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TECHNOLOGICAL CHANGE AND PRODUCTIVITY GROWTH IN THE AGRARIAN SYSTEMS OF NEW ZEALAND AND URUGUAY (1870-2010)

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New Zealand and Uruguay were typical settler economies and were alike in many ways throughout their histories but there were also big differences in how they developed. They were similar as regards size of population, surface area, markets, natural resource endowments, production and trade specialization patterns and the fact that they both attained high levels of income per capita in the early 20th century. They differed in that they had divergent patterns of economic growth and different agricultural productivity growth rates for their main products (wool, meat, dairy produce and leather), which accounted for around 70% of their exports in the hundred years from 1870 to 1970.

The main aim of this paper is to use a systematic case-oriented comparison and the evolutionary theoretical approach to technological change to understand the development of the technological trajectories that boosted productivity in the two countries' pastoral systems in the long-term (1870-2010). I will analyse this in interaction with geographical environment, intensity of resource use (extensive or intensive) and the institutional environment in which technological innovations to raise land productivity were produced, disseminated and adapted.

My main results show that in the 19th century Uruguay had more favourable conditions for pastoral production than New Zealand and, up to the 1930s, higher production volumes per hectare. New Zealand had higher growth rates in all livestock physical productivity indicators from 1870 to 1970 and overtook Uruguay's levels by the mid 20th century. As regards increased land productivity, New Zealand changed completely from an extensive to an intensive pastoral system. This process required technology to improve the soil, thus increasing capital and job investment and changes to the original production function of the pastoral system. In Uruguay livestock rearing was based on natural pasture, extensive production systems and low capital investment, and this stable model remained the same for a relatively long time. This inertia meant that in the long run Uruguay's technological trajectory lagged far behind New Zealand's in the development of soil-improvement technologies. I argue that these differences have, through different channels, conditioned the export performance and the economic growth of both countries.

Keywords: settler economies, technological change, pastoral production, productivity growth.

JEL: N56, N57, O13, O33

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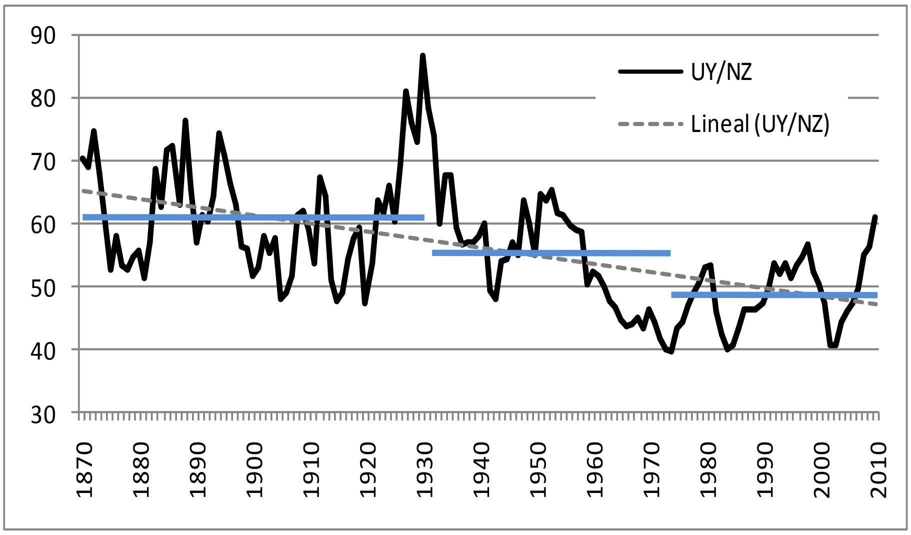
1. Introduction

In economic historiography the countries of the South American Southern Cone, especially Argentina and Uruguay, have been classed as new European settlement societies like two other countries in the southern hemisphere, Australia and New Zealand (Nurkse, 1961; Schedvin, 1990; Lloyd and Metzer, 2006). The fact that these four nations have so many characteristics in common yet have had performed so differently in terms of economics in the long term makes them interesting cases for comparative analysis (Denoon, 1983; Bértola & Porcile, 2002; Gerchunoff and Fajgelbaum, 2006; Álvarez et al, 2007; Filgueira, 2007; Bertram, 2010; Lloyd et al, 2013).

New Zealand and Uruguay are typical cases for comparison because they are similar in many ways including size of population, size of markets, natural resource endowments, surface area devoted to agrarian production (Map 1), their patterns of production specialization, insertion into the world economy and the fact that both achieved a high level of income per capita at the start of the 20th century. They have also exhibited long term differences, and this has aroused interest in both countries and led to attempts to explain why they have diverged in various ways (Kirby, 1975, 1988; Álvarez et al, 2007; Álvarez, 2008, 2013; Álvarez, et al 2011; Willebald, 2011; Álvarez & Bértola, 2013; Schlueter, 2013; Bertoni & Willebald, 2013, among others). The most obvious difference is in income per inhabitant. In 1870 Uruguay's GDP per capita stood at 72 % of New Zealand's but by the last quarter of the 20th century and first decade of the 21st it had fallen, on average, to only 48% (Graph 1)

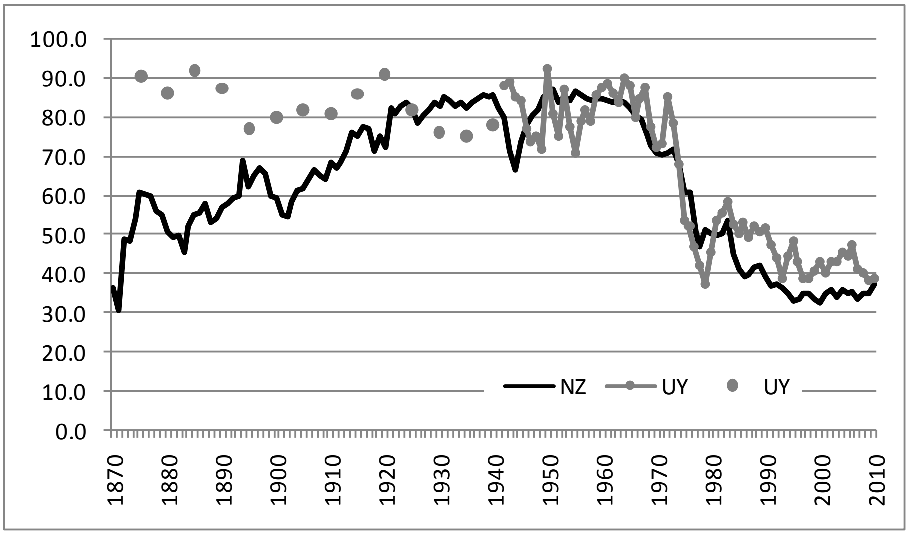
GRAPH 1
RATIO OF GDP PER CAPITA URUGUAY/NEW ZEALAND, 1870-2010



Source: based on Maddison (2009); Maddison Project Database.

These two economies share the characteristic that their development was based on producing and exporting agrarian goods, especially leather, wool, meat and dairy products, derived from livestock rearing. This pattern of production, specialization and trade was the result of a combination of opportunities that emerged during the first globalization of capitalism thanks to the transport revolution, refrigeration technology, and the expansion of demand in Europe for temperate-climate products. These factors favoured the new European settlement economies of the periphery with their excellent natural conditions for agrarian production, and contributed to moulding a highly specialized production structure in New Zealand and Uruguay. Sutch (1969) calls this profile a monocultural economy, a system in which exports depend on a limited number of agrarian products. From 1870 to 1970, an average of more than 70% of New Zealand's exports and more than 80% of Uruguay's were derived from livestock rearing (Graph 2).

