel costs and higher wages, which incentivized the adoption of labor-saving technology such as the tractor. Additionally, greater access to financing, lower tractor prices, and a more conducive agrarian structure for mechanization facilitated a faster and more sustained adoption of this technology compared to Uruguay.

Key words: agriculture, tractor, logistic model, technological adoption and diffusion.

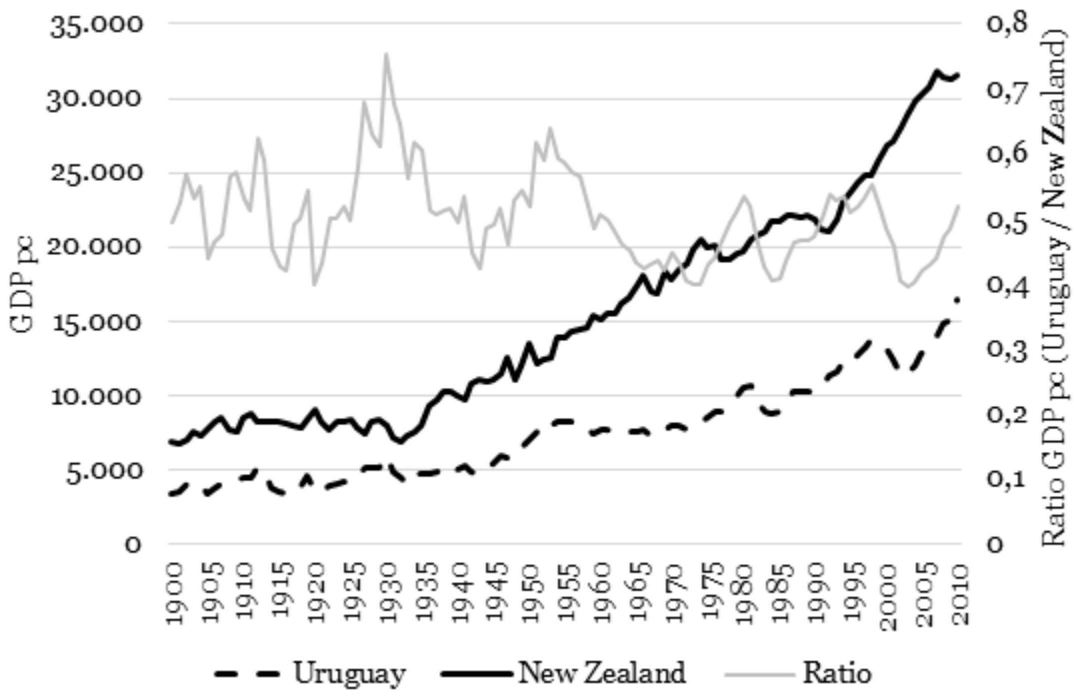
JEL Classification: N56, N57, O13, O33

1. Introduction

Comparative and long-term studies of the temperate climate economies of new European settlements (settler economies) have a long tradition and have been revitalized in recent years with the incorporation of new theoretical and methodological approaches. This has made possible to revisit old debates on the causes of the divergent trajectories between countries with common characteristics in terms of endowment of resources, structures of production and modalities of participation in international trade (Álvarez Scanniello et al., 2007; Álvarez Scanniello & Prado, 2022; Álvarez Scanniello & Menéndez, 2024).

Many authors (Mc Meekan, 1971; Rama, 1979; Barrán & Nahum, 1978; Filgueira, 1997; Duque & Román, 2003; Willebald, 2007; Álvarez Scanniello et al. 2007; Bertoni & Willebald, 2016, 2023) have questioned why countries like Uruguay and New Zealand, which share common characteristics, such as the size of their populations, their territories and markets; the favorable natural conditions for agricultural production, the pattern of productive specialization and the type of international trade based on the export of agricultural goods, have presented so important differences in terms of economic dynamics in the long term. The result has been the widening of the gap –divergence– in terms of income per capita between both economies since the third decade of the 20th century onwards (Figure 1).

Figure 1. Income per capita gap between Uruguay and New Zealand (1900-2010)



Source: Maddison (2009) and Maddison Project Database.

During the First Globalization and until the Great Depression (1870-1930) both economies showed a dynamic export trajectory which was based on a rich specialization on livestock production. In facts, this specialization maintained its predominance throughout the 20th century, but as on one hand, New Zealand's exports had an important dynamism in 1930-1970, Uruguay faced a long period of cattle stagnation. Based on this evolution, some authors have argued that the differences and their consequences in long-term economic performance can be explained by the evolution of productivity in the agricultural sector, relatively higher in New Zealand as a result of the particular institutional and technological trajectories that guided the evolution of the livestock sector (Álvarez Scanniello et al., 2007; Álvarez Sacanniello, 2005; 2007, 2018; Álvarez Scanniello & Menéndez, 2024).

This article shares these concerns and a similar motivation. We propose studying a relevant dimension of the agricultural performance of the settler economies: the technological progress and, in particular, the diffusion and adoption of agricultural machinery in the long term. For this, we select a relevant technology such as the tractor which meant a determinant factor of the evolution and structure of crops in the period.

Although Uruguay and New Zealand have historically been characterized by their specialization in the production of primary goods, with livestock being its more representative output, crops have occupied a prominent place in the productive structure. Given its growing share –although less until recent years– in the export baskets, its significant role as supplier of raw materials for the local industry and food for the domestic consumer market and, finally, its complementary character in the cattle production (an aspect that really has not been studied in depth), crops constitute a relevant activity in the agrarian structure of both economies.

Given that mechanization has its greatest impact on crop production, our focus will be in this type of activity which constitutes a contribution of our paper because the majority of the historiography has tended to remain concentrated on livestock. Then, our main question is: did agricultural mechanization show differences between countries and did Uruguay present a persistently lagging trajectory with respect to New Zealand in the long term? The hypothesis holds that, as in other dimensions of agricultural production (Álvarez Scanniello, 2018; Willebald, 2007), Uruguay presented a sustained delay in technological terms. Although both began to adopt the technology of the tractor in a relatively close period, the agrarian producers of New Zealand quickly advanced in the incorporation of the tractor, evidencing a relative backwardness of the Uruguayan agriculture that was characterized by its persistence throughout the entire 20th century. We are motivated to understand the causes of these different evolutions and we propose to carry out an exploratory analysis of the factors that presumably influenced the different rates of adoption and diffusion of the tractor in both countries. For this, we propose a descriptive and comparative analysis of some of the factors that, according to the specialized literature, has the capacity to influence in the rate of adoption and diffusion of agricultural mechanization.

After this introduction, the chapter is ordered as follows. A general conceptual framework is proposed to address the problem of technical change in the agricultural sector (Section 2) and the empirical strategy that will guide the research (Section 3).

Then, a characterization of the tractorization process in both countries is presented (Section 4) –considering around the six first decades of the century– and a review of proxies of the determinants of mechanization, comparing evolutions, levels and scope (Section 5). As conclusion, some final highlights are presented (Section 6).

2. Conceptual framework and analytical model

The Evolutionary and neo-Shumpeterian approaches to technical change and innovation provides a conceptual framework that allows addressing the complex nature of technical change and the study of its evolution over time, highlighting its tacit, cumulative and dependent of the past nature. Although evolutionary authors have dealt, to a greater extent, with the industrial sector, it is possible to use some of their central ideas in the analysis of the agricultural sector.

According to Pavitt (1984), in supplier-dominated sectors the sources of technical change tend to be located outside the sector. This is the case of industries that produce inputs and capital goods, which provide a large part of the innovations that are incorporated into the sector, or the research and extension organizations at the state level that play a prominent role in the generation of knowledge, in particular, in the improvements that occur at the farm management.[1] Therefore, the generation and use of innovations in the agricultural sector results from the relationship between other industries and organizations creating backward linkages effects (Hirschman, 1958).

