DOI: 10.1111/ehr.13196

THE ECONOMIC HISTORY REVIEW

ORIGINAL ARTICLE

Soils, scale, or elites? Biological innovation in Uruguayan cattle farming, 1880–1913

Emiliano Travieso

Carlos III – Juan March Institute & Figuerola Institute, Universidad Carlos III de Madrid

Correspondence
Emiliano Travieso
Email: etravies@clio.uc3m.es

Abstract

This article examines the economics of innovation in livestock rearing during the first globalisation in Uruguay, the country with the most cattle per person in the world, both then and now. Using a new historical dataset of Uruguayan agriculture, the first one at a sub-provincial level, I exploit regional differences in the adoption of cattle crossbreeding – the genetic improvement of local herds through hybridisation with foreign breeds. Contrary to traditional historiographical claims, I find that this innovation was not primarily explained by the location of enlightened elites (European or local) or by the scale of productive units (i.e. *latifundia*); rather, rural producers invested in crossbreeding wherever their local landscapes and previous productive choices encouraged it. While it affected biological processes that spanned several agricultural calendars, and thereby developed more slowly than innovations in crop farming, technical change in Uruguayan ranching was also environmentally sensitive, largely scale-neutral, congruent with previous agricultural patterns, and hinged on a widespread response from producers.

KEYWORDS

agriculture, biological innovation, cattle, elites, first globalisation, latifundia, soils, Uruguay

Despite the large economic and ecological footprint of global livestock agriculture, we know too little – compared with crop farming – about its history of technical change, especially in the global periphery.[1] This article explores the economics of innovation in cattle rearing in temperate Latin America during the first globalisation, when the international demand for beef was on the rise, driven by improvements in the standard of living in many countries and technological changes in long-distance transport. It does so through a study of cattle crossbreeding in Uruguay, the country with the most cattle per person in the world (then and now) and, therefore, a good place to examine innovation in economies specialised in natural resources.

Cattle crossbreeding – the improvement of local herds through systematic hybridisation with foreign varieties – was a key technological transformation in Uruguayan agriculture. Compared with the local 'Creole' cattle, the new crossbred animals gained weight faster, could be slaughtered at a younger age, and produced meat of a superior quality, which allowed Uruguayan *estancias* (ranches) to access more dynamic external markets. Crossbreeding involved producers across Uruguay because cattle were not, as in other economies, confined to marginal lands; a staple of the rural landscape throughout the country, they were (and to a large extent still are) the cornerstone of the agricultural export economy. While national in scope, the adoption of cattle crossbreeding was extremely uneven geographically, and most rural areas which lagged behind remain poorer to this day.[2] Why were crossbreeds introduced faster in some parts of Uruguay than in others? The question matters beyond the countryside because the effects of this innovation also reached city-dwellers. Crossbreeding impacted food processing industries downstream, while agricultural exports sustained high import rates, tariffs on which were the main source of fiscal revenue for Uruguay's rapidly expanding state, before and during the progressive *batllista* governments.[3] The pace and scope of genetic improvement in Uruguayan cattle herds also played an important role in global livestock markets, where Uruguay punched far above its demographic weight: a country of approximately 1 million people contributed 12 per cent of world beef exports and 10 per cent of world cattle exports between 1895 and 1912.[4]

Unsurprisingly, cattle crossbreeding during the first globalisation is a classic topic in Uruguayan economic history, closely linked to debates about *latifundia*, elites, and long-term development. Yet, our understanding of it remains limited because scholars have not been able to adequately measure the regional divides in the adoption of crossbreeding in order to test their arguments more systematically. Moreover, this rich local conversation has not been sufficiently integrated with global debates surrounding technical change in agricultural history. In this article, I aim to contribute on both these fronts over three major sections. Section I introduces the reader to Uruguay during the first globalisation and summarises the major arguments of the specialist

[1] Federico, *Feeding the world*, p. 87; Olmstead and Rhode, *Creating abundance*, p. 262. For an overview of current global trends, see Thornton, 'Livestock production'. The Food and Agriculture Organization (FAO) estimates (2013 and 2006) suggested that livestock contribute 14.5 per cent or as much as 18 per cent of anthropogenic greenhouse gas emissions; other studies place it between 10 per cent and 18 per cent; FAO, *Livestock's long shadow*; idem, *Tackling climate change*; Herrero et al., 'Livestock'.

[2] Martínez-Galarraga, Rodríguez Miranda, and Willebald, 'Patterns'.

[3] Custom duties accounted for over 60 per cent of Uruguayan fiscal revenue in the period 1870–1904, and about 45 per cent in 1904–13; Bértola, 'Primer Batllismo', p. 179. Named after José Batlle y Ordóñez (President, 1903–7 and 1911–5), *batllismo* was the leading political movement in early-twentieth-century Uruguay; its governments oversaw the expansion of public investment in infrastructure and human capital, as well as the nationalisation of public utilities. The political history literature is vast; a recent influential analysis is Caetano, *República*; for a classic English-language study, see the trilogy by Vanger (*The creator, The model country*, *The determined visionary*).

[4] Yates, *Forty years*, p. 80; United States Department of Agriculture, *Meat*, pp. 215, 225.

literature on Uruguayan cattle crossbreeding and the part it played in the country's 'rural modernisation'. Section II puts those claims to the test using a new, spatially explicit dataset of Uruguayan agriculture *c*.1908, based on agricultural census records, historical maps, and several other archival sources. Section III discusses the results in relation to the broader literature on biological innovation in modern agricultural history, which refers mostly to crop farming, and considers what, if anything, was different about cattle rearing. The conclusion reflects on the economics of biological innovation in livestock production in developing regions past and present.

I | CONTEXT

Within the broad biogeographical region known as the Río de la Plata Grasslands – encompassing all of Uruguay, most of the Argentine littoral, and the southern tip of Brazil – Uruguay is entirely situated in the temperate Campos biome, characterised by widespread grasslands dotted by patches of woodland alongside freshwater courses, as well as by comparatively reliable yearly rainfall.[5] The Campos grasslands themselves differ from their humid Pampas counterparts on the Argentinian side of the Río de la Plata estuary because their soil is generally shallower and, hence, not equally suitable for extensive cereal agriculture.[6] When export-led growth took off in most of Latin America in the 1870s, the livestock economy was Uruguay's growth engine, as mild winters and natural grasses allowed cattle and sheep raising without stabling. On the backs of high prices for beef and wool – lucky tickets in the 'commodity lottery' of the day – real wages in Uruguay (and neighbouring Argentina) were, in 1913, three times higher than in Mediterranean Europe.[7] Immigrants from across the Atlantic showed up in great numbers; relative to Uruguay's population, immigration flows were larger than in the United States.[8] A new country in many ways, Uruguay's comparative advantage remained tied to its natural grasslands. Unlike in other prosperous settler economies, however, these were all already under hooves or crops. The American West, Canada's prairie frontier, the Argentine south, New Zealand's North Island, and the Australian outback all allowed for 'new' (from the perspective of settlers) land to be brought into pasture in the late nineteenth century. With the opening of new pastures, old ones were turned to cropland particularly in the largest settler economies, which led to a global process of grassland conversion.[9]

Some pastures were brought under crops in Uruguay too, particularly in the southwest and in the grain belt surrounding Montevideo, where estate sizes tended to be smaller (figure 1). The evidence points to a diversification of crop choices within farming strategies still dependent on traditional energy sources and techniques, and to an increase of the area under crops of almost 50 per cent between 1890 and 1908.[10] Wheat and maize retained their secular primacy in the Uruguayan crop repertoire, but the expansion was led by other cultigens, as farmers responded

[5] Soriano, 'Grasslands'; Baldi and Paruelo, 'Land-use'.

[6] Paruelo et al., 'Grasslands', p. 237.

[7] Williamson, 'Real wages'. Díaz Alejandro, 'Latin America', is credited with the idea of the 'commodity lottery', which was then popularised by Bulmer-Thomas, *Economic history*.

[8] Sánchez Alonso, 'The other Europeans'.

[9] McNeill, 'Entering the anthropocene', p. 72. Regarding the differences of frontier expansion in settler economies, see Willebald and Juambeltz, 'Land frontier'.

[10] 'Anuario de Estadística Agrícola 1892', returns published in Dirección General de Estadística (hereafter DGE), *Anuario Estadístico 1893*, pp. 152–3; DGE, *Censo General 1908*, II, II, 1131–7. LXXV.

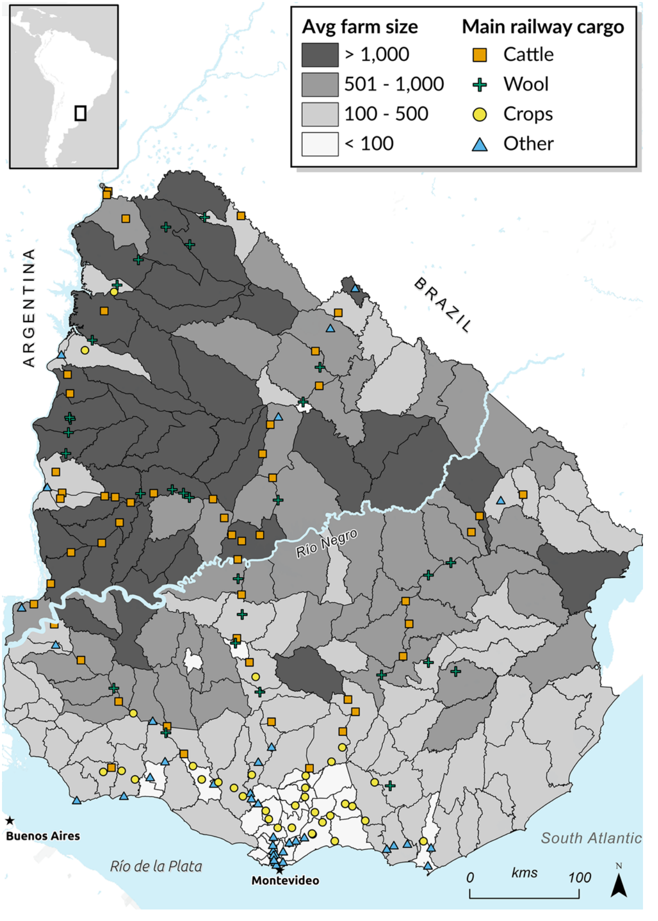


FIGURE 1 Uruguay, *c.* 1910: mean estate size by districts and main cargo loaded in railway stations. *Note*: Estate sizes refer to 1908, railway cargo data to 1909–12, railway station freight profiles are defined as 'cattle' if live animals and cattle hides amounted to more than half of the total cargo weight loaded at the station, 'wool' if wool amounted to more than half of the total cargo weight loaded at the station, and 'crops' if the added weight of wheat, corn, linseed, bran, and hay represented more than half of the total. The rest of the stations are classified as 'other'. *Sources*: 'Establecimientos agropecuarios por secciones', *Censo General 1908*, vol. II, pt. II: 1026–35; Travieso, 'Railroads' [Colour figure can be viewed at wileyonlinelibrary.com]

to the expanded urban demand buttressed by immigration: the hectares cultivated with barley, potatoes, and sweet potatoes doubled between those years. The more-than-threefold expansion of the land occupied by vineyards over the same period is emblematic of rural responses to the rise of urban populations and disposable incomes.[11] Still, by 1908 crop farming occupied only five per cent of Uruguay's agricultural land and produced only 10 per cent of agricultural output.[12]

Despite not incorporating 'new' land, Uruguay managed to maintain high living standards – about three times higher than the Latin American mean, excluding Argentina – in the context of a tripling of its population during the decades of mass migration before 1914.[13] External and domestic developments both played a part in the success of Uruguayan livestock production, which accounted during this period for no less than 40 per cent of GDP and over 80 per cent of exports (figure 2).[14] The global boom for primary commodities kept prices for Uruguayan pastoral

[11] Vineyards occupied 6823 hectares in 1908, up from 2597 in 1892. 'Estadística Agrícola 1892', p. 158; DGE, *Censo General 1908*, vol. II, pt. II, p. 1147. For a social history account of the networks that made such expansion possible, see Beretta Curi, 'Caminos de innovación'.