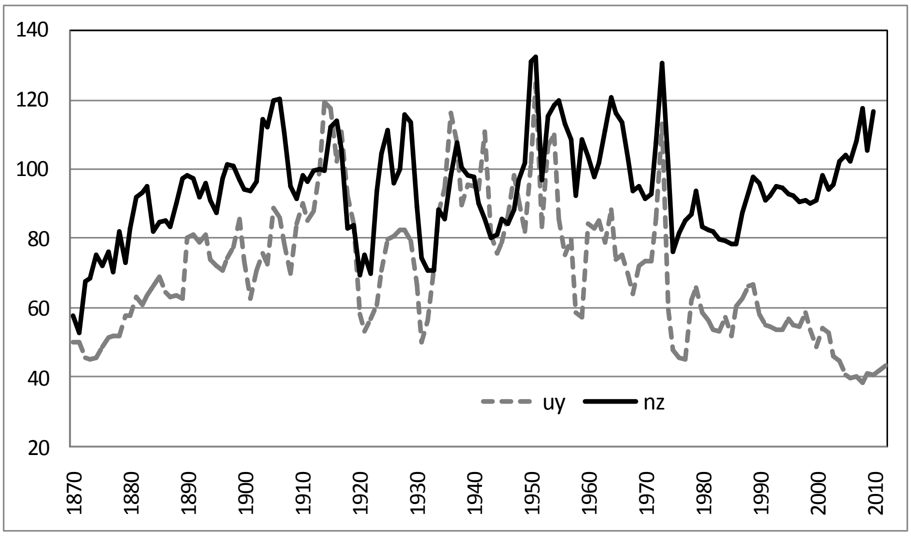
GRAPH 2
SHARE OF LIVESTOCK PRODUCTS IN TOTAL NEW ZEALAND AND URUGUAYAN EXPORTS (%), 1870-2010



Source: based on: NZ, 1870-2006, Briggs (2007); 2007-2010, NZOYB (2012), http://www.stats.govt.nz/. UY: 1892 - 1941 five-year averages based on 1872 - 1890, Millot and Bertino (1996), Figure IV.3, p. 138; 1891 - 1941, Finch (2005), Figure 4.4, p. 162; annual series based on 1942 - 1968, Institute of Economics (1969a), Figure No. 39; 1969-1971, Central Bank of Uruguay (1973) No. 12, Figure 15, p. 40; 1972 - 1974 Central Bank of Uruguay (1979) No. 25, Figure No. 11, p. 26; 1975 - 1992, Central Bank of Uruguay, statistical bulletins for respective years. Economics and economic history data base of the Faculty of Social Sciences, University of the Republic, Uruguay, http://www.fcs.edu.uy/bancoDatos.php; 1993 - 2010 Central Bank of Uruguay, series taken from INE, http://www.ine.gub.uy/economia/externo2008.asp

A logical outcome of this trade specialization pattern was that the two countries had similar trends as regards the terms of exchange (Graph 3). This variable played an important role in the development of both economies as both were heavily dependent on the buying capacity for their exports.

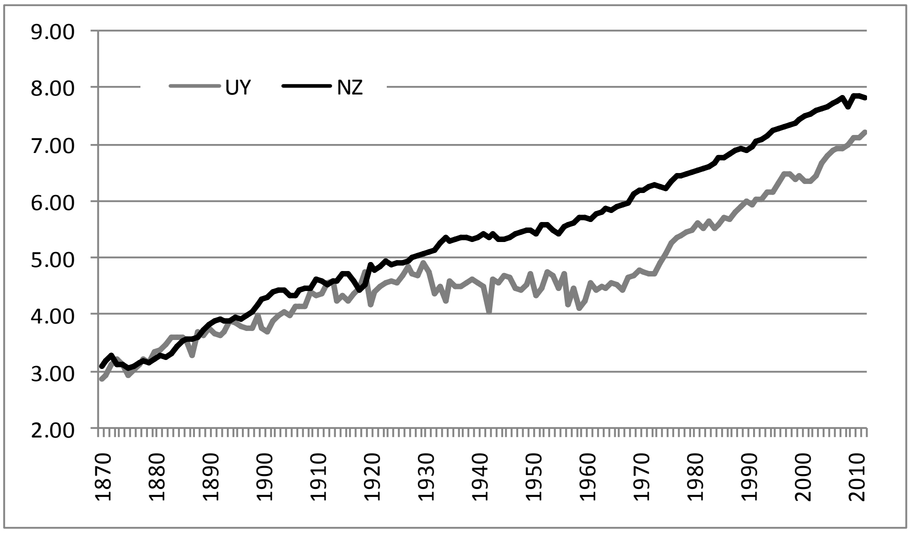
GRAPH 3
TERMS OF TRADE OF NEW ZEALAND AND URUGUAY, 1870-2010



Source: based on NZ, 1870-2002 Briggs (2003, 2007), 2003-2010, Statistics New Zealand, Infoshare, OTP - Terms of Trade-Trend, Table Reference: OTP018AA, www.stats.govt.nz/infoshare. UY- 1870-1971, Bértola (2005) based on Baptista and Bértola (1999), Bértola (1990), 1971-1990, Donnángelo and Millán (2006) based on BCU, 1991-2008, BCU. 2005, Economic Commission for Latin America and the Caribbean (ECLAC), based on figures provided by the International Monetary Fund and national bodies. Base year 2005, http://estadisticas.cepal.org/

In spite of these shared trends, the growth of the two countries' export volumes began to diverge after 1930. Uruguay's exports stagnated, especially in the period 1930-1970, while New Zealand's continued a long term growth trend, albeit at varying rates (Graph 4).

GRAPH 4
REAL EXPORTS FROM NEW ZEALAND AND URUGUAY, 1870-2010 (LOG)

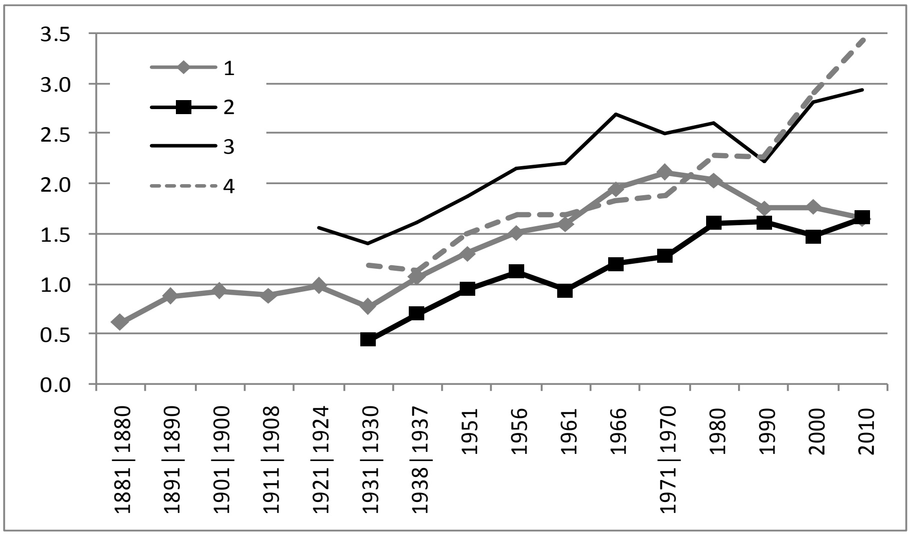


Source: based on NZ, 1870-2005, real exports Briggs (2007), 2006-2010, export volume index, World Bank, World Development Indicatorshttp://data.worldbank.org/. UY, 1870-1913, Baptista-Bértola (1999), Figure A.2, p. 14, 1913-1970, Finch (2005), Figure 4.1, 4.2, 4.3 pp.159-1961; 1970-2010 World Bank, World Development Indicatorshttp://data.worldbank.org/

The fact that Uruguay's economy was lagging behind New Zealand's became evident in the 1930s and the gap was even wider in the 1950s (see Graph 1). The growth of both economies in the period 1930-1973 was based on an export-oriented agrarian sector that earned foreign currency in the international market, and an industrial urban economy that supplied the domestic market thus maintaining high levels of pay and full employment (Easton, 1997; Bértola, 1991; Finch, 2005). However, Uruguay's agrarian export sector was weaker and had less capacity to contribute to economic growth, and at the same time its industrial sector stagnated early, around the 1950s.