On the one hand, the reduction in the relative price of inputs and capital goods in relation to agricultural products will be a stimulus for the incorporation of machinery and equipment carrying "the new" and, at the same time, its diffusion will be a stimulus for the generation of innovations in supplying industries. On the other hand, public institutions that generate and disseminate new technological knowledge play an important role in the agricultural sector. Many times, they are in charge of "bringing closer" to the producer or enabling the practical use of "technological packages" that require, for their adoption, prior learning, sometimes non-existent in the local markets. The importance of research and extension in agricultural activities acquires special relevance if the specific conditions of this activity are taken into account. In particular, the distinctly tacit nature of the use of agricultural techniques, in an environment that cannot be completely industrialized, and it is subject to the natural conditions given by the climate, the characteristics of the soil, the biological cycles, etc., create specific conditions to deal with and take advantages from the available technological supply (Possas et al., 1996).

The features of the agricultural sector –and in general in the supplier dominated sectors– give a manifest prominence to the learning mechanism (learning by doing, learning by using) in the process of diffusion of innovations. Undoubtedly, from this perspective, the previous technological level in the productive units and the rate of

[1] Although there have been private organizations that have also contributed to technical improvements in agriculture, historically, the role of the State has been predominant.

learning and adoption of new techniques will be a determinant of the rate of diffusion of technical change (Scarlato & Rubio, 1994).

The diffusion of technology as a specific field of study in economics has been the subject of multiple studies and analyses based on varied approaches and methodologies. The pioneering research carried out by Mansfield (1961) and Rogers (1962) have highlighted that the diffusion of technology does not occur instantly in the economic and social structure. Innovation and diffusion are not processes that can be separated into watertight compartments, but rather integrate and reinforce each other (Rosenberg, 1976; Metcalfe, 1981). In turn, the diffusion of technology responds, to a large extent, to a process of imitation and it can be argued that it is a discontinuous process, characterized by periods of acceleration and deceleration.

Information and uncertainty are key factors in the early stages of technology diffusion, in which individuals interact and learn –based on experimentation– a new way of doing things. At first learning is subject to a large number of errors and adaptations until slowly learning capacity is reached. In a social system, diffusion plays a central role, in which each individual –or adopter– accepts or rejects the innovation (it is a really “human interaction”; Rogers, 1962). In turn, producers with less risk aversion are the first to adopt a technology and, therefore, the introduction of the “new things” in the production process spreads slowly. Subsequently, as information circulates more quickly, diffusion accelerates and the number of adopters increases. Finally, the diffusion slows down until, gradually, the benefits of the technology decline and its maturity is reached.

According to this approach, the diffusion of technology can be modelled through a normal distribution that, if evaluated in cumulative terms, adopts the shape of an "S" ("inclined"), capable of being represented by a logistic function with respect to time (Jarvis, 1981). The communication of new ideas –in particular, new ways of doing things– between individuals who are part of a specific environment is the essence of the technology diffusion process. Individuals learn on the basis of a previous trajectory and in permanent interaction with their colleagues in that environment. The adoption of technology is a dynamic process that results from experimentation in the use of new techniques and it is the successive adoption that is the dynamic process that explains the diffusion of technology. Some pioneering empirical studies on this subject have made significant contributions, such as Griliches (1957), who identified the "S" shape in the pattern of diffusion of hybrid corn and agricultural machinery in the United States in the period (1933 -1958) and Jarvis (1981) who analysed the diffusion pattern in the improvement of pastures for the case of Uruguay.

3. Empirical strategy

The dynamics followed by the tractor technology can be analyzed from approaches based on diffusion models, which count with the ability of describing the evolution of technology through an inclined-S curve trajectory. With this characterization, several stages can be identified throughout the evolutionary cycle of technology in terms of the pace and direction of change and improvement, from initial innovation to maturity, which roughly coincides with the evolution of their markets, from introduction to saturation (Pérez, 2001). To operationalize this process, we use a logistic function.

3.1 Tractorization: a description of the technological trajectory

First, we obtained some stylized facts to describe the technological trajectory of both economies. For this, we estimated a logistic model with the objective of determining the dynamics of adoption and diffusion of tractor technology for a long period. In the case of Uruguay, the data are taken from Castro Scavone (2018), where the estimates arise from the quantification of the tractor fleet, both in terms of the number of tractors and their power –measured in hp– (Table 1). The National Agricultural Censuses are the main source used, and from them we obtained information on the number of tractors according to power range for the years 1908, 1916, 1930, 1937, 1943, 1946, 1951, 1956, 1961, 1966, 1970, 1980, 1990, 2000 and 2010. As we count with power ranges,[2] so the class midpoints are calculated as a reference of the corresponding power and multiplied by the number of tractors. For the extreme values in which it is not possible to obtain that register, we maintained the limit value reported in the source.

In the case of New Zealand, valuable statistical information was obtained from the New Zealand Official Yearbooks (several years). From the collection and systematization of information, we obtained annual data on the number and power of tractors between 1919 and 1986, and additional estimates were made for the years 1990, 2000 and 2010, with the aim of obtaining comparable series between countries for the entire period.

Table 1. Number and power (hp) of tractors in Uruguay, 1908-2010

Year	Number	Power (hp)	hp per tractor
1908	290	2,278	7.9
1916	734	5,687	7.7
1930	1,606	12,444	7.7
1937	2,256	17,480	7.7
1943	2,889	60,978	21.1
1946	3,188	70,297	22.1
1951	13,258	282,334	21.3
1956	21,777	475,106	21.8
1961	24,695	861,690	34.9
1966	27,856	971,988	34.9
1970	29,577	1,122,358	37.9
1980	32,878	1,628,370	49.5
1990	33,558	1,938,500	57.8
2000	36,348	2,463,446	67.8
2010	33,741	2,486,607	73.7

Source: MGAP – DIEA (several years) and National Agricultural Census.

[2] For example, 1980 census reported the following number of tractors by power range for the country as a whole: 5,083 up to 25hp, 13,860 between 25 and 50hp, 11,596 between 50 and 85hp and 2,339 with more than 85hp.

The stock of tractors in the years 1990, 2000 and 2010 was obtained by adding to the number of tractors in 1986 (latest data reported in the Official Yearbooks) the annual additions of tractors reported in the NZ Transport Agency corresponding to the year 2013 and applying an annual depreciation rate of 10%. An additional problem was to obtain the power of tractors for those final years. Since there is no information, we decided to maintain constant the average power of the last known data (corresponding to 1986).[3] The data and estimates of the number of tractors and power are presented in Table 2.

First, the beginning of the tractor diffusion process coincides: in Uruguay, this happened at the end of the 1920s (with less than 1,000 tractors) and, in New Zealand, where 100 tractors were reported in 1919. At the other extreme, in Uruguay the process of diffusion of the tractor begins to run out at the end of the 20th century, while in New Zealand this occurs in the 1980s, when the stock of tractors started to fall. Thus, the period for which information is available makes it possible to cover practically the entire trajectory of the diffusion process of the tractor in both countries.

Table 2. Number and power (hp) of tractors in New Zealand, 1919-2010

Year	Number	Power (hp)	hp per tractor	Year	Number	Power (hp)	hp per tractor
1919	100	1,762	17.6	1950	34,918	nd	nd
1921	380	6,694	17.6	1951	40,310	nd	nd
1922	412	6,949	16.9	1952	45,734	nd	nd
1923	439	7,634	17.4	1953	52,495	1,270,890	24.2
1924	512	8,813	17.2	1954	55,600	1,349,900	24.3
1925	1,026	17,222	16.8	1956	66,478	nd	nd
1926	2,025	32,360	16.0	1957	71,456	1,769,454	24.8
1927	2,588	39,225	15.2	1960	78,415	nd	nd
1928	2,883	45,234	15.7	1961	80,817	2,082,830	25.8
1929	3,377	51,040	15.1	1964	86,427	2,250,860	26.0
1930	3,891	59,217	15.2	1965	89,421	nd	nd
1931	5,023	79,129	15.8	1966	90,985	2,427,492	26.7
1932	4,856	nd	nd	1967	91,669	nd	nd
1933	4,972	78,024	15.7	1969	95,421	2,623,125	27.5
1934	5,062	79,884	15.8	1970	95,502	2,647,335	27.7
1935	5,349	84,867	15.9	1971	96,666	2,704,008	28.0
1936	5,710	94,905	16,6	1974	95,289	2,736,765	28,7
1937	6,585	112,007	17,0	1977	90,152	2,625,225	29,1
1938	8,030	139,269	17,3	1980	92,349	2,689,201	29,1
1939	9,639	nd	nd	1983	91,925	2,676,854	29,1
1940	11,278	203,387	18,0	1986	81,441	2,371,560	29,1
1941	12,516	236,420	18,9	1987	78,073	2,273,481	29,1
1942	13,967	271,983	19,5	1988	74,845	2,179,476	29,1
1946	18,940	nd	nd	1989	71,964	2,095,594	29,1
1947	21,156	nd	nd	1990	69,186	2,014,688	29,1

[3] We assume a depreciation rate of 10%. Considering that there is information on the stock of tractors and incorporations since 1947, it was possible to simulate several scenarios for the stock of tractors applying different depreciation rates and to compare them with the effective data (up to 1986). A rate of 10% is the one that best fits the known data; therefore, we decided to keep it in the estimates of the stock of tractors for the years 1990, 2000 and 2010.