[12] Data on the number and extension of crop farms from *Censo General 1908*. Sectoral output figures for 1912 from Piñeiro, Bianco, and Moraes, *Trabajadores*, p. 158.

[13] Bértola, 'El PIB per capita de Uruguay'; Programa de Población, *Base de datos*.

[14] Moraes, 'Capitalismo pastor', p. 13; Bonino-Gayoso, Tena-Junguito, and Willebald, 'Accuracy', p. 315.

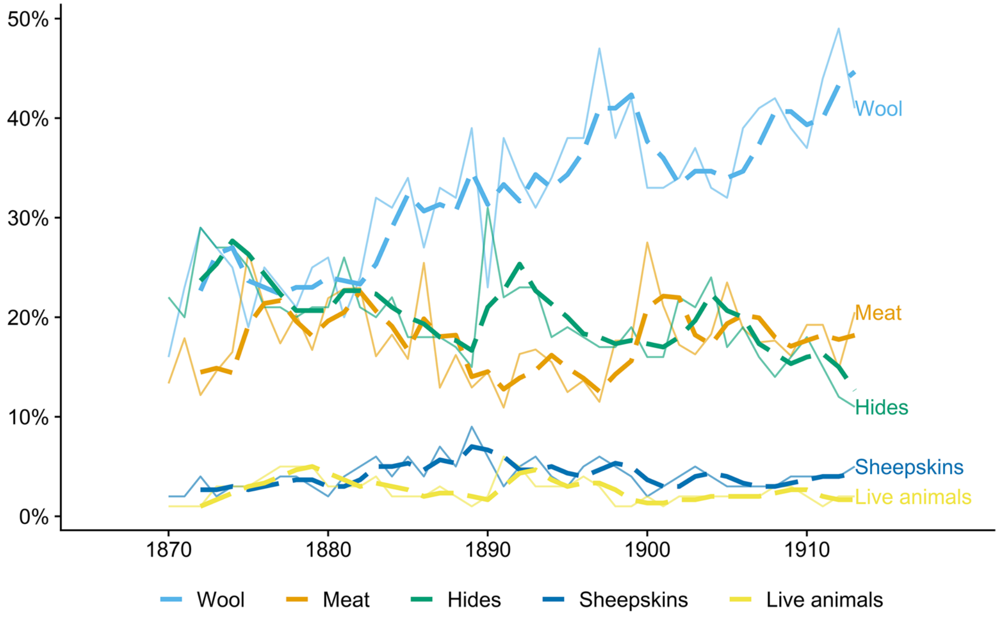


FIGURE 2 Uruguayan exports: value share by top 5 product categories (1870–1913, current prices). *Note*: Dotted line shows 3-year moving average. *Source*: Bonino-Gayoso, Tena-Junguito, and Willebald, 'Accuracy' [Colour figure can be viewed at wileyonlinelibrary.com]

commodities (especially wool and meat) at high long-term levels, while external markets diversified: Brazil remained the single largest partner, but France, the United Kingdom, and Belgium grew in importance as destinations and accounted for half of Uruguay's exports in the period. In terms of product structure, wool kept gaining ground while cattle hides lost their secular leadership. Meat accounted for about 20 per cent of export value throughout, but it became increasingly differentiated as a commodity: whereas almost all meat exported in 1870 was beef jerky, by 1913, corned beef, beef extract, and frozen beef represented two-thirds of meat exports.[15] In the decades that followed, frozen and chilled beef would become Uruguay's top export commodities.[16]

While international prices played a major role, exported quantities also increased thanks to local technical changes in cattle and sheep rearing. Between 1872 and 1908, the volumes of meat and wool produced per hectare in Uruguay more than doubled; herd densities increased somewhat (albeit with large fluctuations throughout the period), but physical output growth was primarily driven by rising beef and wool yields per animal.[17] These productivity gains were achieved mainly through biological innovations: the systematic crossbreeding of domestic sheep and cattle with foreign breeds. These interacted with changes in institutions and farm management practices, notably the enclosure of rangeland with steel wire which protected the increased

[15] Bértola, 'Primer Batllismo', p. 187; Bonino-Gayoso, Tena-Junguito, and Willebald, 'Accuracy', pp. 302, 309–10, and appendix 2.

[16] Moraes, *Pradera*, pp. 120–5.

[17] Ibid., pp. 109–15.

value of livestock and the spread of mixed grazing systems (raising both sheep and cattle in the same fields).[18]

The genetic improvement of sheep developed first in a 'Merino revolution' starting in the 1860s.[19] However, the subsequent transformation of Uruguay's meat industry was driven by the genetic improvement of the 'native' Uruguayan Creole cattle via systematic crossing with British beef breeds (Hereford and Shorthorn). Downstream, this innovation encouraged exports of beef extract and canned meat, and later on, freezing works.[20] Crossbreeding entailed investing in purebred or half-blood Hereford or Shorthorn animals (or hiring their services) and, year after year, improving the genetic makeup of the herd. The result was *mestizo* cattle: crossbreeds who grew faster, gained weight quicker, and produced beef of a superior quality. Crossbreeding was a cumulative innovation, and as the contemporary press and livestock producers themselves noted, the label *mestizo* could refer to different degrees of 'improvement' and breed purity.[21] The signature red coat and white face of Herefords, for instance, were dominant traits transmitted even to animals who were only one-eighth Hereford, which led to the results of the 1908 agricultural census being criticised by some as excessively optimistic.[22] However, despite genetic disparities within crossbred herds, the distinction between 'native' and crossbred cattle was validated by buyers at markets where the former usually sold by the head and the latter by their weight.[23]

Crossbreeds' faster growth rates were not their sole comparative advantage. Uruguayan Creole cattle were general-purpose animals: since colonial times they had been slaughtered to export their hides and supply meat to towns and villages while also providing smallholders with milk and ploughs with draft power. Their economic uses were as diverse as their colours, which ran the whole gamut present in the *Bos taurus* species. Creoles were lean and rangy, with long horns twisting upward and outward on both males and females. They proved highly robust in the face of droughts, poor pastures, and local parasites, to which they had adapted over three centuries, and females' large pelvic openings made calving easy. On the other hand, Hereford and Shorthorn were specialized beef breeds, with homogeneous coat patterns, shorter horns, and a larger, rectangular build, with a thick neck and a wide thorax – all characteristics that were transmitted to their crossbred offspring. Contemporary veterinary technicians advised cattle farmers that crossbreeds were 'finer animals' which could attain much higher weight but were 'more demanding than Creole cattle' in their pasture requirements.[24]

Therefore, crossbreeds were better suited to beef production than Uruguayan Creole cattle; they were also hardier than pure Hereford or Shorthorn animals and, hence, adapted better than

[18] The two classic accounts of the expansion of wire fencing in Uruguay are Barrán and Nahum, *Historia Rural* I, pp. 532–56, and Jacob, *Consecuencias sociales*. Mixed grazing will be discussed below.

[19] Barrán and Nahum, *Historia Rural* I, pp. 140–78; Millot and Bertino, *Historia económica*, pp. 48–55.

[20] Bonino-Gayoso, Tena-Junguito, and Willebald, 'Accuracy', p. 313; Travieso, 'United by grass'.

[21] Barrán and Nahum, *Civilización*, pp. 84–92.

[22] The official publication of the Uruguayan Rural Society was the main forum for these debates; see, for example, Arocena, 'Producción de ganados'.

[23] This market situation was disseminated by rural newspapers: see, for example 'Las exposiciones ferias', *La Campaña* (Departamento de Río Negro), 1 April 1908, p. 1, in Archivo Liebig's-Anglo, Fray Bentos. See also Barrán and Nahum, *Civilización*, p. 65; Millot and Bertino, *Historia económica*, p. 103. Regarding market integration and price responsiveness, see Moraes, 'Capitalismo pastor', p. 28; idem, *Pradera*, pp. 90–1.

[24] Ramos Montero, *Cartilla ganadera*, p. 14. This assessment is confirmed by present-day scientific studies carried out on a reserve herd of approximately 600 Uruguayan Creole cattle; see, for an overview, Armstrong and Postiglioni, 'Bovinos'; regarding comparative biometric measures relative to Hereford cattle, Rodríguez et al, 'Estudio étnico'.

imported purebreds to the year-round outdoor livestock management of Uruguayan producers. This was due not only to crossbreeds inheriting the robustness of their Creole parent, but also to the increased performance of crossbreeds compared with their mid-parent mean (the average characteristics of their parents' breeds), a principle known in animal science as 'heterosis'.[25] Without having read the science behind it, Uruguayan producers in the late nineteenth and early twentieth centuries were keenly aware of the value of hybrid vigour. The deliberate crossing of different varieties and stocks within or across estates, a practice they called '*cambio de sangre*' ('changing the blood'), was known to prevent undesirable characteristics from being passed down a lineage.[26]

In 1908, Carlos Reyles, a famous writer and university lecturer, summarised what livestock improvement meant for Uruguay's material progress: 'what is truly important among us, today, are the herds'.[27] An enthusiastic supporter of cattle crossbreeding, Reyles turned out to be a better intellectual than a rancher; 'wandering around his estate', a contemporary wrote, 'he read Friedrich Nietzsche, a dangerous read in a Uruguayan *estancia*'.[28] Despite inheriting one of the country's largest rural estates, he ended up losing all his land and livestock after a series of poor ranching decisions.[29] As Reyles found out the hard way, redesigning the genetic makeup of entire herds without endangering their survival and reproduction was easier said than done. While the techniques involved (selective mating and isolating herds) were readily understood, crossbreeding with expensive foreign breeds substantially increased an estate's production costs in the short term but could take years to consistently improve yields. There were also substantial risks involved: illnesses such as foot-and-mouth disease or the tick-borne 'Texas fever' (babesiosis, known as 'bovine sadness' in Uruguay) were prevalent among crossbreeds and British beef breeds, which were also more prone to dystocia (calving difficulties); all of which led many producers to avoid experimentation and persist with the hardy Creole cattle.[30] Sequential mating and natural selection could (and did) eventually develop crossbreeds' resistance to these diseases, but this process was lengthy and costly, especially in places where poor grass growth made feed scarcer in winter and slowed down crossbreed herd turnover.

Thus, as contemporary proponents of the innovation noted, there were very rational profitability reasons for individual cattle farmers in Uruguay to be reluctant to invest in herd improvement in the short term, even if from a sector-wide perspective 'abandoning Creole cattle' would ultimately be 'inevitable'.[31] This 'inevitability' hinged on the evolution of Uruguay's export economy (with hides losing their historical importance) and on changes in the meat industry in particular. The unimproved Creole cattle were a good fit for traditional beef jerky production (which favoured lean flesh) but were ill-suited to new technologies of meat preservation: extraction, canning, and especially refrigeration.[32] Despite some earlier attempts, cattle crossbreeding began in

[25] Simm et al., *Genetic improvement*, 108–15.

[26] Regarding the advantages of 'changing the blood' see, for example, Ordoñana, 'Memoria pastoril', p. 370, and 'Toros Hereford', *El Siglo*, 14 October 1913, p. 4, in Biblioteca Nacional Newspaper Collection, Montevideo.

[27] Reyles, *Conferencia*, pp. 15–6.

[28] Cejador y Frauca, *Historia* X, p. 141.

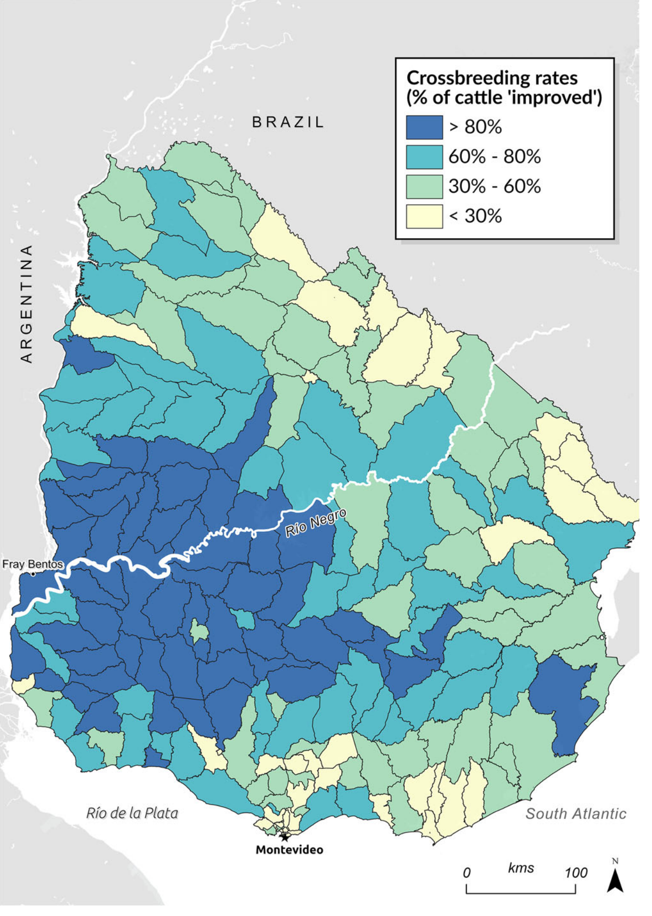
[29] Rama, 'Prólogo', p. vii.