Here I argue that these differences in export performance, which affected the two economies through different channels, reflect differences in the growth of physical productivity in livestock production (Graph 5), especially as regards the productivity of agrarian land (Graph 6).

GRAPH 5
LIVESTOCK PRODUCTION (RATIO NZ/UY)
MEAT EQUIVALENT PER HECTARE, 1870 - 2010



Meat equivalent[2] = kg bovine meat/ha + kg ovine meat/ha + (kg wool/ha x transformation factor) + (litres of milk/ha x transformation factor).

Here four estimations based on different transformation coefficients are proposed:

1- Meat equivalent, classic coefficient[3] (covers meat and wool)

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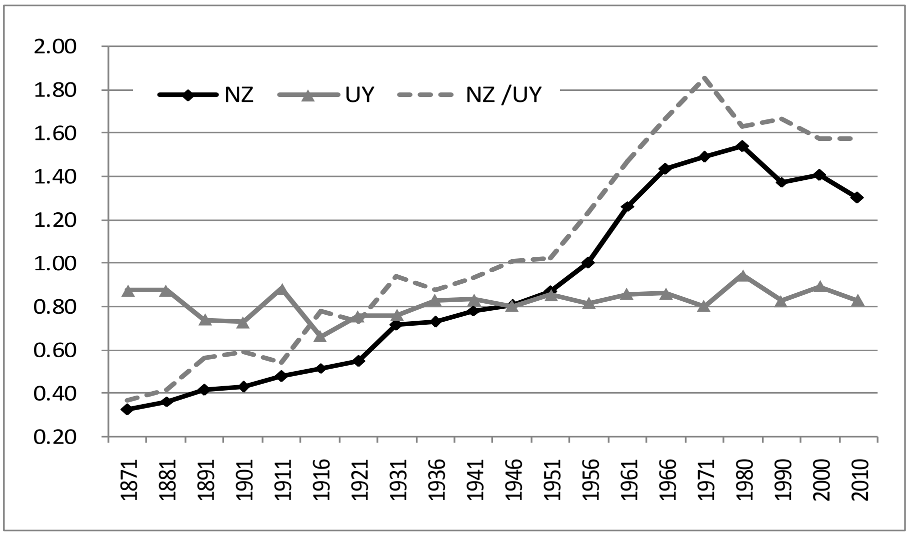
[2] Meat equivalent: this is a homogenous indicator of the physical productivity of livestock that covers the production of the main livestock items: bovine meat, ovine meat, wool and milk. The indicator assumes a production cost of meat, wool and milk based on the fodder requirements of each animal species, so it is also a good indicator of land productivity.

2- Meat equivalent, specific coefficient[4] (covers meat and wool)
3- Meat equivalent, classic coefficient (covers meat, wool and milk[5])
4- Meat equivalent, specific coefficient (covers meat, wool and milk)

Source: Álvarez (2014), pp. 149-159

GRAPH 6
EVOLUTION OF LIVESTOCK UNITS BY HECTARE IN NEW ZEALAND AND URUGUAY, 1870-2010

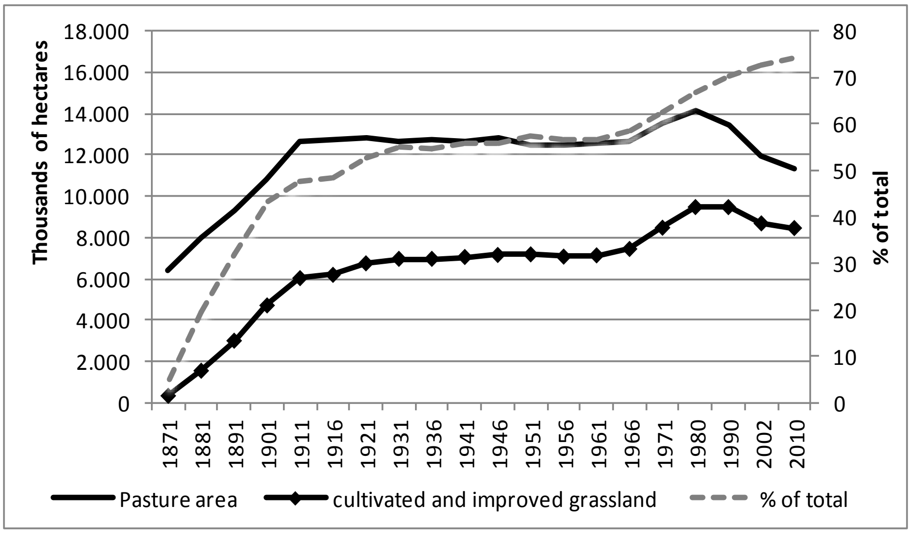


Commentary and source.
The Livestock Unit indicator was constructed taking bovine livestock as a reference species. I applied dynamic ovine-bovine transformation coefficients considering the energy requirements of the two species and the specificities of each livestock system. Source: Álvarez (2014), pp. 135-142.

A key factor in these differences was the different rates at which the two countries implemented technologies that improved the land factor. While in New Zealand the livestock system was based on transforming the soil and creating pasture land (Graph 7), in Uruguay livestock rearing was based on natural grassland with only a low proportion of artificially produced or improved pasture land (Graph 8).

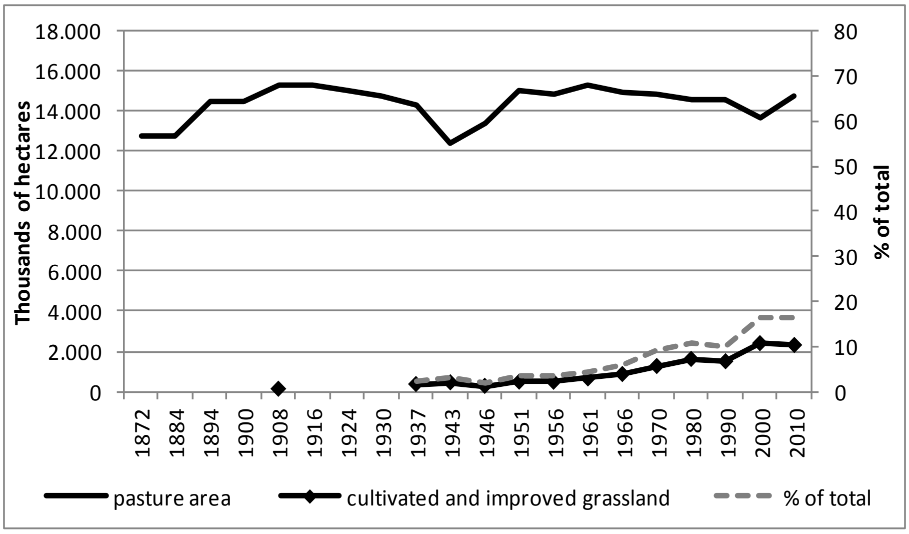
[3] Classic wool-meat transformation factor: 2.48
[4] Specific transformation factor, see Álvarez, 2014, Figures V.4 and V.5, pp. 154 and 155
[5] Milk-meat transformation factor: 0.1