1948	23,423	512,547	21,9	2000	51,502	1,499,728	29,1
1949	27,447	620,456	22,6	2010	49,842	1,451,395	29,1

Source: Statistics of New Zealand (http://www,stats,govtz,nz) and Officials Yearbooks.

A second aspect to consider is the trajectory followed by horsepower per tractor (a proxy for the "size" of the machinery). The contrast between both trends is striking. As Uruguay started with "small" tractors (around 8 hp per tractor) and below the power of New Zealand's tractors (17 hp per tractor), it ended the 20th century well above, with much more powerful machinery (around 70 hp per tractor), while New Zealand's levels increased by less than double compared to the beginning of the century (around 30 hp per tractor). We will return to this point when analyzing the determinants of tractorization.

Finally, considering that the use of this type of technology responds, fundamentally, to agricultural production, we consider appropriate to evaluate the data on the number and power of tractors in terms of arable agricultural hectares. It is true that both countries present similar characteristics –surface, natural conditions, productive structure and specialization, and the use of land–, but to evaluate the mechanization process (tractor diffusion) based on the number of arable hectares constitutes an adjustment that gives greater precision to the analysis.

The number of arable hectares for the years in which information on the number and power of agricultural tractors is available was elaborated from the information provided by the statistical department of the United Nations Food and Agriculture Organization. Agriculture (FAO) [4] (1960 onwards) and complemented by the official statistics of both countries (the National Agricultural Censuses and Agricultural Statistics for Uruguay and the Official Yearbooks for New Zealand).

We propose using a logistic function (equation 1) to fit the current data referred to total power of the stock of tractors in both counties according to the number of "arable lands" (expressed in hectares).

$$P_t = \frac{S}{1+ke^{-bt}} \quad \text{With S, b y k > 0} \qquad (1)$$

Where b represents a technological diffusion coefficient, S is the maximum theoretical value of the logistic function and k is a constant parameter.

We linearize equation 1 and then, we estimate the parameters of the function with ordinary least squares (OLS) method. With this procedure, we obtained b and k, while S is arbitrarily assumed in accordance with the available information. In Uruguay, the maximum power of tractors per hectare is reached in 2000. Then, to establish a "roof" in

[4] According to the FAO definition, "arable lands" are those lands used for temporary crops, lands used for temporary meadows and pastures, and fallow lands (see http://faostat.fao.org). The first data provided by this series is 1960.

the estimation, 1% is added to that record to determine the coefficient S. The same procedure is used for New Zealand, where the maximum is reached in 1983.

In the case of New Zealand, the number and power of tractors in the years 1990, 2000 and 2010 are not used in the estimation of the logistic function. This decision is based on two criteria. First, because the weakening of the process in New Zealand occurred in the 1980s (from 1983 onwards the decline is sustained which indicates the proximity of the matureness of technology); and second, because including data corresponding to the beginning of the 1980s allows capturing adequately the decline of the process without having to include subsequent data (1990, 2000 and 2010, which, in addition, are the result of our own estimations).

The point where the maximum slope of the function is achieved is t=τ, where $\tau = \frac{\ln(k)}{b}$. This calculation offers the turning point of the function and, therefore, the year when the highest growth is obtained. This point coincides with the year when the 50% of the total power of tractors is accumulated.

Based on these results, a characterization of the dynamics and evolution of the incorporation of the tractor in both economies is described and discussed in section 4.

3.2 An exploration of the determinants of tractorization

The study of the diffusion of the tractor and its main determinants has been approached from different methodologies, although a long tradition of studies has focused on factors associated with the profitability differentials between alternative technologies (tractor vs draught animals). For this reason, the analyses based on income and production costs have prevailed. However, recent studies have made important contributions based on new evidence on the importance that can be attributed to the evolution of the design and versatility of the tractors which has expanded the use of this technology in agriculture.

The application of the "threshold" model –originally proposed by Davis (1966)– has been the standard approach in the study of tractor diffusion. This model determines the size required for an agricultural estate to be under the conditions of minimum profitability to incorporate a tractor into the production.

In an influential paper, Olmstead & Rhode (2001) analyse the importance of the scale of production as a determinant of the diffusion of the tractor in agriculture in the United States between 1910 and 1960. Applying an econometric analysis based on the use of simultaneous equations, they found that the scale of production and the adoption of the tractor were co-determined.

Lew & Carter (2018) summarizes the factors usually used in this type of studies, pointing out that the profitability for the farmer derived from the acquisition of a durable good (such as the tractor) depends on its price, on the interest rate and the expectations of the price of inputs (basically fuel), as well as the cost of the technology that is replaced (associated with the cost of labor required to manage the draught animals and part of the production used to feed the animals). Public policies can influence any of these factors, both customs and subsidies that support the activity and those state expenditures destined to support the technological extension. In this study, the authors attribute to the restrictive immigration policy of the United States in the 1920s an upward effect on rural wages and, by this means, a higher rate of adoption of tractors than their Canadian peers.

Manuelli & Seshadri (2014) found evidence that the rate of diffusion of tractor technology in the agriculture of the United States in the first half of the 20th century can be attributed to continuous improvements in tractor quality and to the fact that the use of traditional methods based on blood traction only became unprofitable when there were, together, an increase in wages in tasks with high labor requirements.

Gross (2017) acknowledges the contribution of Manuelli & Seshadri (2014) by considering improvements in tractor design over time as a crucial factor in explaining its diffusion, but goes even further and points out that they should not only be considered design improvements over time, but spatial differences must also be taken into account. So that the diffusion of the tractor depends, not only on the increasing number of users, but also on an increasing number of uses.

Finally, Martini & Silberberg (2006) point out that the introduction of tractor, in addition to promoting labor savings, saves time on tasks. The authors studied the adoption of this type of machinery in the state of Iowa (United States) in the period 1920 -1940 and found evidence that the time saved by adopting the tractor (compared to the traditional blood-drawn method) allowed destining resources to be allocated to other tasks such as raising cattle or providing services to other farmers, and that this was a relevant factor to explain the adoption of the agricultural tractor.

Consequently, the determinants of the adoption and diffusion of the tractor –as substitute for alternative technology, which is the use of blood-traction– could be summarized in the following items:

- price of the tractor (and those costs related to the different customs tariffs when the machinery is imported).
- technical quality of the tractor and its ability to handle various uses (and save time).
- relative price of inputs, such as fuel and labor cost.
- financing of the purchase of the tractor (available bank funds, interest rates and state support).
- different scales of operation.
- promotion of cooperation and immigration policies.

Proxies to these determinants will be presented and the evolutions, levels and scope will be compared in the cases of Uruguay and New Zealand to get an idea closer to the adoption differentials between both economies.