[30] Barrán and Nahum, *Recuperación*, p. 211. Argentinian contemporaries were also concerned about 'acclimation' difficulties and diseases affecting 'fine' cattle; Quevedo, *Las epizootias*, p. 108; Graciano, 'Los caminos', pp. 22–3. Regarding similar worries among US breeders, see Olmstead and Rhode, *Creating abundance*, p. 285.

[31] Asociación Rural del Uruguay, *Cien años*, pp. 87–90.

[32] Finch, *Political economy*, pp. 133–6.

FIGURE 3 Percentage of cattle crossbred in Uruguay by district, 1908. *Source*: 'Ganado por especies, departamentos y secciones', *Censo General 1908*, vol. II, pt. II: 990–7 [Colour figure can be viewed at wileyonlinelibrary.com]



earnest in the 1880s, coinciding with the increase in beef extract production at Liebig's factory in Fray Bentos, but by 1890, only about five per cent of animals had been improved.[33] The process was still underway two decades later, as producers imported expensive pedigree animals from Britain in increasing numbers, notably in the aftermath of the first slaughter at a frozen meat factory in Montevideo in 1904.[34] Crossbred cattle spread sooner and faster in some neighbouring Argentine provinces, where pasture-based ranching was further sustained by large-scale fodder production.[35] However, geographical unevenness was also stark within the Uruguayan countryside, where by 1908 leading areas had already improved almost all of their cattle, while there were still more than two and a half million purely 'native' Creole cattle being raised in other regions (figure 3). After 1914, following the opening of larger frozen meat factories owned by

[33] Purebred British animals were recorded for the first time in Uruguay in 1859 but only started being imported at some scale two decades later. (Vázquez Franco, 'El Uruguay', p. 23.)

[34] Finch, *Political economy*, p. 84. In 1908, to take the benchmark year of our analysis, more certificates for pedigree Hereford animals were granted for export from the United Kingdom to Uruguay than to any other country. Hereford Herd Book Society, *Herd Book XXIX*, 1040–7. Regarding the first frozen meat plant (La Frigorífica Uruguaya), see Beretta Curi, *La industrialización*, pp. 151–2.

[35] For an overview of cattle crossbreeding in Argentina and its historiographical interpretations, see Sesto, *Vanguardia ganadera*, pp. 26–36.

the Chicago Trust, crossbreeding was increasingly adopted in laggard regions as well.[36] By the late 1920s almost all Uruguayan Creole herds had been replaced by crossbreeds, but by then the opportunity window for peripheral primary producers in the world market was closing.[37]

So why did producers in some Uruguayan regions adopt cattle crossbreeding faster than in others during the first globalisation? Three interrelated hypotheses have been proposed, although none have so far been systematically tested. The first one focuses on estate sizes. If large landowners are assumed to prefer land hoarding to innovation, or to prioritise their urban investments over improvements to their estates, then areas characterised by big landholdings would have fewer crossbred herds. This view became part of the mainstream historiographical account of Uruguayan rural development, which argued that 'latifundia engender inertia' and larger average estate sizes in the 'archaic' regions north of the Río Negro (see figure 1) could be tied to lower crossbreeding rates.[38] Such an interpretation found echoes elsewhere in Latin American(ist) historical and social science scholarship in the 1960s and 1970s as part of a literature that identified *latifundia* as a fundamental obstacle to economic development.[39] Economists later pointed out that there was no reason why larger producers would be more risk averse than smaller ones, and that the dominance of large landholdings was not an obstacle to innovation even in the 'backward' areas in the north of Uruguay, where landowners were no less capitalist than their counterparts in the more 'advanced' regions.[40] Finally, one could also expect areas with larger landholdings to be better equipped for innovation adoption, as *latifundia* owners would be in a much better position than smallholders to take risks, invest, and innovate, having access to credit markets from which smaller producers were excluded. Indeed, economic historians working on other Latin American cases found that very large landholdings had been integral to the rise of agrarian capitalism and the increasing commercialisation of agriculture in the late-nineteenth and early-twentieth centuries, rather than at odds with it.[41]

A second possible explanation focuses on a distinctively entrepreneurial rural elite. Historians repeatedly argued that immigrant Basque, French, German, and British producers and their descendants had played a 'formidable' role in cattle crossbreeding.[42] Innovation diffusion in Uruguayan ranching could have been achieved largely thanks to entrepreneurial minorities, especially well-off, often Europe-born producers, who had 'a greater ability to embrace change'.[43] If this was indeed the case, and given the uneven geographical distribution of the rural elite, we would expect areas where they were present to outperform others in crossbreeding adoption.

Finally, the natural environment could be a crucial factor explaining divides in innovation adoption. Producers, of whatever scale, could have chosen to delay their investment in

[36] Millot and Bertino, *Historia económica*, pp. 104–5; Finch, *Political economy*, p. 78.

[37] The 1930 census counted just over 100 000 Creole cattle, representing 1.5 per cent of the total; at present, they persist in small numbers. Ministerio de Ganadería y Agricultura, *Censo General Agropecuario 1930*, p. 16; Rodríguez, *El Uruguay*, p. 23; Vázquez Franco, 'El Uruguay', p. 27; Barrán and Nahum, *Agricultura*, p. 188.

[38] Barrán and Nahum, *Civilización*, p. 309. Barrán and Nahum's seven-volume *Historia rural del Uruguay moderno*, written in the 1960s and 1970s, is the classic text on Uruguayan rural development. For an English-language summary, see Barrán and Nahum, 'Uruguayan rural history'.

[39] For an introduction, see Mörner, 'Spanish American hacienda', and Florescano, *Haciendas*.

[40] Millot and Bertino, *Historia económica*, pp. 89–102.

[41] Bauer, 'Spanish America', offered an insightful reflection on the emerging literature. Pioneering case studies were Miller, 'Mexican junkers' and Sábato, *Agrarian capitalism*.

[42] Barrán and Nahum, *Recuperación*, pp. 205–06.

[43] Millot and Bertino, *Historia económica*, p. 101.

crossbreeding if they were unsure of its profitability. Expected profitability, in turn, could have depended on how fast crossbred cattle could adapt to producers' local environments.[44] In open-air, pasture-based grazing, producers had to consider how their soil and grasses would impact crossbred cattle growth and adaptation, given their larger feed requirements and vulnerability to disease. If this was the case, given soil variation across the country, we would expect areas with comparatively richer soils to adopt crossbreeding faster, thereby showing a higher share of crossbreeds in their herds by the turn of the century.

Previous discussions of these hypotheses in the specialist literature share a substantial empirical limitation: they have been unable to escape the tyranny of administrative geography. As economic historians worked with provinces (the 19 political divisions, *departamentos*, which form Uruguay's second level of government), the number of observations and the level of spatial resolution simply did not allow them to quantitatively test relationships between variables or effectively capture the diversity of local landholding patterns or natural environments. This spatial aggregation problem is not unusual when trying to explain agricultural innovation in the past.[45] It is the premise of this article that district-level data can be used to describe and measure the relationships between estate sizes, soil quality, rural elites, and innovation in cattle raising across the country. Ecological fallacy (interpreting individual characteristics from aggregated data) remains a risk even when working at the level of districts, but it is considerably less severe than in all previous studies which explored the relationships between these variables in Uruguay only at the provincial level.

A new empirical analysis also provides the opportunity to bring the case of technical change in Uruguayan cattle rearing into dialogue with classic debates in the global literature on agricultural innovation. Indeed, the contrast in the Uruguayan literature between the 'latifundia mindset' argument – that a certain *mentalité* delayed crossbreeding in 'backward' areas – and the 'profitability' one – that it was differences in expected benefits, derived from local environments, that explained regional divergence – bears some resemblance to the seminal conversation between rural sociologists and economists on the adoption of hybrid corn in the United States.[46]

II | DATA AND ANALYSIS

Almost 90 per cent of the Uruguayan territory (176 000 square kilometres) is suitable for agriculture, with natural grasslands being the predominant land cover in four-fifths of the countryside and elevations rarely reaching 200 m.[47] Aware of the size of the rural economy, economic historians have relied on provincial data on agricultural output, soil quality, and other variables to sustain their arguments, and produced maps to that effect.[48] Nevertheless, the very high share of land suitable for agriculture and the size of the territory (small by South American standards, but larger, for example, than England and Wales combined) make describing regional variation at the level of provinces entirely inadequate: not only are some of them very large, but their borders – drawn in the late nineteenth century as a result of political calculations and

[44] Millot and Bertino, *Historia económica*, pp. 89–94; Moraes, 'Capitalismo pastor', p. 37.

[45] See, for a classic discussion, Griliches, 'Hybrid corn', fn 38; Dixon, 'Hybrid corn revisited', p. 1458.

[46] Olmstead and Rhode, 'Transformation', pp. 716–7.

[47] Marchesi and Durán, *Suelos*, p. 18; Gautreau, 'Rethinking the dynamics'.

[48] See, for example, the maps in Barrán and Nahum, *Civilización*, pp. 364–5, and Millot and Bertino, *Historia económica*, p. 100.

conflicts – can obscure rather than illuminate fault lines in rural landscapes and economies. This article overcomes that limitation by mapping agricultural and environmental data in 1908 at the spatial level of court districts (n = 210, 197 of which were at least partially rural). The year 1908 is a good vantage point from which to reconstruct the economic geography of Uruguayan agriculture, not only because of source availability, but also because of its place in the chronology of the country's growth path: between 1900 and 1912 Uruguay's real GDP almost doubled, as did the livestock sector's gross value added, reaching levels that would not be reached again until the 1920s.[49] Except for the locations of railway stations, which were taken from previous work,[50] all the other data were constructed from primary sources. Let us briefly introduce these sources and the georeferencing procedures before analysing the resulting dataset.

Data on land, livestock, and crops, which form the basis of the dataset, were transcribed from the 1908 agricultural census, the same major source that previous studies have used, although deployed here at a higher level of spatial disaggregation. This comprehensive enumeration was part of a major statistical project (including population, industrial, and housing censuses) with which the *batllista* government, emerging victorious from Uruguay's last civil war (1904), tried to cement its programme of reforms. An unprecedented and carefully planned operation using the latest technology available, the 1908 *Censo General* is considered by historical demographers a seminal enumeration which reflected the planning needs of an emerging welfare state.[51] As far as the rural economy is concerned, the level of detail requested in the instructions for census-taking was remarkable, even if, as the census' authorities themselves acknowledged, the responses on wages paid, asset value, and output and sales value suffered from massive under-reporting because of taxation concerns.[52] To avoid the distorting effects of under-reporting, none of those variables are included in our dataset, which only contains data on volumes and quantities which were at the time uncoupled from tax calculation. The asset value of land and livestock was not even part of the census questionnaire, perhaps because census planners were aware they were unlikely to get an honest answer and posing the question could endanger the reliability of other responses.

Data on elite ranches were taken from *Pur-Sang*, a well-known trade publication which hired journalists and veterinarians to produce an extensive survey of the 'most distinguished' livestock estates promoting 'scientific crossbreeding and progress'.[53] While the editor thanked the Asociación Rural del Uruguay (Uruguayan Rural Society, ARU) for its technical assistance, the survey was not a propaganda publication: the society did not fund the project, and most estates included were not owned by ARU members.[54] The results were published in two lengthy volumes which provide a detailed account of each ranch considered to be part of the rural elite, complete with its precise location, a history of its creation and development, and details on its production process. This source was previously examined by Barrán and Nahum, the authors of what became

[49] Bértola, 'Primer Batllismo', p. 179.