GRAPH 7
NEW ZEALAND
AREA OF PASTURE LAND, ARTIFICIAL AND IMPROVED GRASSLAND, 1870-2010



Source: Álvarez (2014), Figure VI.1, p. 181

GRAPH 8
URUGUAY
AREA OF PASTURE LAND, ARTIFICIAL AND IMPROVED GRASSLAND, 1870-2010



Source: Álvarez (2014), Figure VI.1, p. 181

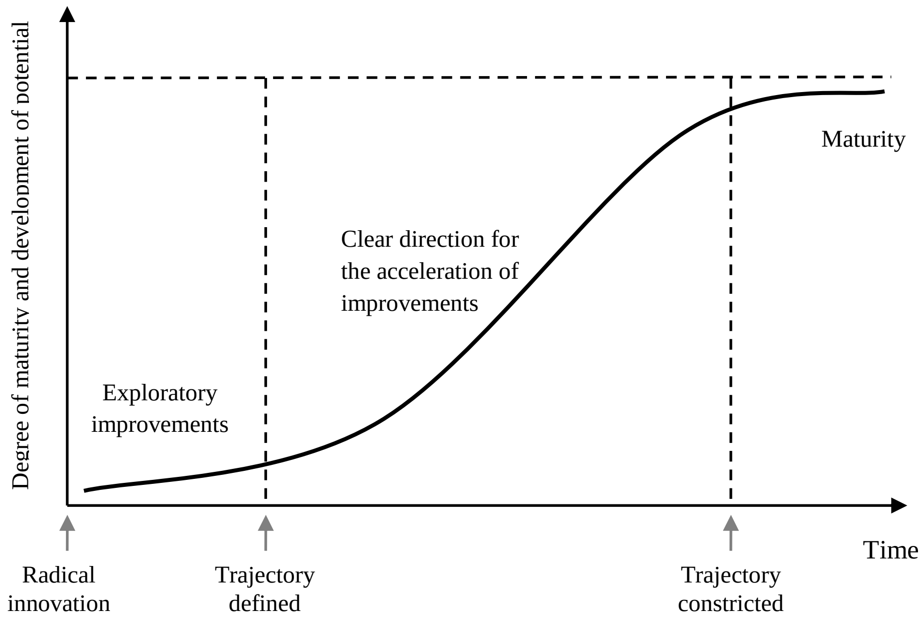
The main questions that emerge from this evidence are: Why did New Zealand develop technologies that improved the land factor and enabled it to maintain higher livestock productivity growth rates than Uruguay? Why did Uruguay not develop technologies to improve the land factor when the productive performance of its main export sectors for most of the 20th century depended on it? These questions make technologies to improve the land factor a central aspect in the comparative analysis of the development of the livestock sector in the two countries.

To tackle this question, my **theoretical approach** in this study considers the main analytical contributions of evolutionist thought (Nelson and Winter, 1982; Lundvall, 1992) about the economic analysis of innovation and technological development (Schumpeter, 1934), especially the relation between technological change, the institutional context and economic performance (Carlota Pérez, 2009). This approach stresses that the research and learning processes involved in innovation take place in the framework of structures and institutions that condition how technology is adopted into economic systems. In addition, technological change is a tacit, accumulative and incremental process that is brought about in the framework of a technological trajectory (Nelson & Winter, 1982) or paradigm (Dosi, 1988; Pérez, 2009). These dimensions are captured in the systematic and territorial approach of "national innovation systems" (NIS) (Lundvall, 1992; Nelson, 1993; Edquist, 1997). An important aspect of the NIS systematic approach is that it is basically a conceptual framework and not a formal theory about technological change, so it helps to highlight the differences between different concrete systems rather than proposing an optimum model (Edquist, 1997). This makes it a conceptual model with great potential for making international comparisons because innovation and learning capacities are strongly rooted in the social and institutional structure of each country.

An understanding of the production and technological dynamics of livestock production require consideration of a series of aspects that pertain to the sector's specific characteristics. Among these, two main aspects of technology as a public good stand out. First, technology is not a rival good; that is to say it is not exhausted with individual use. And second, it is only partially excludible because it is not possible to impede its transfer to and adoption by other agents. As this is a sector dominated by the technology provider (Pavitt, 1984) many innovations are generated in a way that is exogenous to the sector and are incorporated into capital goods and inputs (Cimoli & Dosi, 1993) or produced by public research bodies. Therefore the interaction between technology providers and rural producers is a key element in defining the agrarian sector's technological trajectories (Paolino, 1990).

It is well known that incorporating technology into agriculture requires a big adaptation effort. The adoption of technology is a complex process that involves considerable local research and learning on the part of rural producers because of the specific characteristics of animal and plant biological processes, the varying edaphic qualities and composition of soils, and climate differences between regions and countries. This means that technology adoption processes depend on three main factors: first, the role of public research and diffusion institutions in the framework of what we can call sector innovation systems; second, the rural producers' capacity to interpret the new technology; and third, the economic efficiency of adopting the new technology. As Griliches (1960) showed in his timely study of the pattern of how hybrid maize spread in the United States, diffusion processes tend to develop in an S-shaped logistical growth curve. Once the innovations that initiate a technological trajectory have gestated, technological changes are subject to incremental improvements in an adoption process that follows the changing rhythm of a logistical curve (Pérez, 2009). Changes occur slowly in a first stage, during which actors and organizations undergo a process of exchange and learning, then rapidly and intensely in a second stage once the technology has been disseminated, and then slowly when this trajectory matures. This evolution is shown in Graph 9.

GRAPH 9
TRAJECTORY OF A TECHNOLOGY



Source: based on Pérez (2009), Figure 1, p. 5

The **background** to this article is that precious studies analyzing technical change in the agrarian sector with an evolutionist focus include valuable work by Paolino (1987, 1990, 2001), Mondelli and Picasso (2001) and Moraes (2001), who all made contributions to the analysis of technological trajectories in Uruguay's livestock sector; Álvarez (2008, 2014) and Álvarez and Bortagaray (2007) who produced studies of the institutional frameworks of technological innovation in the New Zealand and Uruguayan agrarian sectors; and Castro, Pradines and Rodríguez (2012) and Castro et al (2013), who contributed to the analysis of technical change as a determinant factor in the evolution of land prices in the long term. All these studies have shown how fruitful this kind of approach can be for understanding the production dynamics of agriculture, and have also provided large quantities of valuable information.

As regards New Zealand, the systematic approach to technological change in the agrarian sector has always featured in the country's historiography (Hawke, 1985; Sinclair, 1988; McKinnon, 1997; Belich, 2001; King, 2003), and in studies that put the focus on institutional design in agrarian research (Nightingale, 1992). This systematic focus responds to a greater extent to the emphasis put on the historical reconstruction of technological change processes in the agrarian sector than to any *ex-ante* heterodox conceptualization of innovation and technological change processes. Tennant (1978), in a study that stands out as a landmark in evolutionist approaches, focused on analyzing the impact of technologies to improve soils and create pasture land, and their relation to New Zealand's economic development.

In the context of my **hypothesis**, the main finding is that the divergence of the New Zealand and Uruguayan agrarian sectors in terms of production performance was the outcome of a long process of technological and institutional changes in specific geographical and historical contexts. New Zealand undertook the gradual transformation of the natural landscape (which included forest clearance in large parts of North Island) and this led to sweeping changes in how the soil was used, to the creation of a livestock system based on producing pasture land, and to the development of capital-intensive livestock specialization. In Uruguay the development of the livestock sector was based on exploiting natural grasslands. This system had high relative levels of productivity, and large production units engaged in extensive livestock production predominated. However, these units had little capacity to develop technologies geared to changing the land factor or intensifying production.

The main **aim** of my study is to identify and compare the long term stages in the technological trajectories of the New Zealand and Uruguayan agrarian systems, so the focus is on the development of technological improvements of the land factor as a production resource.

The **methodological strategy** in this study is to employ a qualitative comparative approach oriented to cases (Ragin, 1987), and I compare the processes of the production of technologies to improve land productivity in the two countries. This approach involves considering the geographical peculiarities of the spaces in which each of these livestock production systems developed and the institutional contexts in which technologies to create and improve pasture emerged.

This article is organized in four sections. First, this introduction, then section two in which I describe the main geographical characteristics of the two countries with special attention to topography and to how the native ecosystem was modified. In section three I present a periodization of the development of each country's livestock system bearing in mind the historical trajectories of the gestation and development of land factor improvement technologies. In section four, by way of a conclusion, I present a sequence of the technological paradigms in each of the two livestock systems.

2. The geographical context of the agrarian systems in New Zealand and Uruguay

It is often pointed out that these countries are alike in many ways: they are both in the southern hemisphere, they have similar climate, similar average temperature (although there is more diversity in New Zealand), similar rainfall (but with marked differences as regards distribution, frequency and intensity), and a comparable surface area for production. However, they have geographical differences that posed specific challenges and conditioned the different evolution of their agrarian systems.