4. A characterization of the tractorization process

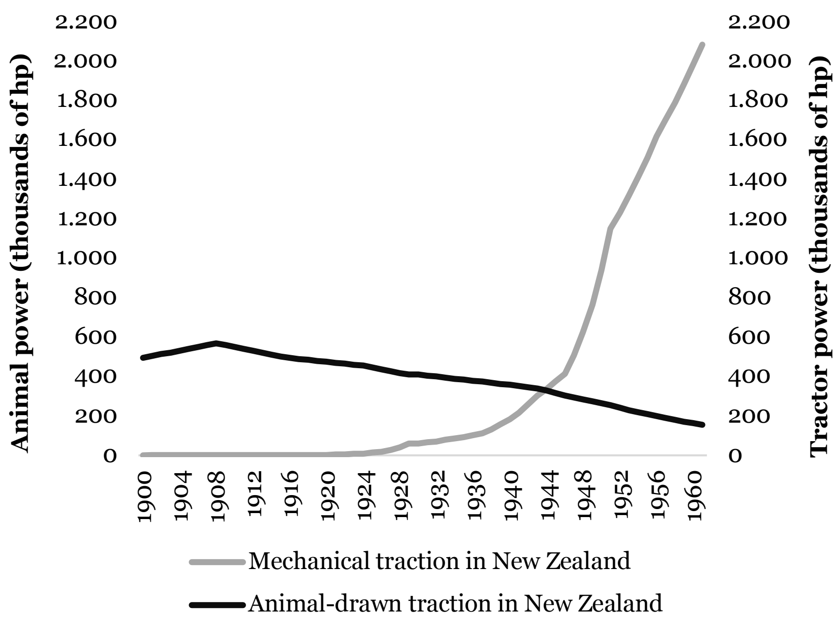
At the end of the 19th century, heavy traction was carried out with pack animals. Draught horses gradually replaced oxen in Uruguay and donkeys and mules in New

Zealand. In order to compare blood traction between countries and, in turn, evaluate the growing importance of mechanical traction in the period, horsepower (hp) is used as a measure. This allows comparing animals with different drag capacities and power of tractors.[5]

At the beginning of the 20th century, blood traction presented similar levels in both countries. However, the process of substitution by mechanical traction was much more dynamic in New Zealand than in Uruguay. At the beginning of the 1940s, mechanical power in New Zealand began to achieve the levels of animal power (levels equalized in 1943) and the same happened in Uruguay more than a decade later (levels equalized in 1956) (Figure 2).[6]

Figure 2. Traction force, 1900-1960

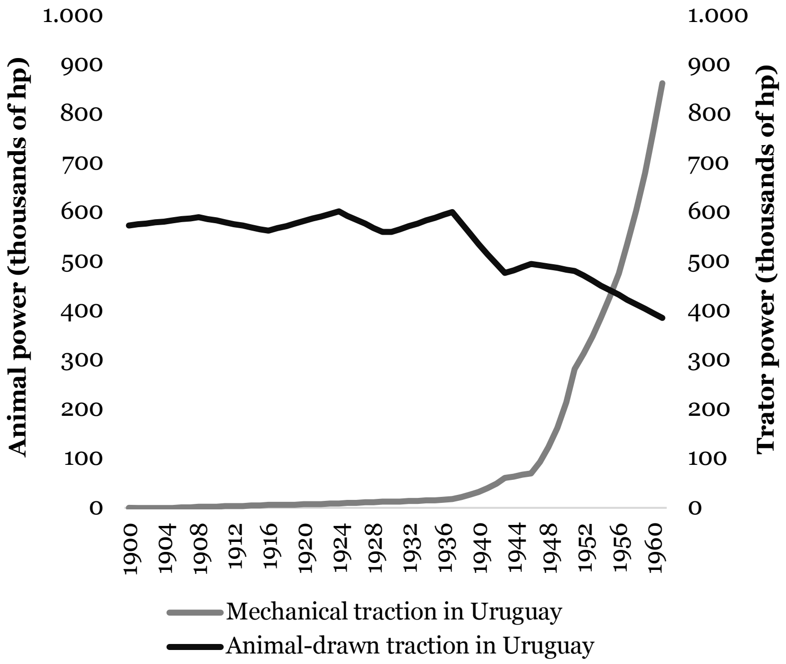
(a) New Zealand



Source: own elaboration

[5] The estimates made by González (1995) were used to express the load power of different draught animals (donkeys, mules, oxen and horses) in horsepower (hp) (p. 36, Table 2.3).
[6] We chose the period (1900-1960) because it covers the first stages of diffusion of the tractor in both countries and allows us to observe more clearly the decrease in blood traction in agricultural activity caused by the extensive use of tractor.

(b) Uruguay



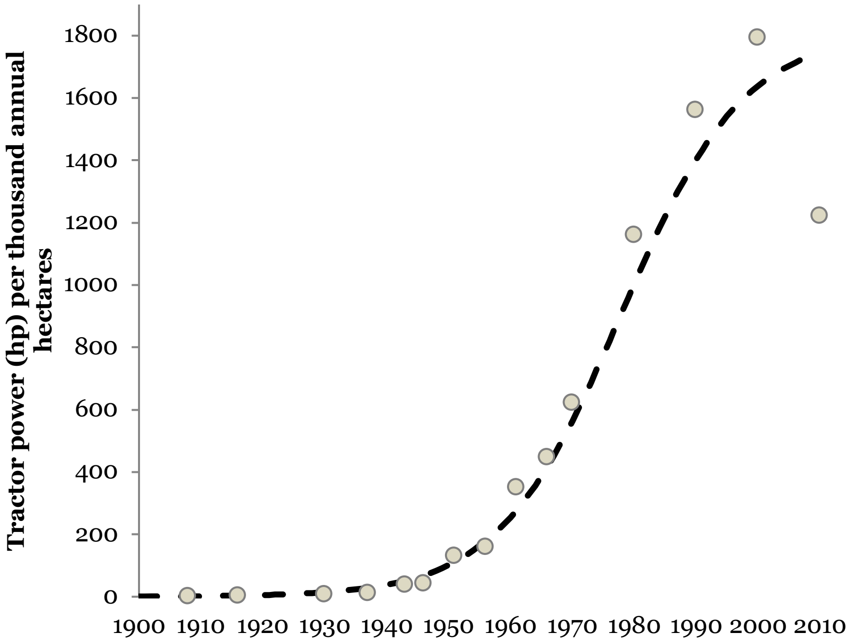
Source: own elaboration

In the beginning of the 1960s, the total power of traction deployed by New Zealand almost doubled that of Uruguay. At that time, New Zealand producers had reduced the work carried out by horses, donkeys and mules to a third while, in Uruguay, oxen and horses still represented a relevant portion of the animal stock.

The diffusion process of the tractor technology followed a trajectory that can be adequately modelled according to a logistic function. With this model, high adjustment coefficients were obtained in the estimates made for both countries (Table 3). This is a technology that was deployed practically throughout the entire 20th century. However, while in the case of Uruguay the final stage of the process is verified at the end of the century, in New Zealand the diffusion of the tractor seems to be in its mature stage already in the 1980s (Figures 3 and 4).

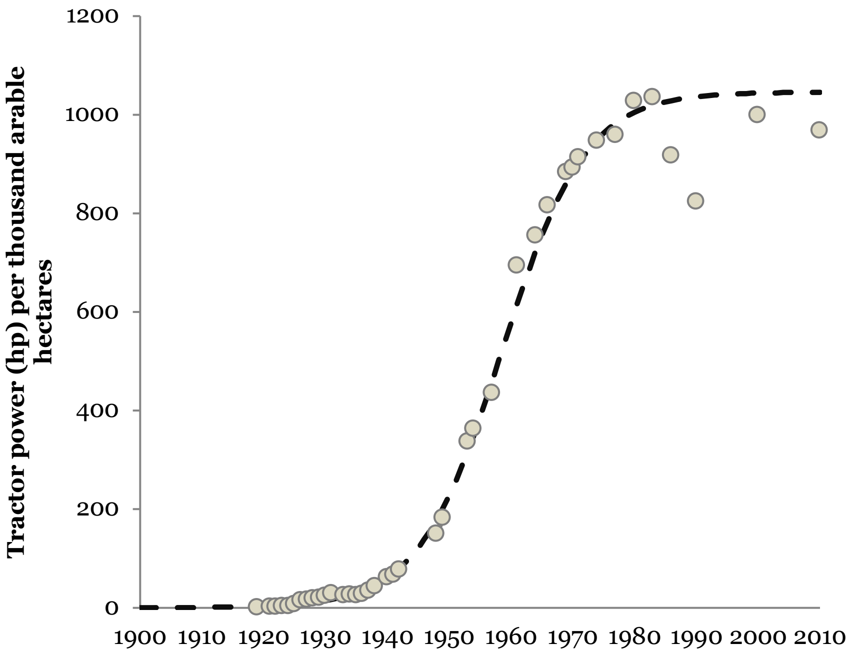
The estimation of the parameters of the logistic model offers additional considerations. The diffusion coefficient b (0.149 and 0.101 for New Zealand and Uruguay, respectively) shows that the process of diffusion was significantly faster in New Zealand. Then, it is possible to calculate the year corresponding to the turning point of the logistic function (τ) (year in which 50% of the tractor power per hectare is accumulated). In New Zealand the turning point occurs almost two decades before that in Uruguay (1959 vs 1978) (Table 3).