[50] Travieso, 'Railroads'.

[51] Calvo, 'Introducción', p. 9; Pellegrino, *Población*.

[52] Dirección del Censo Nacional, 'Instrucciones para el levantamiento de los censos', item VIII (24 September 1908), Biblioteca Nacional, Sala Uruguay, registro 101365; DGE, *Censo General 1908*, vol. II, pt. II, LXXV.

[53] *Pur-Sang. Cabañas y estancias del Uruguay 1916-17; 1917-18*. Facultad de Veterinaria Library, Universidad de la República, location Da5/FV-33015 and FV-33016.

[54] The society's directorate declined twice to 'make a pecuniary contribution' to *Pur-Sang*. 'Libro de Actas de la Comisión Directiva de la ARU, 1909–1914', pp. 205, 207, Biblioteca de la Asociación Rural del Uruguay, Montevideo. Only one-third of the cattle ranching estates included in our sample were owned by ARU members, as revealed by cross-referencing with membership records in 1908; ARU, *Revista de la Asociación Rural del Uruguay,* 1st July 1908, XXXVII, 7, 370–3.

the mainstream interpretation, who relied on it to construct several descriptive indicators of elite *estancias*.[55] However, because their analysis did not anchor these estates in specific spaces, they were not able to systematically examine their effect on crossbreeding in the context of other variables which can only be pinned down at a local level. Because *Pur-Sang*'s survey was undertaken eight years after the census, our dataset only includes the cases of cattle ranches which existed and were owned by the same producers (or their immediate family) at the time of the 1908 census.[56] These were among the largest estates in the country (about 7000 hectares on average, 10 times larger than the mean cattle ranch) and among the most capitalised, with stocks of cattle averaging over 4000 animals.

Environmental data were taken from statistical yearbooks and government reports. Rainfall data refer to the reported annual average at meteorological stations between 1904 and 1914; temperature is taken from the long-term isotherms lines of annual temperature reported by Uruguay's National Meteorology Institute (Inumet) on the basis of data from 1961 to 1990, as no comparable data were found for the beginning of the century; mean altitude was calculated with present-day satellite data using Esri World Elevation Services.[57] Soil quality data refer to Uruguay's Comisión Nacional de Estudio Agronómico de la Tierra (CONEAT) index, an edaphological system of classification that groups homogeneous soils in terms of their long-term potential for grass growth, compared with the national mean (which equals 100).[58] The index was created in 1967 and calculated for the whole country at a highly detailed 1:20 000 scale[59]; it has been of widespread use by producers and researchers ever since, including by economic historians who have applied it to previous periods. Millot and Bertino, whose seminal contribution spearheaded the revisionist interpretation of Uruguay's rural modernisation, used the CONEAT index (albeit only at the level of provincial averages) as the crucial piece of evidence to question Barrán and Nahum's emphasis on the presence of very large landholdings as the cause of relative regional backwardness in adopting cattle crossbreeding.[60]

Geographic information system (GIS) mapping was used to link the different data together and to calculate relevant distances. When data were not reported at the spatial level of court districts, simple methods were used to allocate values to districts. For soils, the predominant edaphological category in the district (in terms of total land cover) was allocated to it; for rainfall, each district was allocated the yearly rainfall value reported at the meteorological station closest to its centroid; for annual temperatures, the isothermal lines reported in the sources were mapped on top of the district map, and the predominant value in each district was allocated to it. Historical district boundaries from 1908 were drawn through a lengthy process of crosschecking sources. The procedure was to work backwards from the 1963 census districts, which have been geo-referenced by Uruguay's National Statistical Institute (INE) and reflected court districts at the time, and 'undo' the boundary changes between 1908 and 1963, which had resulted in the creation of 24 new court districts and the redrawing of some boundaries. Provincial historical maps, available in Uruguayan archives, governmental decrees defining district boundaries, and Araújo's *Diccionario*

[55] See, for example, Barrán and Nahum, *Civilización*, pp. 116–7, 336, 354, 401.

[56] The results of the analysis do not change significantly if all ranches (regardless of whether they were owned by the same family or firm in 1908) are included.

[57] Inumet, 'Precipitación'; Esri, *ArcGis Pro*.

[58] For an overview of the CONEAT system, see Lanfranco and Sapriza, 'Incidence'.

[59] Comisión de Inversiones y Desarrollo Económico, *Zonas*; Ministerio de Ganadería, *Clasificación*.

[60] Millot and Bertino, *Historia económica*, pp. 99–100.

TABLE 1 Summary statistics for selected variables across Uruguayan rural districts

	Mean	**Std. dev.**	**Min.**	**Max.**
Cattle crossbred (%)	65.7	25.0	7.1	99.9
Soil quality (CONEAT index)	101.4	29.4	50.7	168.1
Average estate size (hectares)	677.9	908.6	5.1	7678.9
Elite cattle ranches (% of estates)	1.1	2.3	0	18.8
Temperature (°C, yearly average)	17.0	0.7	16	19
Rainfall (mm, yearly average)	951.7	113.6	720	1152
Elevation (MASL, average)	96.1	55.8	12	238
Distance to Montevideo (km from centroid)	269.9	151.9	4.8	618.7
Distance to railway station (km from centroid)	29.5	25.5	0.7	123.5
Stocking rate (LU per hectare)	0.8	0.5	0.2	5.8
Oxen as share of total cattle (%)	6.7	8.7	0.2	48.7
Steer as share of total cattle (%)	14.6	7.4	0	41.4
Sheep: cattle ratio (heads)	3.3	2.5	0	10.7
Sheep crossbred (%)	82.6	23.2	2.2	99.8

Notes: MASL = meters above sea level; LU = livestock units. The calculation of livestock units is based on feed requirements, following the coefficient developed by INIA [Instituto Nacional de Investigación Agropecuaria], *Revisión y analysis,* (1 sheep = 0.15 cow). See table S1 for the full dataset.
Sources: Censo General 1908; Pur-Sang; "Lluvias. Promedios anuales obtenidos en las 52 estaciones pluviométricas establecidas en la República O. del Uruguay", Anuario Estadístico 1913–14; Ministerio de Ganadería, Agricultura, y Pesca, *Clasificación*; Travieso, 'Railways'; Inumet, 'Precipitación'; Esri, *ArcGIS Pro*.

geográfico del Uruguay (1900) were used to this effect.[61] Table 1 summarises descriptive statistics for all variables.[62]

We can now try to explain local differences in cattle crossbreeding systematically. The effect of soils, estate sizes, elite ranches, and other variables on cattle herd improvement is estimated through an ordinary least squares (OLS) model in the following form:

$$y_i = Constant + \beta_1 SoilQuality_i + \beta_2 EstateSize_i + \beta_3 EliteRanch_i + \gamma X_i + \varepsilon_i \quad (1)$$

On the left side of equation (1), the dependent variable y_i measures the share (percentage) of cattle that was crossbred in the herds of district i in 1908. On the right side, the main independent

[61] Araújo, *Diccionario geográfico*. All maps in this article were drawn by the author using ArcGIS Pro. GIS shapefiles are available online in the replication package. Historical materials consulted: Dirección de Topografía (hereafter MOP), 'Carta del departamento de Cerro Largo', 1951, CPV266, Archivo Nacional de Planos de Mensura, Ministerio de Transporte y Obras Públicas, Montevideo; 'Carta del departamento de San José', CPV261, Archivo Nacional de Planos de Mensura; MOP, 'Mapa del departamento de Canelones', 1945, CPV265, Archivo Nacional de Planos de Mensura; 'Paysandú: creación de uma nueva sección judicial', Decretor del Poder Ejecutivo, 10/01/1900; Pereda, *Paysandú*, p. 41; 'Secciones Judiciales del Departamento de Montevideo', Planera 31, Mapoteca, Archivo General de la Nación, Montevideo; Instituto Nacional de Colonización, 'Soriano: la obra colonizadora en el departamento', 1900, Colecciones digitales de la Biblioteca Nacional, Montevideo.

[62] All statistical analyses were produced by the author using RStudio. The code is available online in the replication package. Software and packages used: Aphalo, *ggpmisc*; Bivand et al. S*patial data*; Grömping, *Relative*; Hebbali, *olsrr*; Hlavac, *stargazer*; Long, *interactions*; R Core Team, *R*; R Studio Team, *R-Studio*; Solt and Yue, *dotwhiske*r; Wickham, *tidyverse*; Wilke, *cowplot*; idem, *ggtext*; Zeileis and Hothorn, *Diagnostic*.

variables of interest are $SoilQuality_i$, which measures the average soil quality (in CONEAT index, the national average being 100) of district i; $EstateSize_i$, which measures the average size (in hundreds of hectares) of the agricultural holdings in district i in 1908; and $EliteRanch_i$, which measures the share of elite ranches in a district's total estates. X is a vector of control variables, and ε is an error term. Controls include the proxies for topography and climate, market access, and agricultural specialisation listed in table 1.

The soil types summarised in the quality index provide a source of exogenous variation, so we can identify their average causal effect by simply adjusting for topography and other environmental variables that affected soil heterogeneity and could have had an effect of their own on cattle crossbreeding. We would expect soil quality to have a positive effect on crossbreeding, as faster grass growth allows for higher herd turnover rates (because animals gain weight faster), thereby increasing the expected returns to genetic improvement with each generation of crossbreeds' adjustment to local conditions. Even if soils were shown to have a positive effect, it could still be argued that they only affected agricultural innovation through institutions or infrastructure: namely, that areas with better soils determined smaller landholding sizes, attracted a certain kind of rural entrepreneur, or encouraged investment in railways, which then, in turn, were responsible for higher levels of cattle crossbreeding. If this was true, then presumably better institutions or infrastructure in laggard regions could have substituted for the positive impact of soils on innovation adoption. Therefore, if we want to test whether soils impacted crossbreeding adoption directly, we can control for landholding sizes and rural elites as well as for access to markets and patterns of agricultural specialisation. These are all mediator variables which are 'bad controls' from the perspective of identifying the total average causal effect of soils.[63] Still, we include them in some specifications because we are also interested in examining how much of the impact soils had on crossbreeding ran through the indirect paths of institutional, market access, and agricultural specialisation variables.

The effect of estate sizes and elite ranches on cattle crossbreeding is much more difficult to identify. Their variation is endogenous to each other (through latent factors such as local political histories) and to other variables which presumably are also correlated with the outcome at the district level. While arriving at an unbiased estimate of their average causal effect is challenging, we can use our dataset to explore their response to the addition of other factors. Local natural environments can obviously produce confounding bias (they are 'parent' variables of both estate size and rural elites while also affecting the outcome) and, hence, are included in all specifications. Similarly, location advantages in terms of access to consumer markets could also explain landholding patterns, presence of rural elites, and agricultural innovation. Finally, regional patterns of agricultural specialisation (average stocking densities, use of cattle for draft power or for slaughter, etc.) shaped 'optimal' farm sizes and the incentives for elite location as well as the profitability of cattle crossbreeding. With all the controls in place, if we trust the mainstream literature on Uruguay, we would expect estate sizes to have a negative effect on cattle crossbreeding rates. If, instead, revisionists are right, there should be no significant effect, which would also be in line with much of the broader literature on agricultural innovation. Both mainstream and revisionist views would agree on elite ranches having a positive, significant effect.