New Zealand's surface area is 27 million hectares distributed on the two main islands: North Island has 114,000 square kilometres and South Island has 151,000. The country's total productive area amounts to barely 50% of the land and it is the result of a long process of modifying the native ecosystem. The main change was that the area of native forest has been reduced and the soil has been adapted for farming and livestock activities. This transformation began with the arrival of the first human settlers, who were of Polynesian origin and came in around 1200 (McKinnon, 1997), and it intensified when mass immigration from Europe started the mid 19th century. In the 13th century, native forests covered about 23 million hectares (approximately 85% of the surface area) but by the mid 19th century this had been reduced to 15.4 million hectares (57% of the surface area). However, the greatest change has taken place in the last 150 years when the area of forest shrank to 6.2 million hectares (23 % of the surface area) and was largely replaced by grassland for livestock production (Taylor & Smith, 1997; Condliffe, 1959).

Uruguay has a surface area of 18.7 million hectares, of which an average of 16.5 million has been devoted to agrarian production. With nearly 90% of its land productive, Uruguay has one of the highest production to surface area ratios in the world (Berreta, 2003). While the landscape and original vegetation have undergone big changes since European colonization began, the transformation was not as widespread or as profound as in New Zealand. The main changes to the grasslands were caused by continual livestock grazing, which has gone on since the beginning of the 17th century when Europeans introduced cattle and horses (Marchesi-Durán, 1969). The natural vegetation of more than 80% of the productive land is grasses and bushes, and there are relatively few trees (Berreta, 2003).

Besides their differences in the production area to surface area ratio and the original vegetation cover, the topography in which New Zealand and Uruguay developed their agrarian systems is very different. Uruguay is basically a gently undulating plain with little land over 200 metres; it forms a transitional area between the Argentine Pampas and the high lands in the south of Brazil (Marchesi and Durán, 1969; Berreta, 2003). New Zealand, on the other hand, is predominantly mountainous with 75 % of its surface area over 200 metres and with mountain chains that rise as high as 3,700 metres (Charteris et al, 1999). This meant that animal grazing took place on the plains of the two islands (with a slope of between 0 and 15º), in the hill country (with a slope of 16 to 20º) and in the mountains or high country (where the slope is more than 20º) (Moot et al, 2009). These geographical differences influenced the two countries' respective technological and institutional dynamics and their conditions of insertion into the world market for agrarian goods, and gave their livestock systems specific characteristics that conditioned their long term development.

3. Stages in the development of the New Zealand and Uruguayan agrarian systems associated with changes in the land factor

Starting in the mid 19th century the geographical and historical conditions of agrarian expansion in New Zealand meant the country had to overcome a series of challenges and restrictions that Uruguay did not have to face. Among the most serious of these were the low productivity of the natural grassland, mainly on the hills and mountains of South Island, and the need to radically change the landscape and native ecosystem of North Island, which was mainly covered in forest (Condliffe, 1959; Taylor & Smith, 1997). These limitations gave an early impulse to efforts to find technologies to transform the soil, and these were developed and employed to improve the productivity of the land resource.

Uruguay was quite different in that after the mid 19th century the development of livestock rearing was based on the intensive use of the natural grassland. Until the First World War the country did not need to improve the soil in order to successfully maintain its position in the world agrarian products market. However, the early maturity of a technological trajectory that was very dynamic until the first decade of the 20th century (Moraes, 2001) was followed by a long period of stagnation that continued until the 1980s (Irigoyen, 1991). The country only began to emerge from stagnation in the 1990s (Mondelli and Picasso, 2001), and an intense process of improvement in agriculture only really got under way in the first decade of the 21st century (Errea et al, 2011).

3.1. New Zealand: the transformation of the natural landscape, changes in the use of soils and the creation of an agrarian system based on the production of pasture

In New Zealand we can distinguish five broad stages in the agrarian sector's development from the mid 19th century to the present day.

1. In the first (1840 - 1870), which was characterized by colonization and the occupation of land, livestock production was established on the natural grasslands of South Island. This was mainly the extensive rearing of sheep and it did not require large capital investment or the intensive use the labour, so the ranchers quickly made big profits (Nightingale, 1992). By 1860 nearly all the available land on the plains of South Island was occupied by colonists (Sinclair, 1988), but these grasslands were under-used as there was a high ratio of land to livestock (Sinclair, 1988; McAllon, 2009). In this stage the geographical conditions on North Island made it unsuitable for livestock because the land was largely covered in dense forest, and in addition there was resistance from the Maori communities, who jealously defended their sovereignty and way of life (Belich, 1996; Boast, 2009).
2. The second stage (1870-1920) was of extensive growth in which the occupation of the plains and grasslands of South Island was completed, the agrarian frontier expanded into the high lands and forests of North Island, and land improvements were developed that improved productivity on the grasslands. The increase in agrarian activity in this period was characterized by three main processes. First, there was a huge increase in livestock: the number of sheep doubled and the stock of cattle increased by a factor of 7.4. (Bloomfield, 1984). Second, the area of grazing land greatly expanded with an increase from 6.4 to 12.5 million hectares (see Graph 7). And third, there were land-improvement efforts based on the introduction of foreign grasses of British origin.[6] The adoption of British pasture cultivation techniques was mainly driven by the revolutionary impact of the new technology of refrigeration (Tennant, 1978; Sinclair, 1988; Belich, 2001). Its main results were that agrarian production diversified with products of higher-value like meat and dairy produce (butter and cheese); the area of cultivated pasture increased

[6] The Standard technique for producing pasture was to rotate crops: tubers, cereals and fodder. After some years of shepherding the land had to be ploughed to renew the pasture growth cycle.

enormously from 1.4 to 5.7 million hectares between 1881 and 1911,[7] mainly in North Island; and trade links with Great Britain were reinforced. However, the British pasture production technique contributed to rapidly exhausting the soil's natural fertility, a problem that was tackled with chemical and organic fertilizers like guano, phosphates and bonemeal, which were commonly used in this stage. However, fertilizers were costly and their effectiveness decreased over time, and this stimulated research into the natural deficiencies of the soil and the development of domestic technologies for producing pasture.

3. In the third stage (1920-1966) production intensified with the development of important technological innovations that greatly increased the productivity of agrarian land. Within this stage two sub-periods can be identified.
    a. In the first (1920-1940), scientific knowledge of plants and soils advanced, and this made it possible to implant high-yield pasture on the country's plains and low lands. This development is associated with the scientific work of Alfred Cockayne and Bruce Levy, who were botanists from Canterbury University College and Victoria University College, respectively (Nightingale, 1992). These innovations consisted in producing perennial strains of ryegrass with high nutritional value for animal feed, and cultivation combined with local varieties of clover that increased the capacity to fix nitrogen in the soil and reduced the need for fertilizers. The combined impact of these two discoveries (the development of an autochthonous strain of ryegrass and combined cultivation with clover) was enormous. It showed that it was possible to develop permanent high-yield pasture in New Zealand and replace the traditional techniques like extensive fodder crops and crop rotation on pasture, which were costly and yielded decreasing returns. The next steps were to disseminate these innovations among producers and create a seed certification system that guaranteed that high quality pasture was sown.
    b. In the second sub-period (1940-1966), especially after the Second World War, there was greater productivity growth on livestock land (see Graph 6). These results were the consequence of three processes. First, fertilization and sowing on cover by aeroplanes (aerial topdressing) was used,[8] which meant the new techniques could be implemented in mountainous areas. Second, there was new

[7] Bloomfield (1984) Table V.8 pp. 171-173, Table V.11 p. 179 and Álvarez (2014) Table AVI p. 165
[8] It is estimated that from 1950 and 1953 the area fertilized with this technique increased from 19,500 to 500,000 hectares, and by 1970 had reached 3.2 million hectares (Tennant, 1978, Table 6.2, p. 192).

investment in improving the soil in mountainous regions, especially by creating fields for the efficient use of improved pasture. The State made expensive investments in public works like roads, electrification, house-building and land distribution, geared to establishing livestock enterprises in regions of very low production aptitude.