Figure 3. Estimation of a logistic model for Uruguay, 1900-2010



Source: own elaboration based on data from MGAP – DIEA (several years), National Agricultural Censuses

Figure 4. Estimation of a logistic model for New Zealand, 1900-2010



Source: our data based on FAO - Statistical Division, http://faostat.fao.org and statistics of New Zealand http://www.stats.govt.nz Official Yearbooks collections.

Table 3. Estimation of a logistic models for New Zealand and Uruguay, 1900-2010

	Coefficient of correlation	Maximum value (S)	Diffusion coefficient (b)	Constant (k)	Turning point (τ)
New Zealand	0,9842	1,036	0,149	367	1959
Uruguay	0,9464	1,974	0,101	1,193	1978

Source: our data.

The dynamics that followed the diffusion of the tractor in both countries may be characterized with additional information presented in Table 4. From the estimation of the parameters b and k, it is possible to obtain the year for which the percentage "x" of the tractor power was accumulated in each country. The results show that tractor technology spread more rapidly in New Zealand than in Uruguay along the whole period and the differences widened in time. In 1944, 10% of the power of tractors per hectare of land was reached in New Zealand, while in Uruguay this occurred in the mid-1950s. Uruguay accumulated 10% of the tractor power 12 years later than New Zealand and 90% 26 years later. While tractor technology was practically widespread in New Zealand by the end of the 1970s, in Uruguay this happened towards the end of the 20th century.

Table 2. Power of tractors (hp) accumulated in the period of diffusion in New Zealand and Uruguay

Accumulated percentage of power of tractors /1000 hectares	Year		Difference (years)
	New Zealand	Uruguay	
10%	1944	1956	12
20%	1949	1964	15
30%	1953	1970	17
40%	1956	1974	18
50%	1959	1978	19
60%	1961	1982	21
70%	1964	1986	22
80%	1968	1992	24
90%	1973	2000	26

Source: own data.

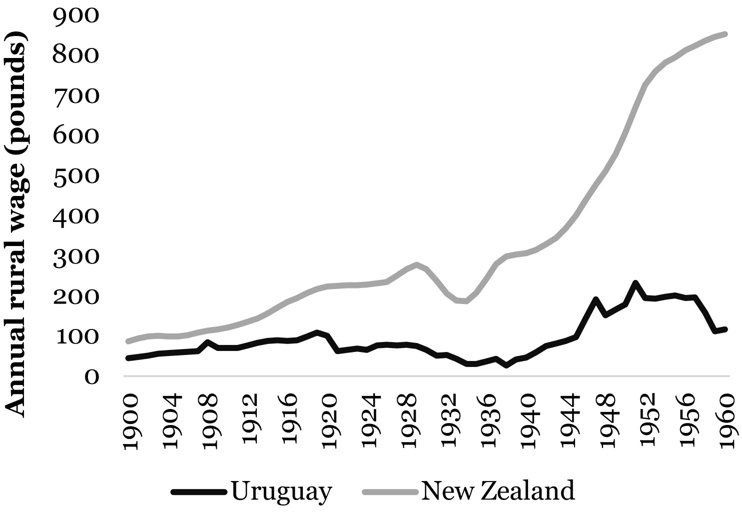
5. Determinants of mechanization. Proxies and comparisons.

According to our literature review, we identified some relevant factors to study the determinants of tractor adoption and diffusion. We propose a descriptive analysis, from a historical and comparative perspective, of the causes of the lag in the adoption of the agricultural tractor in Uruguay compared to New Zealand. Our period of analysis is from the beginning of the 20th century to 1960, since it is during this span that technology takes off and expands (remember that New Zealand reaches its turning point in 1959).

In addition, it is the period usually selected by those authors who study the diffusion of the tractor from a historical perspective (Olmstead & Rhode, 2001; Manuelli & Seshadre, 2014, for the United States; Lew, 2000, for Canada; Lew & Cater, 2018, for Canada and the United States). In the case of Uruguay and New Zealand, that period undoubtedly captures the first stages of diffusion of the tractor and its subsequent expansion.[7]

Rural wage. In order to compare the rural wages of Uruguay and New Zealand in the period 1900-1960, it was necessary, previously, to make some estimates. For Uruguay, we obtained information on annual nominal wages at current prices of the agricultural sector that covers the years 1900, 1908, 1919, 1936, 1945, 1955 and 1963, and we interpolated to obtain annual series. In the case of New Zealand, annual estimates were obtained and no interpolations were necessary (see details in Appendix). First, we compared nominal wages at current prices expressed in the same currency (pounds; Figure 5). From the comparison of nominal wages, a suggestive result is obtained: although both countries have historically presented a similar productive specialization, competing in products and markets, and therefore prices and wages could be expected to converge, the result does not seem to follow this direction. So, if high wages are a factor that encourages the incorporation of labor-saving technology, such as mechanization, then New Zealand producers found in adopting the tractor an adequate solution to face the growing trend of rural wages.

Figure 5. Rural wage in Uruguay and New Zeeland. In current pounds (1900-1960)

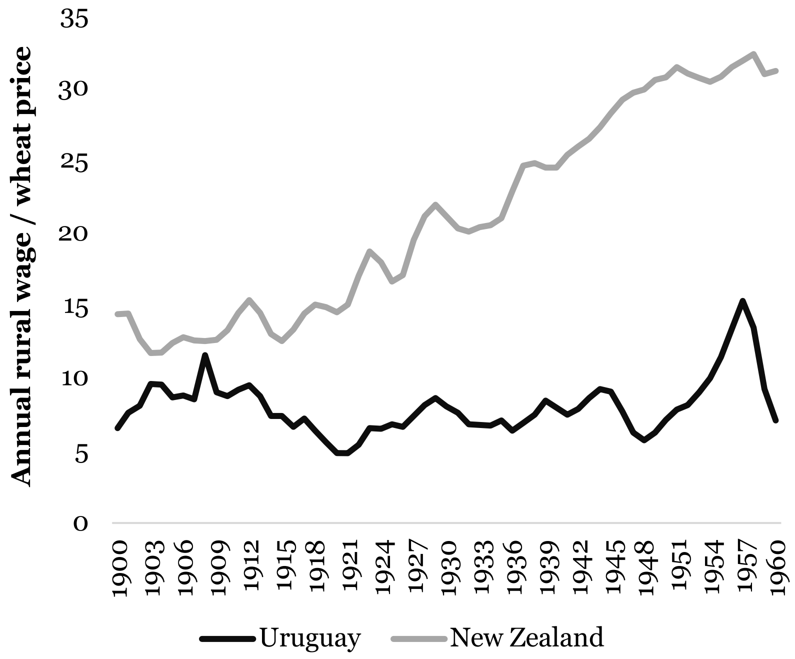


Source: Own data

[7] This paper does not analyse the complementarity between crops and livestock. This possible relationship would have led to extend the period of analysis until, at least, the 1980s. It is likely that during the 1960s-1970s the policies that promoted the adoption of the New Zealand model in Uruguayan livestock have had significant effects on mechanization. This problem, which requires a long-term view, will be part of next steps in our research agenda.