Expectations for our control variables are less controversial. Among agricultural controls, we would expect stocking rates and steers as share of total cattle to have a positive effect, reflecting preceding specialisation in beef cattle. Sheep crossbreeding (which had been adopted earlier)

[63] Following the 'backdoor' and 'front-door' criteria for controlling confounding bias introduced in Pearl, 'Graphical models'. On mediation and direct causal effects in linear systems, see Pearl, *Causality*, pp. 126–30.

should also be associated with higher rates of cattle improvement, as it is likely that areas where producers saw first-hand the benefits of investing in genetic improvement in one ruminant would be more willing to make the investment on another. On the other hand, the share of oxen in total cattle (a proxy for plough agriculture in a landscape where tractors were an extremely rare sight) should have a negative effect, as they are associated with local specialisation in arable farming and, therefore, with less space for permanent pasture and lower returns to investments in crossbreeding.[64] The sheep-to-cattle ratio would, in principle, have a negative effect, because specialisation in sheep raising, which historiography associates with smaller and poorer producers, would suggest lower benefits to investments in cattle herd improvement.[65] Among geographical controls, we would expect elevation to have a negative effect on crossbreeding, as in Uruguay it is associated with rugged and dry areas, less suitable for cattle rearing. Differences in temperature and yearly rainfall are not particularly large in the dataset, but we would expect the initial diffusion of less hardy purebred or crossbred animals in this open-air grazing system to be made more difficult in areas with excess yearly rainfall and lower temperatures, both leading to mud problems which limit cattle performance.[66] Finally, proximity to railway stations should have a positive effect on cattle crossbreeding, as better transportation allowed for improved market access without animals losing weight on their way to the slaughterhouse, whereas increasing the distance to Montevideo (both the largest domestic market and the main export hub) should have a negative effect on cattle herd improvement.

Table 2 presents the results of the regression analysis; the visualisation in figure 4 facilitates the interpretation of the effects estimated by the full model (column 4 in table 2), which was tested for multicollinearity, heteroskedasticity, and spatial autocorrelation.[67]

The model in the preferred specification explains 60 per cent of the total variance in local cattle crossbreeding rates. While all three predictor variables of interest have a positive impact, only the effect of soil quality is statistically significant. The results in column 1 suggest that local environments accounted, directly or indirectly, for 17 per cent of the variation in cattle crossbreeding rates across Uruguayan districts, with a 10-unit increase in the soil quality index (with values ranging from 50 to 170 and a standard deviation of 30) resulting in an additional 3.3 per cent of cattle being crossbred. Columns 2 and 3 show that the significance and size of this effect was robust to the inclusion of other factors, including proxies for market access and for the other predictors cited in the literature: the scale of estates and the presence of ranching elites. In other words, the effect of soils on cattle improvement did not operate through scale (better land encouraging a landscape of small producers who were more innovative than large ones) or through elites (i.e. better soils attracting 'enlightened' producers, who then had an impact on crossbreeding).

Column 4 additionally suggests that most of the positive effect soil quality had on crossbreeding adoption did not go through the path of agricultural specialisation. These specialisation variables,

[64] By 1908, there were only 290 engines in rural Uruguay (some of them tractors) and about 200 000 plough oxen and horses; *Censo General 1908*, LXX, LXXV; Bertoni, *Energía*, pp. 105–6; Castro Scavone, 'La mecanización'. In the leading crop farming province (Canelones), the district-level share of oxen in 1908 was highly correlated ($r = 0.86$) with the share of ploughs in 1916, when tools were reported at that level; *Estadística Agrícola 1916*, CCXII.

[65] Barrán and Nahum, *Civilización*, pp. 31–2, 133; Millot and Bertino, *Historia económica*, pp. 49, 112–3.

[66] We do not have data on seasonal rainfall variability, for which the expectation would be different, as periods of drought affected crossbred cattle more than other livestock.

[67] All variables had variance inflation factors under 2.6; a studentized Breusch–Pagan test at the 5 per cent level failed to reject the null hypothesis of homoskedasticity; and the Moran's I statistic for the residuals was 0.17. See the replication package for more details.

TABLE 2 Impact of soils, estate size, and elites on cattle crossbreeding at the district level, 1908

	Outcome: cattle crossbred (% of total)					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Soil quality (CONEAT index)	0.327***	0.316***	0.337***	0.241***	0.278***	0.263***
	(0.072)	(0.071)	(0.075)	(0.059)	(0.071)	(0.063)
Average estate size (hectares)		0.002	0.002	0.002	0.009	0.001
		(0.002)	(0.002)	(0.002)	(0.008)	(0.002)
Elite cattle ranches (% of estates)		2.260***	2.165**	0.861	1.038	3.832
		(0.829)	(0.840)	(0.622)	(0.649)	(3.074)
Topography and climate controls	Yes	Yes	Yes	Yes	Yes	Yes
Temperature (°C, yearly average)	8.214***	4.909*	3.437	5.693**	5.433**	5.501**
	(2.727)	(2.888)	(3.534)	(2.726)	(2.740)	(2.733)
Rainfall (mm, yearly average)	−0.022	−0.023	−0.027	−0.003	−0.004	−0.004
	(0.017)	(0.016)	(0.017)	(0.013)	(0.014)	(0.013)
Elevation (MASL, average)	0.045	0.049	0.055	−0.093***	−0.096***	−0.095***
	(0.038)	(0.036)	(0.037)	(0.031)	(0.031)	(0.031)
Market access controls	No	No	Yes	Yes	Yes	Yes
Distance to Montevideo (km)			0.013	−0.026*	−0.025**	−0.024*
			(0.016)	(0.012)	(0.012)	(0.012)
Distance to railway station (km)			0.009	−0.162***	−0.170***	−0.164***
			(0.072)	(0.054)	(0.055)	(0.054)
Agricultural specialisation controls	No	No	No	Yes	Yes	Yes
Stocking rate (LUs per hectare)				4.696	4.410	4.482
				(3.025)	(3.040)	(3.033)
Oxen as share of total cattle (%)				−1.042***	−1.084***	−1.072***
				(0.217)	(0.221)	(0.219)
Steer as share of total cattle (%)				0.612***	0.591***	0.591***
				(0.218)	(0.219)	(0.219)
Sheep:cattle ratio (heads)				2.775***	2.849***	2.811***
				(0.638)	(0.642)	(0.639)
Sheep crossbred (%)				0.188**	0.194***	0.191***
				(0.073)	(0.074)	(0.074)
Interaction terms						
Estate size × soil quality					−0.0001	
					(0.0001)	
Elite ranches × soil quality						−0.027
						(0.027)
Observations	197	197	197	197	197	197
R^2	0.174	0.234	0.237	0.603	0.605	0.605
F Statistic	10.12***	9.66***	7.31***	21.39***	19.92***	19.93***

Notes: MASL, meters above sea level. This table reports OLS estimates of equation (1), where the outcome variable is the percentage of cattle crossbred in 1908. Columns 5 and 6 include interaction terms. Standard errors reported in parentheses. Observations are all Uruguayan rural (or partially rural) court districts (*secciones judiciales*). ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The full dataset is available in table S1.
Sources: see table 1.

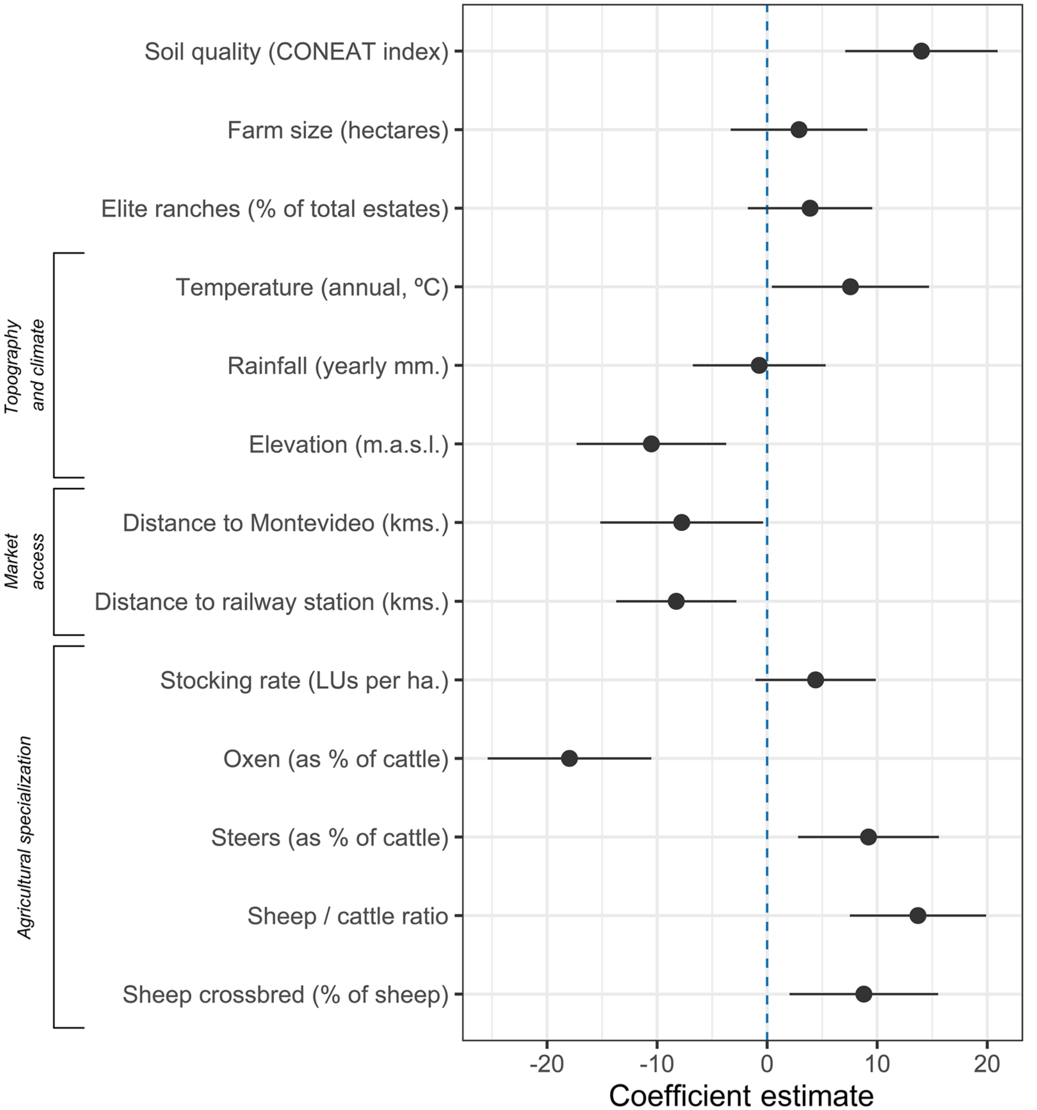


FIGURE 4 Explaining local differences in cattle crossbreeding in Uruguay, 1908 (all rural districts, $n = 197$; $R^2 = 0.6$). *Note:* Results obtained by estimating equation 1 using cattle crossbreeding (% of bovines crossbred) as the dependent variable, as in column 4 of table 2. To facilitate interpretation, the coefficients are rescaled by twice the standard deviation of the variable in the dataset (on this method, see Gelman, 'Scaling'). *Sources*: see table 1 [Colour figure can be viewed at wileyonlinelibrary.com]

which can be seen as 'descendants' of soil types, were also significant predictors of crossbreeding (notably the share of total cattle that were oxen or steers), which is why the magnitude of the impact of soils decreases when they are included. However, the direction and the significance of the coefficient for soils remains, suggesting that they also impacted crossbreeding adoption through more direct mechanisms. It should also be noted that, among the other geographical variables, temperature and elevation regain their significance when agricultural controls are included: ranching specialisation in drier areas was less conducive to the adoption of crossbreeding.

Regarding scale and elites, when all controls were included, estate sizes and the share of elite ranches had no significant effect on cattle crossbreeding adoption at the district level (column 4). Furthermore, neither was the effect of scale and elites on crossbreeding significant when considering their interaction with soils. There was no statistically significant difference in the effect of estate sizes or elite ranches between districts with richer soils and districts with poorer soils (columns 5 and 6).

Among the control variables, the only statistically significant effect which runs contrary to expectations is the sheep-to-cattle ratio. This apparent paradox results from a concave relationship between this ratio and the outcome variable.[68] A plausible explanation is that very high numbers of sheep relative to cattle suggest an almost complete specialisation in sheep, more common in dry interior regions, which correlated negatively with cattle crossbreeding adoption. Meanwhile, medium levels of this ratio suggest the systematic practice of mixed grazing, where sheep were raised alongside cattle; a pasture management system which the local literature has linked to highly productive regions in modernising Uruguay.[69] Contemporary ranching manuals recommended it as a pastoral equivalent of crop rotation, and producers found that raising both species was an effective insurance policy against both disease and climate events, as cattle tolerated excess rain better than sheep, who in turn resisted droughts more effectively.[70] In mixed grazing areas, ovine crossbreeding, which developed earlier than cattle crossbreeding, encouraged higher sheep stocking densities.[71] Drawing from the rural sociology literature, this could be understood as a ‘congruence effect’: a previous innovation in the same domain increasing the likelihood of adopting a further innovation (and a more costly one, in this case).[72] We will return to congruence effects in the next section.