4. Between 1966 and 1980 the total area under pasture increased by 2.5 million hectares, as did the area of improved and artificial pasture. This new expansion was mainly in mountainous regions and was a response on the part of rural producers to the fall in the wool price on the world market. This process of expansion and intensification (MacLeod and Moller, 2006) made possible a marked increase in the stock of sheep and cattle for meat, and at the same time improved land productivity in terms of livestock unit per hectare (See Graph 6). It was also the result of incentive policies (financing and agro subsidies) promoted by the government to stimulate domestic production and counteract very serious problems (Dalziel and Lattimore, 2004) caused by the fall in international prices for the country's exports and the impact of the oil crisis at the beginning of the 1970s. Expanding the area under pasture into mountainous regions called for considerable research into how pasture could be adapted to very sloping land. This involved, among other aspects, developing a body of knowledge about the optimal weight of animal population, the seasonality of production, and the most suitable distribution of aerial fertilizer use. The result of these efforts was that the technology to produce and improve pasture was refined and, starting the 1970s, a specific pasture management system for these regions was developed (Moot et al, 2009).
5. Since the 1980s New Zealand's agrarian system has moved into a new stage of intensification. The total area under pasture has been reduced by nearly 3 million hectares and the improved area by 1 million hectares (see Graph 7). The sector most affected has been extensive ovine production; there has been a considerable change in the composition of the stock with an increase in meat and milk livestock (Moot et al, 2009). There were two main reasons behind this reduction in pasture area. The first was that subsidies for the agrarian sector were discontinued (Nightingale, 1992) during reforms implemented by the Labour Party in the 1980s in a move to liberalize and deregulate the economy (Wallace & Lattimore, 1987). The second was that the paradigm of New Zealand's agrarian system began to change and the ecological sustainability of intensified production became a central aspect of agrarian development. In the context of this change of focus, the

government implemented a package of incentives to stimulate producers to reduce livestock production on marginal land and replace pasture with the planned reintroduction of native vegetal species (Moot et al, 2009). Pasture on natural grassland and rural land in mountainous regions above 900 metres was controlled and limited, and forestation on the steepest sloping land affect by erosion was promoted. This change of paradigm was consolidated in the 1990s when the focus shifted more to the sustainability of the agrarian system based on a balance between intensification and biodiversity (MacLeod & Moller, 2006). There were some contradictions in this trend. On the one hand, an agrarian development model geared to biodiversity and environmental sustainability was gaining ground and there was a shift towards agrarian diversification and changes in how the soil in high regions was used. But on the other hand production in the most productive regions and those of easiest access was greatly intensified. This applied in particular to the milk cattle sector, in which the use of nitrogenous and superphosphate fertilizers greatly increased, and the irrigated area was expanded (OECD, 2008).

3.2. Uruguay: the intensive use of natural grassland and the late incorporation of technologies to improve the land factor

Three broad stages of this sector's development in Uruguay can be identified, considering the livestock sector's long term production performance and the technological dynamics associated with improving the land factor.

1. Broadly speaking we can identify a first stage that covered the last quarter of the 19th century and the first decade of the 20th. In this period an increase in foreign demand led to rising production and productivity based on diversifying animal stocks and developing a collection of technological changes (enclosing land with wire fences, genetic improvements in livestock, British investment in infrastructure and transport). There were also institutional changes (legislation to consolidate ownership rights, strengthen the State's political power and create a factors market). One of the effects of these was that more efficient use could be made of the country's natural grasslands (Barrán and Nahum, 1977; Millot and Bertino, 1996; Moraes, 2001; Finch, 1980, 2005).
2. The second stage was from the second decade of the 20th century to the 1980s. Natural grassland's maximum potential was reached around the time of the First World War and from then until the 1980s the sector's performance was in a state of what has been defined as dynamic stagnation (Barbato, 1981; Irigoyen, 1991; Moraes, 2001). The main cause of this was that although grassland had reached its maximum potential, technologies to

improve the soil and overcome this restriction on growth were not developed or successfully adapted. In this long period of stagnation, three sub-periods can be identified that were associated with the development of different strategies oriented to improving land productivity.

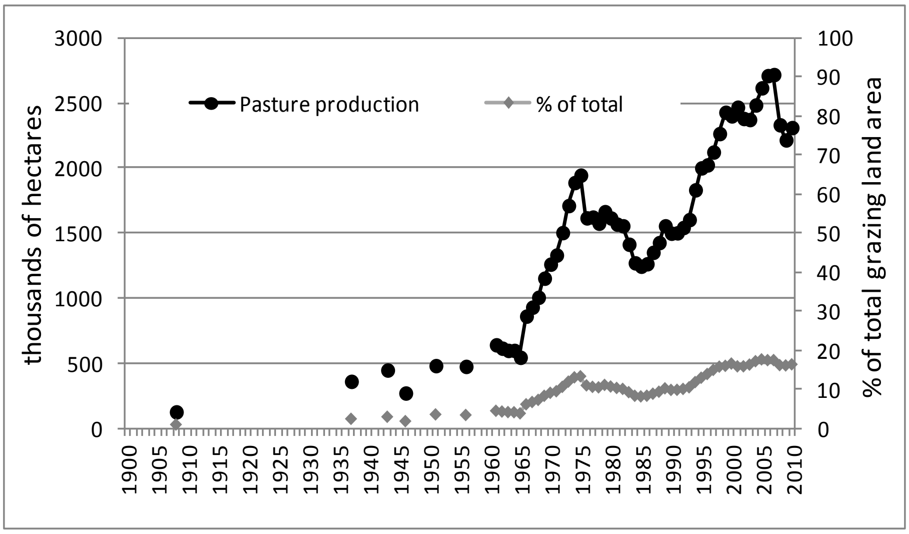
a. In the first sub-period (1914–1930) it became evident that the technological trajectory that made the sector very dynamic up to the First World War had matured (Moraes, 2001). In this context it was realized that the natural grasslands had reached their production limit and this was one of the main restrictions on the expansion of livestock production. Various solutions to this problem were gestating (Finch, 1992), ranging from traditional fodder agricultural production to improving the natural grassland (Millot and Bertino 1996; Moraes, 2001; Bertino et al, 2005). The former line of research did not take account of the specificities of the climate or the edaphic characteristics of the Uruguayan environment, which was not very favourable for the development of fodder agriculture. The latter was research into the country's soil and natural grassland, but this did not enjoy the public sector support it needed in order to be effectively developed.

b. From 1930 to 1950, improving natural grassland was explored as the possible most suitable solution in the Uruguayan environment, and an investment scheme to improve animal management was implemented (Campal, 1969; Astori, 1979; Reig and Vigorito, 1986). There were some studies in which sowing on cover to improve the quality of production on the grasslands was postulated (Spangenberg, 1936), land plots were sub-divided, fields were made and shepherding rotated to take better advantage of natural pasture (Gallinal et al, 1938; Ronsengurtt, 1946). To do this, it was proposed that credits subsidized by the State should be made available to producers (Gallinal et al, 1938). The results of this initiative were limited as regards raising land productivity, and the persistent stagnation of production led to this whole line of work being abandoned and a switch to exploring technological solutions imported from other livestock-rearing countries.

c. Starting in the 1950s there was an initiative to adopt the technological improvement and pasture cultivation package that had been successfully developed in New Zealand (Campal, 1969; Astori, 1979a, 1979; Moraes, 2001; Álvarez and Bortagaray, 2007). The main measures taken included the introduction of a subsidies scheme for the use of fertilizers and a request to the World Bank and the United Nations Food and Agriculture Organization (FAO) for foreign technical assistance. This second initiative bore fruit in 1950 when a group of foreign specialists visited the country and jointly with local experts analyzed the main problems in Uruguayan agriculture. In 1951 a team of experts was sent to Australia, New Zealand and the United States to learn about those countries' agrarian technologies. The Uruguayan specialists reacted with varying degrees of intensity, adhesion and enthusiasm. Their good impression New Zealand's technological development of livestock production and especially of the technology to produce pasture and improve grassland, along with the influence outstanding New Zealand specialists like Dr. McMeekan (Campal, 1969; Herrera, 2006) generated a favourable attitude toward adopting what later came to be called the "New Zealand technological package". In this context New Zealand came to be seen as a model of agrarian development for Uruguay and gave rise to a series of publications (Figure 1) comparing the two countries' livestock systems in the 1950s. The New Zealand experience was seen as offering a real solution and possible technological horizon for Uruguayan agriculture.