Second, we expressed the rural wage in terms of the main agricultural item of both countries: wheat (Figure 6). We calculated the ratio between the annual wage at current prices of each country in relation to the price of the ton of wheat (annual average) expressed in the same currency, and the result is even more compelling. While in the 1910s the wage measured in units of wheat was practically the same in both countries, by the 1960s the value of the indicator practically doubled in New Zealand. This evidence reinforces our hypothesis that New Zealand agricultural producers had greater incentives than their Uruguayan counterparts to capitalize on their farms.

Figure 6. Rural wage in Uruguay and New Zeeland. In current pounds expressed in unities of wheat (1900-1960)

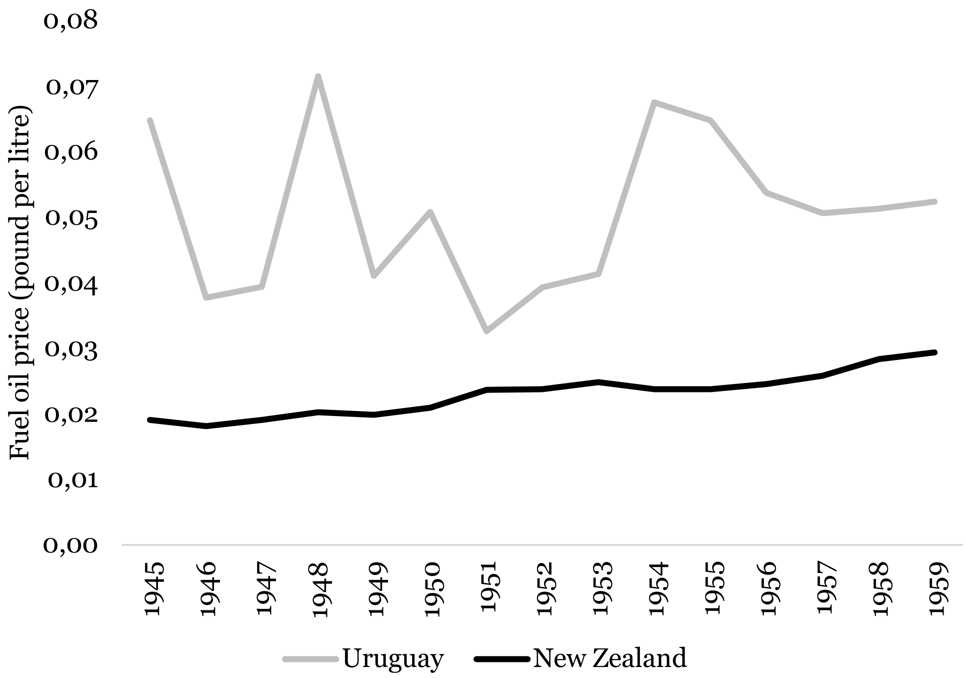


Source: own data

Fuel price. To compare fuel costs in Uruguay and New Zealand, we have partial information available only for the period 1945-1958. However, this is a relevant period during which both countries were in the middle of the tractor diffusion process. The comparison is based on nominal fuel oil prices per litre in each country, expressed in pounds. For Uruguay, the available information comes from Oxman (1961), which reports import data of fuel oil in dollars and tons and, so, our price is an import unit value; the corresponding period is 1945-1958. In the case of New Zealand, we consider an equivalent measure using the items "Fuel and lubricants" (in pounds) and "Crude petroleum, fuel oil, etc." (in gallons) from the Statistical Yearbook 1959 (average 1956-1958). Since we also have information on fuel cost trends in New Zealand's agricultural sector (Hussey & Philpott, 1969; Table XIV, 1949–1950 = 100), we project the price backward using this index.

The comparison reveals a significant difference in fuel oil prices between the two countries. While New Zealand maintained relatively stable and lower prices (around a 50% in average), Uruguay experienced greater volatility and higher costs (Figure 7). Since fuel prices directly impact the operating costs of mechanized agriculture, the observed differences may have influenced the speed and extent of tractor adoption in each country. In this sense, lower fuel costs in New Zealand may have facilitated mechanization, reinforcing the role of the tractor as a labor-saving technology in response to rising rural wages.

Figure 7. Fuel oil in Uruguay and New Zeeland. In current pounds per litre (1945-1958)

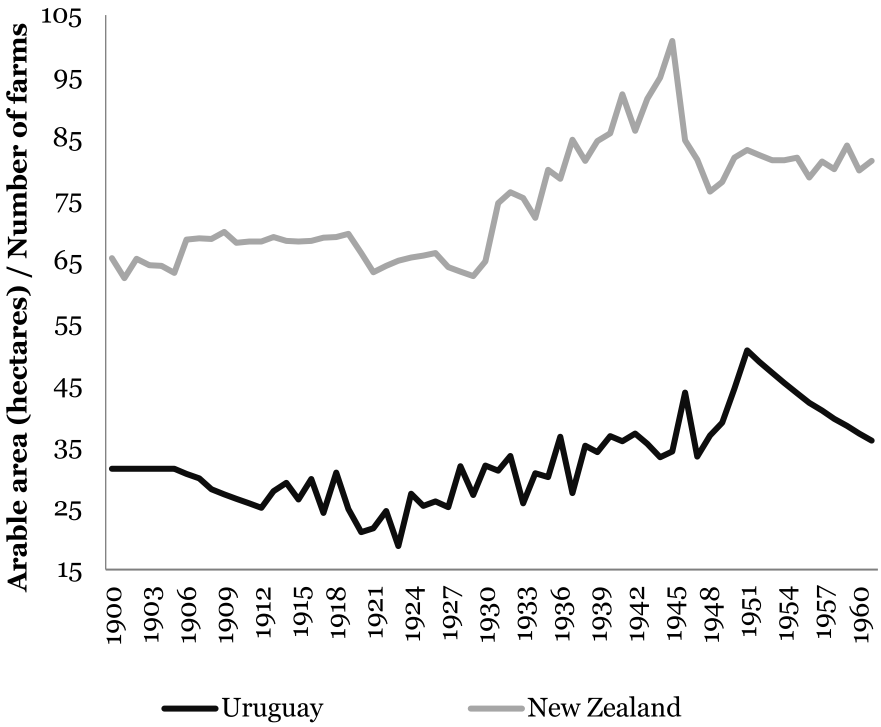


Source: own data

Production scale (size of the plots). The importance of the scale of production as a determinant of the incorporation of technology has been a prominent factor in the literature on agricultural mechanization. It is true that in order to test a hypothesis of this nature, a wide and varied set of information is required to make it possible to compare the profitability of alternative production methods. However, in this article we opted for a partial approximation that, in any case, we consider valid and that consists of comparing the average size of agricultural plots. So, we need information on the area of land devoted to crops and the number of the corresponding plots in both countries. In the case of Uruguay, detailed annual information is available for both variables. However, for New Zealand, the information is partial and it was necessary to make some assumptions in order to obtain an annual series (see Appendix). Although the cultivation area shows similar averages in both countries during the first half of the 20th century (around 1 million hectares), in Uruguay there was a greater number of establishments, which resulted in a size appreciably lower. While, on average, the plots destined to cultivation in Uruguay only exceeded 40 hectares around the 1950s, in New Zealand, the same indicator reached values greater than 60 hectares in every year (Figure 8).

With these results, and at least at this level of analysis, it is possible to conjecture that the average size of New Zealand farmers gave them greater margin to overcome scale restrictions compared to Uruguayan ones, who faced a structural problem of agricultural sector consisting of the agricultural smallholding (CIDE, 1967).[8] This evidence can be combined with the evolution followed by horsepower per tractor (a proxy for the "size" of the machinery). Uruguay increased its tractor fleet by incorporating larger machinery than New Zealand, but it was allocated to smaller plots, very likely leading to significant inefficiencies.