Among market access controls, it should be noted that the effect of railways in the full model was statistically significant and sizable, the implication being that being 10 km farther away from a train station reduced crossbreeding rates by more than 1.5 per cent. This reflects the fact that – as a railway workers’ strike in 1908 revealed – 70 per cent of cattle transportation was done via rail, especially so for improved crossbreeds.[73] While droving, the traditional means of transporting cattle, was still widely practiced on the Uruguayan plains, railway transportation grew in importance for ranchers as crossbreeds began to outnumber Creole cattle: between 1895 and 1904, less than 600 000 cattle per year were transported in trains; between 1905 and 1913, over 1.4 million a year.[74] Greater care in husbandry required greater care in transport so that the animals would not lose the fat and muscle they had developed, while crossbreeds’ shorter horns also facilitated the logistics of railway transportation.

The analysis of a much more disaggregated dataset has shown that, despite historiographical claims, neither estate sizes nor ranching elites were significant predictors of crossbreeding at the district level in Uruguay. Considering this, how can these results contribute to our understanding of what *did* drive innovation in livestock rearing, in modernising Uruguay and beyond?

[68] The coefficient estimate for the quadratic term in the regression (sheep-to-cattle^2) is -0.55, significant at the 5 per cent level; see table S2 in the supplementary materials.

[69] Moraes, ‘Transformaciones rurales’, p. 16. On the technical compatibility of cattle and sheep as grazing partners in pasture-based husbandry, see Phillips, *Cattle behaviour*, pp. 103–4.

[70] Ramos Montero, *Cartilla ganadera*, pp. 25–6.

[71] Barrán and Nahum, *Recuperación*, pp. 171–5; Millot and Bertino, *Historia económica*, pp. 102–8.

[72] For a succinct presentation of this mechanism, see Brandner and Straus, ‘Congruence’.

[73] Barrán and Nahum, *Civilización*, p. 101.

[74] Herranz-Loncán, ‘Railways’; Barrán and Nahum, *Agricultura*, p. 137.

III | PROFITABILITY, CONGRUENCE, AND INTERACTION

To organise the discussion, let us retrace the two main paths that scholars explored to explain agricultural technology adoption in a debate some 60 years ago.[75] The first is the economic incentive route, in which regional differences in expected profitability are what determines the adoption of new livestock or cultigens, or the hybridisation of already known varieties, resulting in crossbred animals, as in our case, or in a hybrid cultigen in the case of Zvi Griliches' classic 1957 study.[76] The key idea was later summarised by Schultz when he argued that if 'differences in profitability are a strong explanatory variable it is not necessary to appeal to differences in personality, education, and social environment' to account for regional variation in agricultural innovation adoption.[77]

Several of the geographical variables in our dataset shaped local profitability scenarios: soil quality, elevation, and temperature were significant predictors of local cattle crossbreeding. Regardless of the presence of elite ranchers in a district or of average landholding sizes, rural producers in modernising Uruguay engaged in crossbreeding where their local environments encouraged it. Fertile soils, warmer winters, and less rugged terrain provided better grass varieties year-round to sustain the larger feed requirements of crossbreeds, especially in winter, avoiding or limiting the need to stock up on additional fodder. Suitable environments made investing in crossbreeding more profitable in the short term, but, as they were associated with higher land prices, they also made it increasingly more necessary.[78] While Uruguay remained land-abundant in global comparison, in the late nineteenth century, land supply was inelastic and relative factor scarcities were changing even faster there than in other settler economies which still had access to an open frontier.[79] Cattle crossbreeding was an efficient land-saving response because crossbreeds could reach their target weight (and thus free up land) faster. Nevertheless, as in other stories of technical change in the countryside, the distinction drawn by the induced innovation hypothesis between (biological) land-enhancing innovations and (mechanical) labour-enhancing innovations was blurred at best in this case.[80] The new crossbred animals increased output per worker as well as per hectare, even if they required slightly more total labour to manage fenced pastures and more carefully control the mating process.[81]

However, geography was by no means the whole story: local differences in expected profitability were also explained by preceding productive choices, which cannot be accounted for just by environmental factors. In areas which had become specialised in arable agriculture, where oxen represented a large share of total cattle, producers did not have an incentive to invest in bovine genetic improvement, because their Creole animals were bred primarily to work, not to be

[75] Olmstead and Rhode, 'Transformation', pp. 716–7; Skinner and Staiger, 'Technology adoption', pp. 547–8.

[76] Griliches, 'Hybrid corn'.

[77] Schultz, *Transforming traditional agriculture*, p. 164.

[78] We lack district-level data on land prices, but there are indications that land prices in Uruguay effectively reflected potential grass growth; see Barrán and Nahum, *Historia Rural II*, p. 171. The comparative literature has explored, in different developing contexts, whether land prices reflected soil quality (and other fundamentals determining present value); see, for example, Carmona and Rosés, 'Land markets'.

[79] Williamson, 'Land'; Bértola, 'A 50 años', p. 142. Regarding changing factor–price ratios in US agriculture, see Olmstead and Rhode, 'Induced innovation.'

[80] The induced innovation model is defined and applied in Hayami and Ruttan, *Agricultural development*. For an insightful critique, see Olmstead and Rhode, *Creating abundance*, pp. 6–10.

[81] Barrán and Nahum, *Historia Rural* I, p. 108. For an authoritative contemporary account of changing ranching routines, see Ramos Montero, *Cartilla ganadera*, p. 21.

slaughtered for their beef. These choices likely resulted in regional differences in social and human capital as well, which we cannot capture with our data but can hypothesise about: farmers in areas with a tradition of crop farming probably lacked the connections to access purebred or crossbreed bulls as well as the know-how to get into the livestock business. Conversely, areas where a large share of cattle were steers (*novillos*: castrated males approximately 18–24 months of age destined for the killing floor) stood to profit greatly from crossbreeding with beef-specialised breeds. With opposite signs in their coefficients, these two variables combined to explain 20 per cent of the local variance in cattle crossbreeding.[82]

The second explanatory path, associated with rural sociologists in the debates in the 1960s, emphasises the social embeddedness of agricultural innovations through ‘congruence’ and ‘interaction’ effects.[83] The influence of previous patterns of behaviour on the likelihood of investing in an innovation – the ‘congruence’ effect – was implicit in Barrán and Nahum’s argument that the ‘possessive rather than dynamic’ mentality of Uruguay’s large landowners, which had been forged over decades marked by political and economic instability, conspired against cattle crossbreeding in large parts of the country.[84] However, in the rural sociology literature, congruence can also be a force working in favour of innovation adoption. This dimension is captured in our data by variables which reflect previous innovations in sheep breeding: the share of crossbred sheep and the ratio of sheep to cattle. While sheep were raised in a range of local environments, both in the more arid northeast and in the well-irrigated western littoral, genetic improvements to increase wool (and, later, mutton) yields did not develop in the same way everywhere. It seems likely that livestock producers who practised mixed grazing (with cattle and sheep sharing the range) and had crossbred sheep themselves, or cattle farmers who had neighbours that raised sheep and had successfully crossbred them, were more inclined to invest in the genetic improvement of cattle. These ‘congruence’ variables account for 13 per cent of local variance in cattle crossbreeding in our model.[85]

Another channel emphasised by rural sociologists is the ‘interaction’ effect: the impact of ‘change agents’, early adopters who, by allowing rural producers to see first-hand the outcome of innovation, make diffusion more likely. If not profitability itself, this mechanism can still change the *perception* farmers have of profitability, which, as Havens and Rogers argued, is ultimately what counts for market responsiveness to lead to agricultural technology adoption.[86] In the literature on Uruguayan rural modernisation, this effect was seen as a spill over from a distinctively entrepreneurial group: *estancieros empresarios* – ‘pioneering’, ‘modern’, or ‘progressive’ ranchers, as they called themselves, in contrast to ‘farms that miserly keep to the character of a time long gone’.[87] Barrán and Nahum’s influential account echoed the self-perception of these producers, often European or of very recent European descent: they were the drivers of change from ‘an extensive, careless, and wasteful’ Uruguayan countryside and towards ‘a more intensive, more rational, and more capitalist’ rural economy.[88] Our data allow us, for the first time, to

[82] The individual contributions of independent variables to R^2 were averaged over orderings among regressors, following Chevan and Sutherland, ‘Hierarchical partitioning’.

[83] See, for an overview, Rogers, *Diffusion of innovations*, pp. 63–6.

[84] Barrán and Nahum, *Civilización*, p. 79.

[85] Regarding the calculation of relative contributions to R^2, see footnote 80.

[86] Havens and Rogers, ‘Adoption’, p. 414.

[87] Barrán and Nahum, *Historia Rural* I, pp. 172–3; Fernández, ‘Prefacio’, p. 5.

[88] Barrán and Nahum, *Historia Rural* I, p. 175.

quantitatively measure the effect of these elite producers, rather than relying on their own accounts of their influence. While the share of elite ranches in a district did have a positive effect on crossbreeding adoption, this relationship worked only through their effects on agricultural specialisation, as elites were more associated with livestock production than with small-scale crop farming. Controlling for agricultural specialisation (column 4 of table 2) significantly reduced the estimated relationship between elites and crossbreeding.

It seems, then, that these elite 'modernising' ranchers overstated their direct influence, and later some historians echoed their narrative. The issue here is not that the 'interaction' mechanism posited by rural sociologists was insignificant, but that communication across the social system of livestock producers was not limited to the spill over effect of rich, self-styled 'progressive' cattle owners in a district, who, if we trust the *Pur-Sang* survey, owned about 18 per cent of crossbred cattle but only 1 per cent of total livestock ranches and farms. Cattle crossbreeding in Uruguay also developed in farms and ranches which did not register their animals with official herd books, which is hardly surprising given how widespread innovation adoption was, involving more than eight million animals over two decades. The vast majority of livestock producers left no written accounts of how they encountered and adopted systematic genetic improvement through crossbreeding, so we lack evidence of these micro-level networks among common cattle farmers.

Selective livestock breeding was, as environmental historians have argued in other contexts, part art and part science, and could be learnt through book knowledge or everyday experience and conversation.[89] While rich breeders could travel abroad or benefit first-hand from veterinary expertise, common producers relied on word of mouth or on the advice they could get from newspapers. For example, letters to the editor of *El Siglo*'s 'countryside section' asked specific questions about how to look after crossbred bulls and received detailed answers:

> Question—I would be grateful if you could answer me this query: I have two bulls in my stable, animals that are for me a considerable capital suffering from foot-and-mouth disease, what must I do to heal them? (signed) A rural man.
>
> Answer—Keep both animals stabled with a good hay bed that you shall change often. Wash their mouth ulcers with antiseptic solutions. There are many useful solutions: here are some you can easily prepare in your estancia, all of them efficient (…) Keep the animals on a light diet of tender fodder and cooked grain.[90]

While it affected more lumpy capital goods than most biological innovations in arable agriculture, cattle crossbreeding in Uruguay was also sensitive to local landscapes, largely scale-neutral, and hinged on a widespread response from producers.[91] However, the slow pace of the process, taking well over two decades to reach its maturity, and its spatial unevenness, should alert us to some important differences with innovations in arable farming in the late nineteenth and twentieth centuries. Technical change in cattle farming can be perhaps more closely compared with tree-crop agriculture, where many biological innovations also face a substantial lag between investment and return: a cow will only start bearing calves when she is about 30 months old, with pregnancy lasting over nine months. In these sectors, biological innovation not only substantially changes

[89] Derry, *Bred for perfection*, pp. 17–47; Woods, *Herds*, pp. 141–64.

[90] *El Siglo*, 31 October 1913, p. 7, in Biblioteca Nacional Newspaper Collection.