This led to the implementation of some measures, which were supported by foreign aid from the World Bank and the (FAO) as part of the Agriculture Plan. Apart from the financial and technical aspects of the plan and a big expansion of the area of improved and implanted grassland (see Graph 10), the adoption of this technology developed more slowly than expected and the results were not what had been foreseen in that, in particular, they did not have the expected impact in terms of helping to overcome the stagnation of the sector's production. The diffusion of this technology stalled quite early, in the mid 1970s, and the process of adoption stopped at very low levels, around 12% of the total pasture area (see Graph 10). These results were certainly modest and their impact varied both from region to region in the country and among the different livestock production segments (Paolino et al, 1987). There were various different sub-regional trajectories and a heterogeneous collection of business strategies (Paolino, 1990). Several different analyses found that this was because the high levels of investment involved meant a great risk for the producers since the two countries' environments differed as regards soil, climate, etc. Other reasons were that there was not enough accumulated knowledge about agronomy in Uruguay to be able to implement the new technology (Astori, 1979; Reig and Vigorito, 1986; Paolino, 1990), and that the profitability of pasture production based on the New Zealand technological package was relatively low (Institute of Economics, 1969b; Jarvis, 1982). Given the cost structure and the low profitability of investment to raise land productivity, Uruguayan livestock producers would have had to acquire more land in order to increase production rather than intensify its use (Clahe-Cinam, 1963), mainly because land was relatively cheap (Kirby, 1988). Thus stagnation continued and the livestock sector's production and productivity did not significantly improve over previous levels until the 1980s (Irigoyen, 1991).

GRAPH 10
EVOLUTION OF IMPROVED AND ARTIFICIAL GRASSLAND AND FODDER CROPS



Left-hand axis: production of pasture in thousands of hectares
Right-hand axis: production of pasture as a percentage of total area
Source: 1908, 1937 to 1956: Agriculture Census; 1961 - 1976, production of pasture (improved fields and artificial grassland) Paolino (1990) Table V2, p. 240; 1977 - 2008, DIEA, agriculture statistics based on DICOSE, http://www.mgap.gub.uy/; 2009 and 2010, Statistics Yearbook 2013, http://www.mgap.gub.uy/; annual fodder crops 1937 to 1956 Agriculture Census, 1961 - 1966, Astori, (1979) Figure 29, p. 743, 1967 - 1969 linear interpolation, 1971 - 1975, linear interpolation; 1977 - 2008, DIEA, agriculture statistics based on DICOSE, http://www.mgap.gub.uy/; 2009 and 2010, Statistics Yearbook 2013, http://www.mgap.gub.uy

3. In the 1990s and the first decade of the 21st century there was a series of sweeping changes that had a big impact on the sector's technological dynamics and production performance of agriculture and put an end to the long structural stagnation that had lasted most of the 20th century (Mondelli & Picasso, 2001; Buxedas, 2001; Piñeiro and Moraes, 2008). The trend changed because of a number of factors, the most evident of which were higher levels of investment, a reduction in the area of natural grassland, and the expansion of the area of improved pasture and fodder crops. The increase in investment was due to an increase in credit for the agrarian sector in an international context that facilitated the flow of capital to the Uruguayan market thus helping to create a favourable environment for producers to make efforts to improve productivity (Mondelli & Picasso, 2001). A large

part of this new investment went to raise land productivity. From 1990 to 2000 the area under fodder (improved fields, artificial grassland and fodder crops) jumped from 1.5 to 2.4 million hectares and at the same time the number of fields per establishment was increased. The combination of these two changes was that improvements in animal management could be introduced. As regards technologies to produce pasture, the improvements were part of the same technological paradigm that was tried in the 1960s (Paolino, 2001), and there were various regional and business sub-trajectories in the types and intensity of the innovations adopted (Mondelli & Picasso, 2001, Tommasino, 2010). In the first decade of the new century, agrarian product grew strongly, at a rate above that of the economy as a whole, while the agrarian sector was undergoing an intense structural change process. Farming production increased markedly not only in production volumes but also in the total area of land in use, and its share in exports overtook that of the traditional livestock sectors. Nevertheless, the intensification dynamics of livestock production gained strength (Errea et al, 2011). This expansion of farm agriculture meant a reduction in the area under pasture. This was mostly at the expense of natural grassland, although fodder production also decreased towards the end of the decade from its 2007 peak of 2.7 million hectares to 2.3 million hectares. Land productivity in terms of livestock units per hectare did not increase significantly as there was a reduction in the ovine stock. The incorporation of other animal feed techniques based on the increasing use of concentrated fodder and feed lots (Tommasino, 2010) made it possible to raise meat and milk production without a significant increase in the animal load per hectare (Graph 6).

4. Main conclusions

My aim in this article is to characterize the New Zealand and Uruguayan livestock systems with an analysis on their technological trajectories as they sought to raise land productivity. This was a key factor that determined the rate at which the two countries' livestock production grew in the long term and how their exports performed. My main objective was to understand how their technological trajectories were initiated and developed in interaction with other important factors like geographical environment, natural resource endowments and how intensively these were used, and the institutional context in which technological innovations to raise land productivity were produced, disseminated and adapted.

In New Zealand, livestock production changed relatively early from an extensive system to an intensive one. Besides developing and applying better technologies to improve the land factor on a large scale, this required raising the levels of capital investment and work to increase the sector's original production function. The growth in New Zealand's land productivity was based on three main pillars: first, the impact of refrigeration, which enabled the country to export new livestock products like meat and milk; second, the production frontier in North Island expanded and forests were cleared to bring new land into livestock production and the family farm system was consolidated; and third, scientific and technological knowledge was developed which made large scale pasture production feasible and intensified production. In the different stages, public policies played a key role in a variety of ways including regulating the land market and introducing subsidy and credit schemes to stimulate the intensification of production.

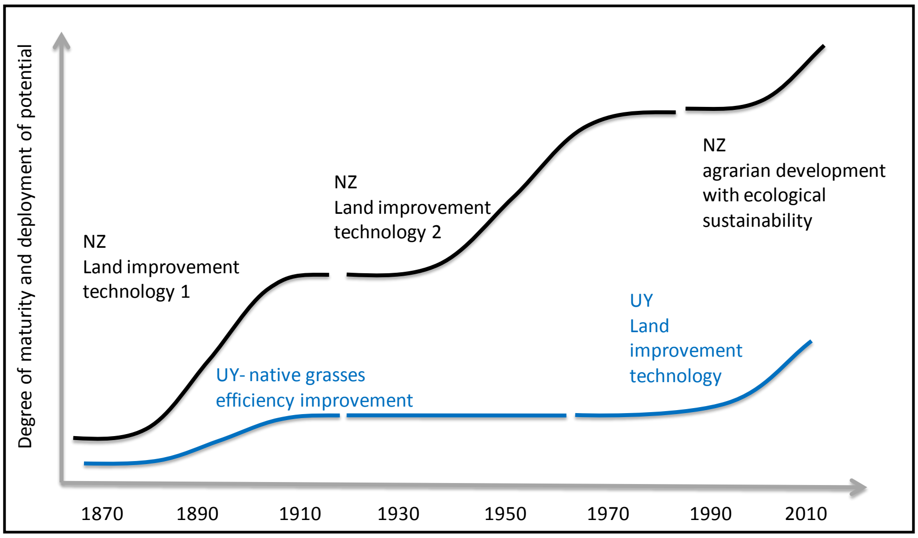
In Uruguay, livestock production was based and on the extensive use of natural grassland with low levels of capital investment and inputs, and while this system very stable it suffered from inertia in the long run. Some technological solutions to improve the natural grassland were attempted but had little effect. In the mid 20th century it was decided to introduce pasture production technologies that had been developed in New Zealand, and considerable financial and technical resources were invested in the effort to adapt them. However, the results were disappointing and the new systems were diffused in a very irregular way in different parts of the country. Then, in the 1990s, after a long period of trials and learning, the technological paradigm that had evolved in New Zealand in the 1920s crossed a dissemination threshold in Uruguay and the country was able to overcome, albeit it to a modest degree, the stagnation of production in the sector.