Figure 8. Size of the plots destined to cultivation in Uruguay and New Zealand (1900-1960)



Source: own data

Land tenure. Unlike the scale of production, which has captured the attention of historians and economists in the study of the adoption of agricultural machinery, the land ownership system (property, lease, etc.) has been a relatively little studied issue. Uruguay and New Zealand differ from those of other countries in which the increasing

[8] The discussion *minifundio vs latifundio* was very in vogue in the 1960s, not only in Uruguay but also in the rest of Latin America (Sorbring, 2006).

of the cultivation area was possible through leasing contracts and obtain very favorable scale and profitability conditions in the short term, as was the case of farming in Argentina (Hora, 2012). In contrast, in New Zealand and Uruguay, the capitalization of small agricultural plots, with very strong competition from the livestock activity (dairy and meat and wool livestock) and, therefore, with reduced possibilities of expansion, had to face restrictions of investment that expressed itself in difficulties for the acquisition of machinery.

Since it was not possible to obtain information on the landownership regime disaggregated by production item (crops and livestock) for both countries, the comparison is made based on the landownership regime of the total agricultural sector. This constitutes an important limitation because the situation between both types of activities was different but the biases are not obvious. The selected tenure indicator is the share of hectares under ownership regime in relation to the total hectares. In the case of Uruguay, the agricultural censuses provide disaggregated information between area under lease and ownership, and this classification was used. The case of New Zealand deserves some specific considerations because a significant share of the country's productive area was, in the period under analysis, in the hands of the State, which administered the land in accordance with criteria of promoting production and development (Álvarez Sacanniello, 2008).

Although the leases imply well-defined property rights, the terms of the contracts can condition the investment decisions of the producers. In general terms, if the producer is a tenant, he will make short-term decisions; that is, he will pay attention to his present production, which could lead him to neglect aspects such as crop management, the application of fertilizers or other practices that compromise future productivity. In the case of investing in equipment and machinery, which involves a high fixed cost, the owner will be in a better position to carry out investment planning because he has terms longer than the lease, as well as the use of property collateral to be able to borrow. So, the nature of the lease (characteristics of the contract, terms, renewals, etc.) is a relevant factor that must be taken into account in this type of analysis.

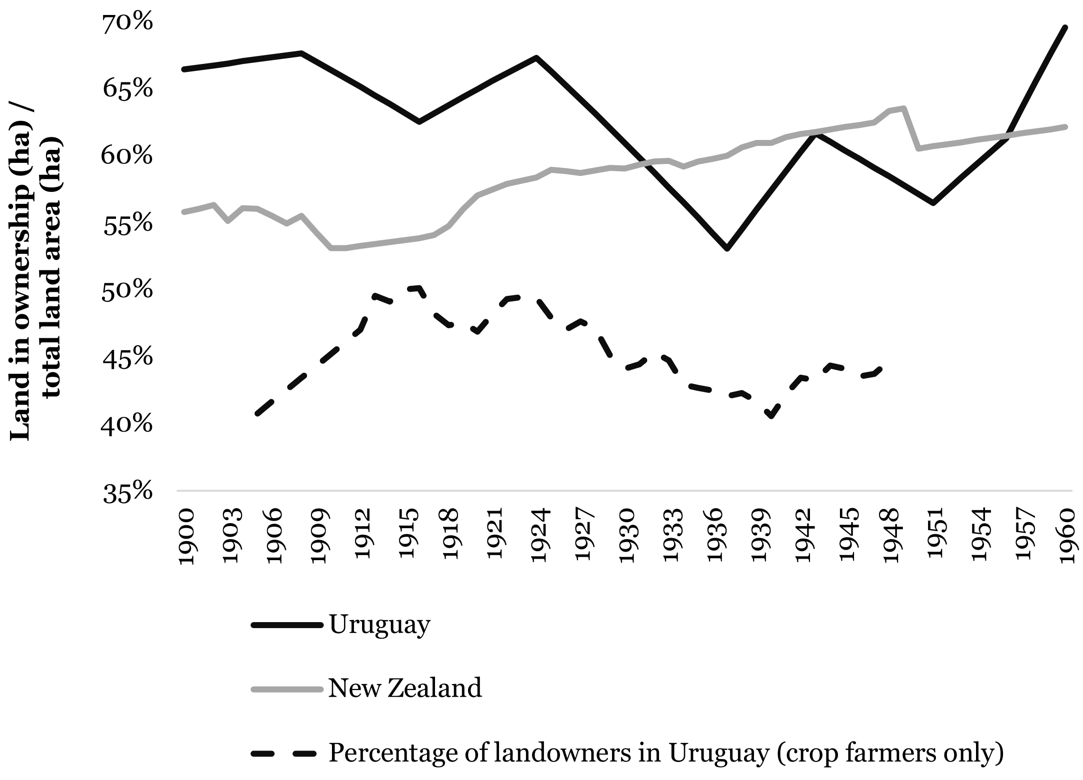
Considering that in New Zealand a part of the lands owned by the State were granted under regimes that refer to long periods (25 or 33 years, and with very favorable renewal conditions), we opted to assimilate a portion of those lands as land owned by "somebody", which resulted in the property regime being located somewhat above the data reported in the source (see Appendix).

Disaggregated data on the State land tenure regime, only is available for 1920-1927. The categories are: pastoral purpose; small grazing areas; perpetual lease; occupation with purchase right; renewable lease. On average, the categories of perpetual leases, occupation with right of purchasing and renewable leases represented 27.4% of the total State land, while the pastoral categories and small grazing areas occupy the remaining 72.6%. Our decision was to add to the owned area reported in the source, that 27.4% of State land each year and the remaining 72.6% to the leased area.

The result does not allow us to identify a decidedly greater presence of land under ownership in New Zealand compared to Uruguay. While in the first decades of the century the relationship favored Uruguay, since the 1930s, and following a growing trend, the area under ownership in New Zealand tended to be above that of Uruguay (Figure 9).

Complementing this analysis, and taking advantage of additional information in the case of Uruguay, we illustrate the percentage of farms under ownership regime. This is an indicator that, although measures the same phenomenon, it is of a different nature and was only obtained for Uruguay. The evolution reinforces our argument: agricultural sector in Uruguay had to face a problem that New Zealand had a minor impact, which refers to the capitalization of leased establishments.

Figure 9. Landownership in the agriculture in Uruguay and New Zealand (1900-1960)



Source: own data

Price of tractor. Those economies that do not have an agricultural machinery industry face some restrictions, such as the higher cost of acquiring machinery abroad and the difficulty of adapting the technology to the specific requirements imposed by natural conditions. Given that we do not have information for Uruguay, we used the data for Argentina reported in Bil (2011), which cover a good part of our period (Table 5) and are a good proxy. In the case of New Zealand, we estimated the price of acquiring imported tractors[9] for the years 1940, 1947, 1950, considering imports of agricultural tractors and tractor patents.

Table 5. Price of agricultural tractor, current USD

Years	Uruguay (1)	New Zealand (2)	(1)/(2)
1928	1,020		
1933	850		
1937	975		
1940	940	560	1.7
1947	1,660	794	2.1
1950	2,450	976	2.5

Source: (1) Bil (2011); (2) Own estimates (based on Official Yearbooks and NZ Transport Agency, 2013)