[91] Federico, 'Growth', pp. 59–60.

the commodities produced (calves and fruits) but also permanently alters major – often the main – capital goods (cows and bearing trees). As with tree crops, yield increases in cattle raising are far more difficult to measure than in arable agriculture, and hence, the merit of crossbreeding and other innovations is not always easy to prove in the short term.[92] Unlike bearing trees, however, ruminants are, in most countries, spatially dispersed, making sector-wide innovation adoption, particularly genetic change, much slower than would be theoretically possible, even today.[93] The ability of cattle to move, and their affiliative behaviour, also make some risks that can result from attempts at biological innovation (notably infectious disease) even more difficult to contain and isolate than in tree cropping.

IV | CONCLUSIONS

This article has dealt with a traditional question in Uruguayan economic history – why was cattle crossbreeding adopted faster in some parts of Uruguay than in others? – but its answers have wider implications. Breeds themselves are of course entirely a human construct, a case of 'flesh made word', as environmental historian Harriet Ritvo puts it.[94] That being said, cattle and sheep breeds were hugely meaningful for economic actors, and understanding how they were adopted and transformed in landscapes at the forefront of global cattle farming, such as Uruguay in the first globalisation, can teach us something about the economics of technical change in livestock agriculture.

Through a quantitative analysis of agriculture and environments in Uruguay during the first globalisation, the first one at the local level, I took up classic arguments in the specialist economic historiography and attempted to integrate them with (also long-standing) debates in the agricultural innovation literature. I found that the diffusion of cattle crossbreeding in Uruguay hinged upon the widespread market responsiveness of livestock producers of different sizes, rather than on an enlightened minority. Regional divides in adopting this innovation were due to local differences in its expected profitability, shaped by soil conditions and previous productive choices, and not to the alleged risk aversion of very large landowners nor to the lack of entrepreneurial spirit of cattle farmers in 'backward' areas. When they focused on the contrast between 'the small group of progressive breeders' and 'the great mass of producers stuck in their ways', historians were taking elite contemporary voices rather too much at their word.[95]

Part of the literature on agricultural innovation often depicts farmers as having a 'show me' attitude towards technical change, which is, after all, perfectly rational: aware of how circumstantially sensitive most agricultural innovations are, they want to see them at work in a context similar to theirs before committing to them.[96] Livestock producers, like tree crop farmers, have an even greater incentive to maintain such a stance when it comes to biological innovation because the natural processes they deal in simply require much more time to develop than those of arable farming. Wholesale changeovers from one variety or breed to another are not possible within one

[92] Federico, *Feeding the world*, pp. 70–1.

[93] Thornton, 'Livestock production', p. 2858.

[94] Ritvo, *The platypus*, pp. 76–81.

[95] Barrán and Nahum, *Civilización*, p. 85.

[96] Olmstead and Rhode, 'Transformation', p. 716; Evenson and Westphal, 'Technological change', p. 2248; Federico, *Feeding the world*, pp. 103–5.

or two agricultural years. Moreover, if the adoption of a biological innovation goes wrong in cattle rearing, the result can be not just facing the failure of a single 'crop' of calves, but also losing crucial capital goods and compromising the herd for years to come. All of this does not mean that the livestock sector is condemned to relative backwardness, but that technical change cannot be assumed to quickly spread from relatively advanced regions to backward ones. In our own days, the innovations necessary for the livestock sector to transform itself in a carbon-constrained economy can only succeed if enough attention is paid to the very diverse agroecological realities of livestock rearing, including the productive strategies and profitability of pastoralism in increasingly fragile lands of the global periphery.

ACKNOWLEDGEMENTS

I benefitted from discussions at the universities of Barcelona, Cambridge, Carlos III de Madrid, Stellenbosch, and Universidad de la República (Uruguay). I am grateful to my PhD supervisor at Cambridge, Gareth Austin, and to the Cambridge Group for the History of Population and Social Structure. Special thanks are also due to colleagues who commented separately: Nicolás Bonino-Gayoso, Pablo Castro Scavone, Ewout Frankema, Alfonso Herranz-Loncán, Juan Infante-Amate, Dácil Juif, María Inés Moraes, Leigh Shaw-Taylor, Antonio Tena-Junguito, and Henry Willebald. William Travieso provided key advice on sources. I am thankful to editor Giovanni Federico and two anonymous referees from the *Review*, whose suggestions and criticisms were extraordinarily detailed and immensely improved this article. Research funding from the Cambridge International Trust, the Ellen McArthur Fund, and King's College, Cambridge is gratefully acknowledged. All translations are mine, as are all mistakes.

ORCID

Emiliano Travieso https://orcid.org/0000-0002-6692-7680

REFERENCES

Aphalo, P., *ggpmisc: Miscellaneous Extensions to 'ggplot2'*. [software] R package version 0.4.6 (2022).

Araújo, O., *Diccionario geográfico del Uruguay* (Montevideo, 1900).

Armstrong, E. and Postiglioni, A., 'Bovinos y ovinos Criollos del Uruguay', *Agrociencia Uruguay*, 14, 3 (2010), pp. 33–41.

Arocena, C. A., 'La producción de ganados puros y mestizos en el Río de la Plata', *Revista de la Asociación Rural*, XXXVIII, 10 May 1909), pp. 322–33.

Asociación Rural del Uruguay, *Revista de la Asociación Rural del Uruguay*, 1st July 1908, XXXVII, 7.

Asociación Rural del Uruguay, *Criadores del Uruguay: cincuentenario de la fundación de los registros genealógicos de la Asociación Rural del Uruguay* (Montevideo, 1937).

Asociación Rural del Uruguay, *Cien años de la Asociación Rural del Uruguay I: Pensamiento y acción de la Asociación Rural del Uruguay en el siglo XIX* (Montevideo, 1972).

Baldi, G. and Paruelo, J. M., 'Land-use and land cover dynamics in South American temperate grasslands', *Ecology and Society*, 13, 2 (2008), article no. 6.

Barrán, J. P. and Nahum, B., *Historia rural del Uruguay moderno*, vol. I (Montevideo, 1967).

Barrán, J. P. and Nahum, B., *Historia rural del Uruguay moderno*, vol. II. (Montevideo, 1971).

Barrán, J. P. and Nahum, B., *Historia rural del Uruguay moderno III: Recuperación y dependencia, 1895–1904* (Montevideo, 1973).

Barrán, J. P. and Nahum, B., *La civilización ganadera bajo Batlle (1905–1914)* (Montevideo, 1977).

Barrán, J. P. and Nahum, B., *Agricultura, crédito y transporte bajo Batlle (1905–1914)* (Montevideo, 1978).

Barrán, J. P. and Nahum, B., 'Uruguayan rural history', *Hispanic American Historical Review*, 64 (1984), pp. 655–73.

Bauer, A. J., 'Rural Spanish America, 1870–1930', in L. Bethell, ed., *The Cambridge history of Latin America* IV: *c.1870 to 1930* (Cambridge, 1986), pp. 151–86.

Beretta Curi, A., *La industrialización del Uruguay 1870–1925: cinco perspectivas históricas* (Montevideo, 1978).
Beretta Curi, A., 'Los caminos de innovación en el agro: inmigración, redes de agricultores, elites y viticultura en el Uruguay de la modernización (1870–1900)', *Tempos Históricos*, 16, 2 (2012), pp. 41–69.
Bértola, L., *El PBI uruguayo 1870–1936 y otras estimaciones* (Montevideo, 1998).
Bértola, L. 'Primer Batllismo: reflexiones sobre el crecimiento, la crisis y la guerra', in L. Bértola, *Ensayos de historia económica: Uruguay y la región en la economía mundial 1870–1990* (Montevideo, 2000), pp. 167–90.
Bértola, L., 'A 50 años de la curva de Kuznets: crecimiento económico y distribución del ingreso en Uruguay y otras economías de nuevo asentamiento desde 1870', *Investigaciones de Historia Económica*, 1, 3 (2005), pp. 135–76.
Bértola, L., '*El PIB per capita de Uruguay, 1870–2016: una reconstrucción*', Programa de Historia Económica y Social working paper no. 48 (Montevideo, 2016).
Bertoni, R., *Energía y desarrollo: la restricción energética en Uruguay como problema (1882–2000)* (Montevideo, 2011).
Bivand, R. S., Pebesma, E., and Gomez-Rubio, V., *Applied spatial data analysis with R* (New York, 2013).
Bonino-Gayoso, N., Tena-Junguito, A., and Willebald, H., 'Uruguay and the first globalization: on the accuracy of export performance, 1870–1913', *Revista de Historia Economica – Journal of Iberian and Latin American Economic History*, 33, 2 (2015), pp. 287–320.
Brandner, L. and Straus, M. A., 'Congruence versus profitability in the diffusion of hybrid sorghum', *Rural Sociology*, 24 (1959), pp. 381–3.
Bulmer-Thomas, V., *The economic history of Latin America since independence* (3rd edn., Cambridge, 2014).
Caetano, G., *La república batllista* (Montevideo, 2013).
Calvo, J. J., 'Introducción', in J. Bengochea, W. Cabella, J. J. Calvo, M. Fernández Soto, M. Koolhaas, M. Nathan, I. Pardo, A. Pellegrino, and C. Varela, *Detrás de los tres millones: la población uruguaya luego del Censo 2011* (Montevideo, 2013), pp. 9–12.
Carmona, J., and Rosés, J. R., 'Land markets and agrarian backwardness (Spain, 1904–1934)', *European Review of Economic History*, 16 (2012), pp. 74–96.
Castro Scavone, P., 'La mecanización del agro en Uruguay 1908–2010, aplicación de un modelo logístico para medir su trayectoria', *Revista Uruguaya de Historia Económica*, 8, 13 (2018), pp. 9–29.
Cejador y Frauca, J., *Historia de la lengua y literatura castellana*, vol. X (Madrid, 1919).
Chevan, A. and Sutherland M., 'Hierarchical partitioning', *American Statistician*, 45 (1991), pp. 90–96.
Derry, M. E., *Bred for perfection: shorthorn cattle, collies, and Arabian horses since 1800* (Baltimore, 2003).
Díaz Alejandro, C. F., 'Latin America in the 1930s', in R. Thorp, ed., *Latin America in the 1930s: the role of the periphery in world crisis* (1984), pp. 17–49.
Dixon, R., 'Hybrid corn revisited', *Econometrica*, 48 (1980), pp. 1451–61.
Esri Inc. *ArcGis Pro* [software] Version 2.9.0. (2021).
Evenson, R. E. and Westphal, L. E., 'Technological change and technology strategy', in T. N. Srinivasan and J. Behrman, eds., *Handbook of development economics*, vol. 3, part A (Amsterdam, 1995), pp. 2209–99.
Federico, G., *Feeding the world: an economic history of agriculture, 1800–2000* (Princeton, NJ, 2005).
Federico, G., 'Growth, specialization, and organization of world agriculture', in L. Neal and J. G. Williamson, eds., *The Cambridge history of capitalism* II: *The spread of capitalism: from 1848 to the present* (Cambridge, 2014), pp. 47–81.
Fernández, A. H., 'Prefacio', in A. H. Fernández, ed., *Pur-Sang: cabañas y estancias del Uruguay: la ganadería nacional en 1916 y 1917* (Montevideo, 1917), pp. 5–8.
Finch, M. H. J., *A political economy of Uruguay since 1870* (1981).
Florescano, E., ed., *Haciendas, latifundios y plantaciones en América Latina* (Mexico City, 1975).
Food and Agriculture Organization, *Livestock's long shadow: environmental issues and options* (Rome, 2006).
Food and Agriculture Organization, *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities* (Rome, 2013).
Gautreau, P., 'Rethinking the dynamics of woody vegetation in Uruguayan campos, 1800–2000', *Journal of Historical Geography*, 36 (2010), pp. 194–204.
Gelman, A., 'Scaling regression inputs by dividing by two standard deviations', *Statistics in medicine*, 27 (2008), pp. 2865–73.
Graciano, O. F., 'Los caminos de la ciencia: el desarrollo inicial de las ciencias agronómicas y veterinarias en Argentina, 1860–1910', *Signos Históricos*, 6, 12 (2004), pp. 8–36.

Griliches, Z., 'Hybrid corn: an exploration in the economics of technological change', *Econometrica*, 25 (1957), pp. 501–22.

Grömping, U., 'Relative importance for linear regression in R: the package relaimpo', *Journal of Statistical Software*, 17, 1 (2006), pp. 1–27.