This analysis of the two countries' long term livestock system technological trajectories shows clearly that Uruguay lagged far behind New Zealand in the development of land factor improvement technologies. In addition, I find a sequence of three technological paradigms in New Zealand and two in Uruguay. Identifying these paradigms is one of the main conclusions of my article.

4.1. An overview of trajectories and technological paradigms

In this analysis of the stages of development of livestock systems we can identify a sequence of three land improvement technological paradigms in New Zealand. The first was a cycle of formation, development and maturity that lasted from the 1880s to the 1920s (Pérez, 2009), the second ran from the 1920s to the 1980s and the third is still in its consolidation and expansion phase. In Uruguay, on the other hand, we find two broad technological paradigms. During the first, natural grassland was the main livestock production resource and technologies to improve the land factor were not introduced. This was the situation from 1860 until the First World War and in practice it went on until the 1950s. The second phase came about when the second technological paradigm developed in New Zealand was imported and adapted in an attempt to narrow the technological gap between Uruguay and that country. Graph 11 is a schematic representation of the two countries' livestock production technological trajectories.

GRAPH 1
SCHEMATIC MODEL OF THE TECHNOLOGICAL TRAJECTORIES OF THE NEW ZEALAND AND URUGUAYAN LIVESTOCK SYSTEMS, 1870-2010



Source: author's elaboration based on the technological trajectory model proposed by Pérez (2009)

4.1.1. New Zealand

a) Paradigm 1. The refrigeration revolution, which began in the 1880s, had a massive impact on the New Zealand livestock system and the prevailing low levels of productivity in that country because it called for an improvement in the production capacity of the land factor to make livestock production a viable enterprise on a national scale. The expansion of the land frontier in North Island, the historical characteristics of the process and the conditions imposed by geography and the native ecosystem, with dense forests and a landscape in which hills and mountains predominated, contributed to the emergence, especially in North Island, of an agrarian system based on small and medium size production units, and land ownership and management at the family level. Meanwhile, on South Island, large livestock production units based on natural grassland continued to predominate. Before the 1920s the dominant technological paradigm for pasture production was imported from Great Britain and consisted in planting foreign pasture seed, crop rotation and the use of fertilizers to compensate for the soil's natural low fertility levels.

b) Paradigm 2. The near failure of British production techniques and the limits imposed by nature and the geographical environment made it necessary to develop local technological knowledge and innovations with a systematic focus on the management of the biological cycles of the soils, plants and animals. Local innovations like autochthonous strains of ryegrass and crops combined with leguminous plants to increase the soil's natural fertility had been developed, but to intensify production there had to be very considerable investment in the necessary inputs and big public investment in infrastructure. These techniques spread among producers thanks to various extension programmes and the State supported their implementation through schemes to subsidize the purchase of machinery and inputs. Until the 1940s the improvements were mainly implemented on low land and hills, and after the Second World War the intensification process was extended to mountainous areas where access was more difficult. This meant the implementation of a series of incremental innovations to intensify production on marginal land.

c) Paradigm 3. In the 1990s the paradigm of how the land factor was used changed and public policies for the sector were reoriented. In recent decades the development of the New Zealand agrarian system has been based on two pillars. First, improved economic efficiency among the productive units after public subsidies for the sector were discontinued in the 1980s, and second, a shift in approach towards ecological sustainability based on a balance between intensification and biodiversity.

4.1.2. Uruguay

a) Paradigm 1. The good conditions on Uruguay's natural grasslands, along with a collection of sweeping technological and institutional changes, made it possible for livestock production to increase until the early decades of the 20th century. In this period and subsequently the producers' main strategies to raise productivity were geared to improving the quality of the bovine and ovine stock especially in terms of genetics and animal health. It was realized quite early that land productivity was a limiting factor on livestock expansion, but it was not until well into the 20th century that efforts were mooted to provide strong incentives to generate land improvement technologies. This meant going beyond the initiatives made by institutions, scientists and specialists in the agrarian sector in the first half of the 20th century.

b) Paradigm 2. In the period after the Second World War, when the stagnation in the sector became more evident as the terms of exchange worsened, it became only too clear that strong measures were needed to overcome the production limits of the country's natural grasslands. In this context, the government implemented financial and technical policies strong enough to implant technologies to improve the land factor. In line with the prevailing technological and economic paradigm, there was an initiative to import pasture production technologies from New Zealand and serious efforts were made to disseminate them and get producers to adopt them. The results were rather limited because it was expensive to learn and adopt technology developed in another geographical context, it was expensive to implement this technology, and in terms of relative profitability there was no great difference between the new techniques and traditional production methods based on natural grassland. After thirty years of learning, the Uruguayan livestock sector managed to overcome its long stagnation in the 1990s. It achieved this in a heterogeneous process of adopting new technology, which occurred more rapidly in the milk-producing regions of Uruguay and in agriculture regions, in a domestic and international context that rewarded more intense production. However, the Uruguayan livestock system is still at low levels of soil improvement and pasture production occupies an area no greater than one sixth of the country's total pasture land.

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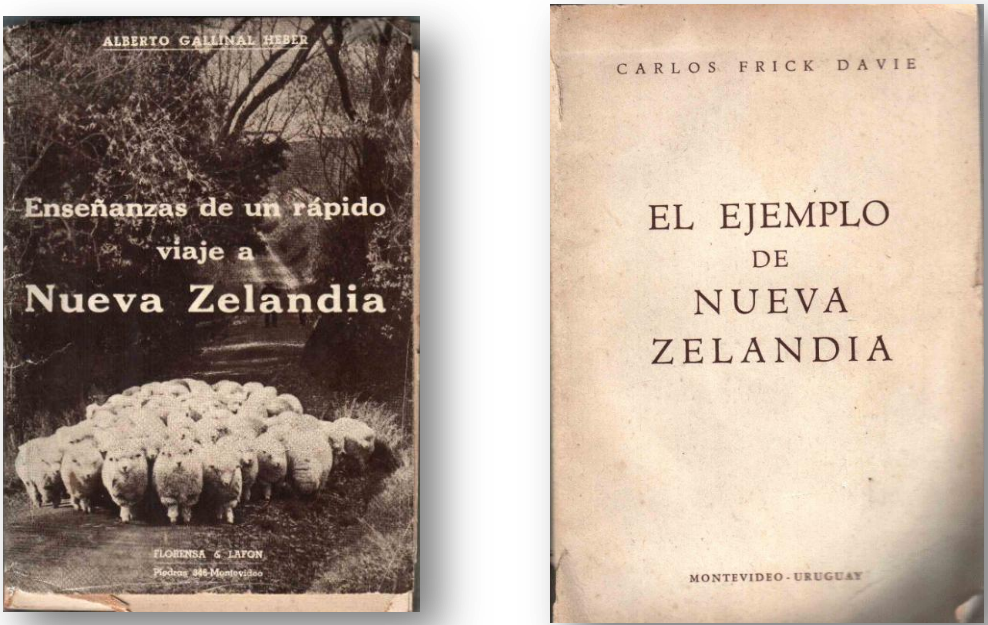
Annex

MAP 1
NEW ZEALAND AND URUGUAY IN THE WORLD

Source: based on Planisphère politique. Site enseignant Géographie Première, Collection D. Husken, A. Bervas. Hachette Livre, 2011.

FIGURE 1
NEW ZEALAND, THE PATH TOWARDS THE TECHNOLOGICAL FRONTIER.



The covers of books published in 1951 and 1960 (Gallinal, 1951, and Davie, 1960) respectively. These were the first pioneering publications that began to establish the image of New Zealand agriculture as an example for Uruguay to follow.