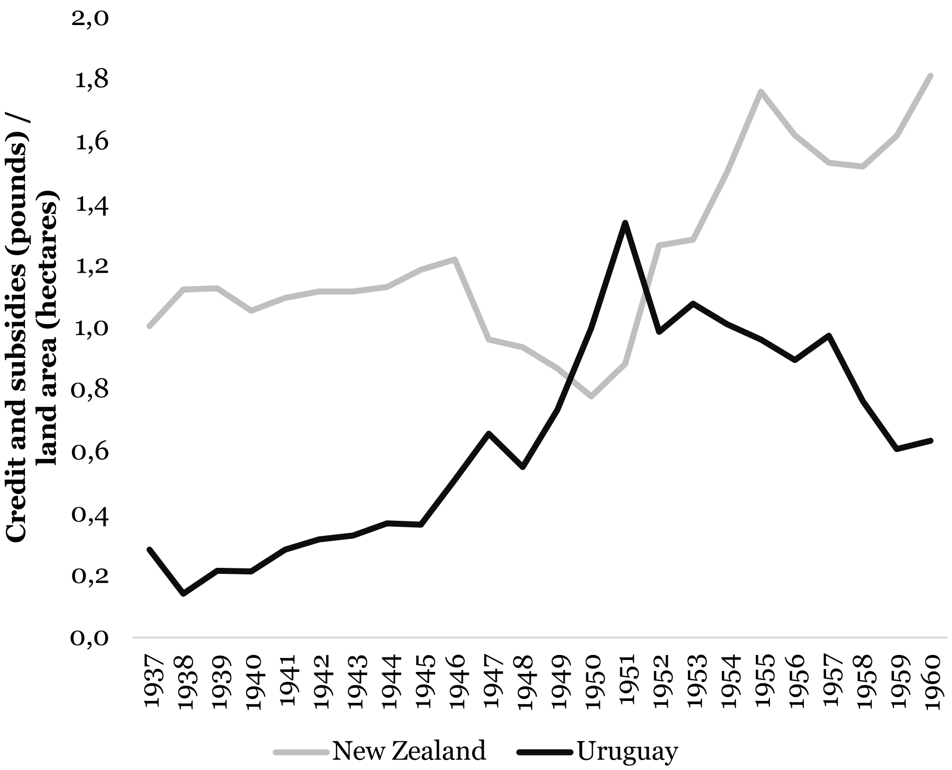
Our estimates have limitations, but they offer reasonable levels of magnitude. According to this evidence, we can affirm that the effort for Uruguayan producers was greater than that of the New Zealand producers and, therefore, this was a factor that imposed higher restrictions for the diffusion of the tractor in Uruguay.

Agricultural credit. The policy of supporting the agricultural sector was systematically more intense in New Zealand (Hawke & Latimore, 1999) than in Uruguay (Álvarez Scanniello et al., 2007). Since the beginning of the 20th century, the New Zealand government supported the development of the agricultural sector through diverse instruments (infrastructure, research, price controls, marketing, subsidies) as in Uruguay the support was fragmentary and of short-term. The availability of credits is an expression of the different institutional frameworks that characterized the sector in both countries. In the case of Uruguay, there is information on loans granted by the Banco de la República (BROU) which, as state bank and development promoter, represented the bulk of loans for production (CIDE, 1967). In the case of New Zealand, there is information on all commercial banks, classified by the sectoral destination of the funds received by the agricultural sector.

We compare the annual amounts (pounds in both countries) in terms of hectares devoted to agricultural production. The result allows us to observe that New Zealand producers benefited from better credit conditions that, in addition to obtaining a greater amount of funds to face current expenses, probably allowed them to be in a better position to program medium and long-term investments, as is the case of mechanization (Figure 10).

[9] Since 1943, the mechanization of agriculture was favored by the agreement between the New Zealand government and its US counterpart in the context of the approval of the Lend-Lease Legislation (1941) in the United States. The Lend-Lease Act allowed, via imports, to New Zealand producers (as well as other countries allied with the United States in World War II) to increase their supply of tractors and a wide range of agricultural machinery under very favorable conditions.

Figure 10. Financing of agricultural production (pounds per hectare of land) in New Zealand and Uruguay (1937-1960)



Source: Own elaboration based on data from CIDE (1967) and Official Yearbooks (various years)

6. Final remarks

Our approach based on indicators of technological trajectories allowed to deepen the analysis of the problem of adoption and technological diffusion from a comparative and long-term perspective.

The estimation of the diffusion model based on the quantification of tractor power for Uruguay (1908-2010) and New Zealand (1919-2010) verified that the process of diffusion of tractor technology followed a trajectory that can be modelled adequately based on the estimation of a logistic function, and that the period considered makes it possible to capture practically the entire trajectory that this technology followed.

Since a comparative analysis of the process of adoption and diffusion of the tractor, we appreciated notorious differences between countries. We obtained evidence that confirms that in New Zealand the mechanization process had a higher rate of diffusion and Uruguay remained persistently behind in the adoption and diffusion of the tractor. According to our contrast, we consider that the rural wage, relatively lower in Uruguay compared to New Zealand, was a relevant factor to explain the greater dynamism in which New Zealand producers incorporated tractor technology. In the same sense, the lower cost of fuel oil in New Zealand would have been an advantage for the adoption and diffusion of the tractor compared to the case of Uruguay, which had to face higher prices in a context of greater fuel price volatility.

In turn, as previous literature has analyzed in the case of livestock, it can be conjectured that the agrarian landownership structure and the access to financing sources imposed restrictions on Uruguayan producers to the incorporation of technological change. The agricultural smallholding, characterized by very small scales of production and leasing conditions, and the difficulties in accessing financing sources were two aspects that played a (relative) favorable role in New Zealand. Finally, the price of the tractor was compared, which allowed us to confirm that Uruguayan producers had to face higher purchase prices than their New Zealand peers, having to operate as an additional restriction on the acquisition of tractors.

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Appendix

Table A.1. Estimates corresponding toUruguay

Variable	Observed Years	Estimation Method	Source
Nominal annual wage at current prices (pesos)	1900, 1908, 1919, 1936, 1945, 1955, 1963	Linear interpolation	For 1900, Willebald (2015); for 1908-1963, Marmissolle et al. (2023)
Annual wheat price per ton (pesos)	1900-1960		Nahum (2009)
Credit (pesos)	1937-1960		CIDE (1967)
Agricultural area (hectares)	1900; 1908-1950; 1951, 1956, 1961	Linear interpolation	Nahum (2009)
Agricultural plots	1905; 1912-1948; 1951; 1956; 1961	Interpolations: 1906-1911; 1949-1950; applying the total plots index to crop farms forward from 1951: 1952-1955; 1957-1960, and applying the agricultural area index to agricultural plots backward from 1905: 1900-1904	Nahum (2009)
Total agricultural plots	1951; 1956; 1961	Linear interpolation	Agricultural censuses, MGAP (observed years)
Land tenure regime	1900; 1908; 1916; 1924; 1937; 1943; 1951; 1956; 1961	Linear interpolation	Agricultural censuses, MGAP (observed years)
Total agricultural land	1900; 1908; 1916; 1924; 1937; 1943; 1951; 1956; 1961	Linear interpolation	Agricultural censuses, MGAP (observed years)
Draft animals	1900; 1908; 1916; 1924; 1930; 1937; 1943; 1946; 1951; 1956; 1961	Linear interpolation	Bertoni (2002)

Table A.2. Estimates corresponding to New Zealand

Variable	Observed Years	Estimation Method	Source
Nominal annual wage at current prices (pounds)	1900-1960	The variation of reported wage data in the Official Yearbooks is applied to continue the wage series reported in Willebald (2015)	For 1900-1913: Willebald (2012); for 1913-1960: Official Statistical Yearbooks.
Annual wheat price per ton (pounds)	1900-1960		Willebald (2012) based on Official Statitical Yearbooks (several years)
Credit (pounds)	1937-1960		Official Statitical Yearbooks (observed years)
Agricultural area (acres)	1900-1909; 1911; 1916-1960	Linear interpolation	Official Statistical Yearbooks (observed years)
Agricultural plots	1916; 1919; 1922; 1926; 1930-1936	Linear interpolation: 1917-1918; 1920-1921; 1923-1925; 1927-1930; 1960, and applying the agricultural area index to agricultural plots backward from 1916: 1900-1915 and forward from 1936: 1937-1960	Official Statistical Yearbooks (observed years)
Total agricultural land	1900-1908; 1910-1911; 1916-1927; 1929-1930; 1932-1942; 1947-1950; 1960	Linear interpolation	Official Statistical Yearbooks (observed years)
Land tenure regime	1900-1908; 1910-1911; 1916-1927; 1929-1930; 1932-1942; 1947-1950; 1960	Linear interpolation	Official Statistical Yearbooks (observed years)
Land under Crown ownership	1900-1908; 1910-1911; 1916-1927; 1929-1930; 1950; 1960	Linear interpolation for missing years between 1900-1930	Official Statistical Yearbooks (observed years)
Crown-owned land disaggregated by type of tenure	1920-1927	A constant 66.4% (56.7% pastoral land + 9.7% perpetual leases) is applied to Crown-owned land in 1900-1919 and 1928-1960	Official Statistical Yearbooks (observed years)
Draft animals	1900-1960		Official Statistical Yearbooks (observed years)

Other sources

International exchange rate series: Officer (2001).