Havens, A. E. and Rogers, E. M., 'Adoption of hybrid corn: profitability and the interaction effect', *Rural Sociology*, 26 (1961), pp. 409–14.

Hayami, Y. and Ruttan, V. W., *Agricultural development: an international perspective* (Baltimore, 1985).

Hebbali, A., *olsrr: tools for building OLS regression models* [software], R package version 0.5.2 (2018).

Hereford Herd Book Society, *The herd book of Hereford cattle*, vol. XXIX (Hereford, 1908).

Herranz-Loncán, A., 'The role of railways in export-led growth: the case of Uruguay, 1870–1913', *Economic History of Developing Regions*, 26, 2 (2011), pp. 1–32.

Herrero, M., Gerber, P., Vellinga, T., Garnett, T., Leip, A., Opio, C., Westhoek, H. J., Thornton, P. K., Olesen, J., Hutchings, N., Montgomery, H., Soussana, J.-F., Steinfeld, H., and McAllister, T. A., 'Livestock and greenhouse gas emissions: the importance of getting the numbers right', *Animal Feed Science and Technology*, 166 (2011), pp. 779–82.

Hlavac, M., *stargazer: well-formatted regression and summary statistics tables* [software], R package version 5.2.1 (2018).

Instituto Uruguayo de Meteorología (Inumet), *Estadísticas climatológicas: precipitación media anual* (1961–1990). Available at: https://inumet.gub.uy/clima/estadisticas-climatologicas/caracteristicas-climaticas.

Jacob, R., *Consecuencias sociales del alambramiento (1872–1880)* (Montevideo, 1969).

Lanfranco, B. and Sapriza, G., 'Incidence of the CONEAT index and other quality determinant factors of farmland prices', *Agrociencia*, 14, 2 (2010), pp. 89–102.

Long, J. A., *interactions: comprehensive, user-friendly toolkit for probing interactions* [software], R package version 1.1.0 (2019).

Marchesi, E. and Durán, A., *Suelos del Uruguay* (Montevideo, 1969).

Martínez-Galarraga, J., Rodríguez Miranda, A. and Willebald, H., 'Patterns of regional income distribution in Uruguay (1872–2012): a story of agglomeration, natural resources and public policies', in D. Tirado-Fabregat, M. Badia-Miró, and H. Willebald, eds., *Time and space: Latin American regional development in historical perspective* (London, 2020), pp. 271–307.

McNeill, J. R., 'Energy, population, and environmental change since 1750: entering the anthropocene', in J. R. McNeill and K. Pomeranz, eds., *The Cambridge world history* VII, part 1: *Production, destruction, and connection, 1750–present* (Cambridge, 2015), pp. 51–82.

Miller, S., 'Mexican junkers and capitalist haciendas, 1810–1910: the arable estate and the transition to capitalism between the insurgency and the revolution', *Journal of Latin American Studies*, 22 (1990), pp. 229–63.

Millot, J. and Bertino, M., *Historia económica del Uruguay II: 1860–1910* (Montevideo, 1996).

Moraes, M. I., 'El capitalismo pastor: dinámica tecnológica e institucional de la ganadería uruguaya entre 1870–1930', *Historia Agraria*, 29 (2003), pp. 13–44.

Moraes, M. I., *La pradera perdida: historia y economía del agro uruguayo. Una visión de largo plazo, 1760–1970* (Montevideo, 2008).

Moraes, M. I., '*Las transformaciones rurales en el Uruguay de la segunda mitad del siglo XIX: una síntesis revisada*', in A. Beretta Curi, ed., *Agricultura y modernización, 1840–1930* (Montevideo, 2011), pp. 13–42.

Mörner, M., 'The Spanish American hacienda: a survey of recent research and debate', *Hispanic American Historical Review*, 53 (1973), pp. 183–216.

Olmstead, A. L. and Rhode, P., 'Induced innovation in American agriculture: a reconsideration', *Journal of Political Economy*, 101 (1993), pp. 100–18.

Olmstead, A. L. and Rhode, P. W., 'The transformation of northern agriculture, 1910–1990', in S. L. Engerman and R. E. Gallman, eds., *The Cambridge economic history of the United States* III: *The twentieth century* (New York, 2000), pp. 693–741.

Olmstead, A. L. and Rhode, P. W., *Creating abundance: biological innovation and American agricultural development* (New York, 2008).

Ordoñana, D., 'Memoria pastoril', in D. Ordoñana, *Pensamientos rurales sobre necesidades sociales y económicas de la República*, vol. 1 (Montevideo, 1892), pp. 368–81.

Paruelo, J. M., Jobbágy, E. G., Oesterheld, M., Golluscio, R. A., and Aguiar, M. R., 'The grasslands and steppes of Patagonia and the Río de la Plata plains', in T. T. Veblen, K. R. Young, and A. R. Orme, eds., *The physical geography of South America* (Oxford, 2007), pp. 232–48.

Pearl, J., 'Comment: graphical models, causality and intervention', *Statistical Science*, 8 (1993), pp. 266–9.

Pearl, J., *Causality: models, reasoning, and inference* (2nd edn., New York & Cambridge, 2009).

Pellegrino, A., *La población de Uruguay: breve caracterización demográfica* (Montevideo, 2010).

Pereda, S., *Paysandú y sus progresos* (Montevideo, 1896).

Phillips, C., *Cattle behaviour and welfare* (2nd edn.,Oxford, 2002).

Piñeiro, D., Bianco, M., and Moraes, M. I., *Trabajadores de la esquila: pasado y presente de un oficio rural* (Montevideo, 2003).

Programa de Población, Facultad de Ciencias Sociales, Universidad de la República, *Base de datos sociodemográficos* (Montevideo, 2014).

Quevedo, J. M., *Las epizootias del ganado argentino* (Buenos Aires, 1909).

R Core Team, '*R: a language and environment for statistical computing*', *R Foundation for Statistical Computing* (Vienna, 2019), available at https://www.R-project.org/ (accessed 16 August 2022).

R Studio Team, *RStudio: Integrated Development for R* [software] (version 2022.02.2) (2022).

Rama, Á., 'Prólogo,' in C. Reyles, ed., *El terruño y primitivo* (Montevideo, 1953), pp. vii–xxv.

Ramos Montero, A., *Cartilla ganadera: indicaciones generales más necesarias para organizar una estancia moderna* (Montevideo, 1909).

Reyles, C., *Conferencia del señor Carlos Reyles, leída en Molles con motivo del Congreso Ganadero celebrado en Diciembre de 1908* (Montevideo, 1909).

Ritvo, H., *The platypus and the mermaid, and other figments of the classifying imagination* (Cambridge, Mass., 1997).

Rodríguez, M., Fernández, G., Silveira, C., and Delgado, J., 'Estudio étnico de los bovinos criollos del Uruguay: I. Análisis biométrico', *Archivos de Zootecnia*, 50, 190 (2001), pp. 113–18.

Rodríguez, S., *El Uruguay como país agropecuario. Su desarrollo actual y perspectivas para su futuro* (Montevideo, 1929).

Rogers, E. M., *Diffusion of innovations* (5th edn., New York, 2003).

Sábato, H., *Agrarian capitalism and the world market: Buenos Aires in the pastoral age, 1840–1890* (Albuquerque, 1990).

Sánchez Alonso, B., 'The other Europeans: immigration into Latin America and the international labour market (1870–1930)', *Revista de Historia Económica - Journal of Iberian and Latin American Economic History*, 25 (2007), pp. 395–426.

Schultz, T. W., *Transforming traditional agriculture* (New Haven and London, 1964).

Sesto, C., *La vanguardia ganadera bonaerense, 1856–1900* (Buenos Aires, 2005).

Simm, G., Pollott, G., Mrode R., Houston, R., and Marshall, K., *Genetic improvement of farmed animals* (Wallingford, 2020).

Skinner, J. and Staiger, D., 'Technology adoption from hybrid corn to beta blockers', in Berndt, E. R. and Hulten, C. R., eds., *Hard-to-measure goods and services: essays in honor of Zvi Griliches* (Chicago, 2007), pp. 545–70.

Solt, F. and Yue, H., *dotwhisker: dot-and-whisker plots of regression results* [software], R package version 0.5.0 (2018).

Soriano, A., 'Río de la Plata grasslands', in R. T. Coupland, ed., *Natural grasslands: introduction and western hemisphere* (Amsterdam, 1991), pp. 367–407.

Thornton, P. K., 'Livestock production: recent trends, future prospects', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365 (2010), pp. 2853–67.

Travieso, E., 'Railroads and regional economies in Uruguay, *c.*1910', *Revista Uruguaya de Historia Económica*, VII (2017), pp. 30–57.

Travieso, E., 'United by grass, separated by coal: Uruguay and New Zealand during the first globalization', *Journal of Global History*, 15 (2020), pp. 269–89.

Vanger, M. I., *José Batlle y Ordoñez of Uruguay: the creator of his times: 1902–1907* (Cambridge, Mass., 1963).

Vanger, M. I., *The model country: José Batlle y Ordoñez of Uruguay, 1907–1915* (Hanover, NH, 1980).

Vanger, M. I., *Uruguay's José Batlle y Ordoñez: the determined visionary, 1915–1917* (Boulder, 2010).

Vázquez Franco, G., 'El Uruguay entre la Convención de Paz y los Convenios de Ottawa', *Cuadernos de Marcha*, 4 (1967), pp. 15–40.

Wickham, H., *tidyverse: easily install and load the 'tidyverse'* [software], R package version 1.2.1 (2017).

Wilke, C., *cowplot: streamlined plot theme and plot annotations for 'ggplot2'* [software], R package version 1.1.1. (2020).

Wilke, C., *ggtext: improved text rendering support for 'ggplot2'* [software], R package version 0.1.1 (2020).

Willebald, H. and Juambeltz, J., 'Land frontier expansion in settler economies, 1830–1950: was it a Ricardian process?', in V. Pinilla and H. Willebald, eds., *Agricultural development in the world periphery. a global economic history approach* (2018), pp. 439–66.

Williamson, J. G., 'Real wages, inequality and globalization in Latin America before 1940', *Revista de Historia Económica - Journal of Iberian and Latin American Economic History*, 17, S1 (1999), pp. 101–42.

Williamson, J. G., 'Land, labor, and globalization in the Third World, 1870–1940', *Journal of Economic History*, 62 (2002), pp. 55–85.

Woods, R. J. H., *The herds shot round the world: native breeds and the British Empire, c.1800–1900* (Chapel Hill, 2018).

Yates, P. L., *Forty years of foreign trade* (London, 1959).

Zeileis, A. and Hothorn, T., 'Diagnostic checking in regression relationships', *R News*, 2, 3 (2002), pp. 7–10.

OFFICIAL PUBLICATIONS

Comisión de Inversiones y Desarrollo Económico, *Zonas de uso y manejo de los suelos del Uruguay* (Montevideo, 1967).

Dirección General de Estadística, *Anuario Estadístico de la República Oriental del Uruguay, Censo General de la República en 1908* (Montevideo, 1911).

Dirección General de Estadística, *Anuario Estadístico de la República Oriental del Uruguay 1893* (Montevideo, 1895).

Dirección General de Estadística, *Anuario Estadístico de la República Oriental del Uruguay. Años 1913 y 1914* (Montevideo, 1916).

Instituto Nacional de Investigación Agropecuaria (INIA), *Revisión y análisis de las bases históricas y científicas del uso de la equivalencia ovino-bovino: hacia una nueva equivalencia para ser utilizada en Uruguay* (Montevideo, 2012).

Ministerio de Industrias, Dirección de Agronomía, *Censo General Agropecuario 1930* (Montevideo, 1932).

Ministerio de Agricultura y Pesca, *Clasificación de suelos*. Carta de reconocimiento de suelos del Uruguay, vol. I. (Montevideo, 1976).

Ministerio de Industrias, *Estadística Agrícola Año 1916* (Montevideo, 1917).

United States Department of Agriculture, *Meat situation in the United States, Part I: Statistics of live stock, meat production and consumption, prices, and international trade for many countries* (Washington, DC, 1916).

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Travieso, E., 'Soils, scale, or elites? Biological innovation in Uruguayan cattle farming, 1880–1913', *Economic History Review*, 76 (2023), pp. 498–524. https://doi.org/10.1111/ehr.13196