

# Total Factor Productivity in Agriculture in a small and natural resources abundant economy. The case of Uruguay, 1870s-2010s

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# **Total Factor Productivity in Agriculture in a small and natural resources abundant economy. The case of Uruguay, 1870s-2010s**

Pablo Santiago Castro Scavone(\*) y Henry Willebald(†)

## **Resumen**

Este artículo presenta una estimación de largo plazo de la productividad total de los factores (PTF) del agro uruguayo para el período 1870–2016. A partir de un enfoque de contabilidad del crecimiento y de la construcción de un nuevo conjunto de datos históricos, se obtienen estimaciones homogéneas y consistentes de la PTF del sector agropecuario y de sus principales subsectores: cultivos y ganadería. El análisis sitúa la dinámica de la productividad dentro de la trayectoria general de desarrollo del país, destacando la interacción entre el cambio tecnológico, los arreglos institucionales y la inserción internacional. Los resultados identifican tres patrones de largo plazo interrelacionados: ciclos de modernización asociados a olas de adopción tecnológica e integración externa; prolongados períodos de estancamiento adaptativo, en los que el crecimiento se apoyó principalmente en el uso extensivo de los recursos naturales; y una alternante divergencia sectorial entre cultivos y ganadería, vinculada a regímenes tecnológicos e institucionales diferenciados. En conjunto, la PTF agropecuaria creció a una tasa media anual menor al 1% entre 1870 y 2016, reflejando una trayectoria de innovación discontinua más que un proceso lineal de progreso. Las mejoras en eficiencia se materializaron cuando instituciones, políticas y mercados se articularon de manera coherente, y se estancaron cuando dichas condiciones se debilitaron. Al combinar la medición de la PTF de largo plazo con una interpretación histórica, el trabajo contribuye a una mejor comprensión de los determinantes estructurales de la productividad agrícola y del papel del agro en el desarrollo económico de Uruguay.

Palabras clave:

Clasificación JEL: N56, O13, O33, O47, Q16

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## **Abstract**

This article presents a long-run estimate of total factor productivity (TFP) in Uruguayan agriculture for the period 1870–2016. Drawing on a growth accounting framework and the construction of a new historical dataset, it provides homogeneous and consistent estimates of TFP for the agricultural sector as a whole and for its main subsectors: crops and livestock. The analysis situates productivity dynamics within the broader trajectory of national development, highlighting the interaction between technological change, institutional arrangements, and international integration. The findings identify three interrelated long-term patterns: cycles of modernization associated with waves of technological adoption and external integration; prolonged episodes of adaptive stagnation, during which growth relied primarily on the extensive use of natural resources; and alternating sectoral divergence between crops and livestock, linked to differentiated technological and institutional regimes. Overall, agricultural TFP grew at an average annual rate lower than 1% between 1870 and 2016, reflecting a discontinuous path of innovation rather than a linear process of progress. Efficiency gains materialized when institutions, policies, and markets were coherently aligned, and stalled when such conditions weakened. By combining long-run TFP measurement with historical interpretation, the paper contributes to a deeper understanding of the structural determinants of agricultural productivity and of the role of the agricultural sector in Uruguay's economic development.

Keywords:

JEL Classification: N56, O13, O33, O47, Q16

## 1. Introduction

Uruguay's agriculture has historically been the backbone of the economy, driving growth, providing employment, and generating foreign exchange. Over the long run, the sector has undergone significant transformations, shaped by technological change, institutional arrangements, and shifts in demand, both domestic and external. Understanding how these forces interacted to determine the evolution of productivity is fundamental to interpret Uruguay's economic development as a whole.

The study of Total Factor Productivity (TFP) in agriculture contributes to the interpretation of economic development because it isolates the contribution of technical change and efficiency improvements in the growth of output beyond the increases in inputs. For economies historically dependent on primary exports and based on the exploitation of natural resources, like Uruguay, TFP growth reflects the capacity to sustain economic progress beyond extensive use of land and labour, and to adapt to structural and technological challenges over time.

Despite the central role of agriculture in Uruguay's history, research on the sector's long-term productivity performance remains limited. Many studies focus on recent decades –mostly from the 1990s onwards– (Ceroni et al., 2022; Paolino et al., 2014) and those that look further back rarely extend earlier than the 1960s (Oyhantçabal Benelli, 2019). Much of the literature also emphasizes partial measures of productivity, such as yields per hectare or per worker (Álvarez Scaniello et al., 2024; Álvarez Scaniello, 2014) or considering only a sub-division of the activity (as Moraes, 2001, that only refers to livestock for 1870-1970), rather than comprehensive estimates of TFP that can reveal the underlying dynamics of technical change and efficiency.

This study aims to provide a historical approximation of agricultural TFP in Uruguay over the long run, situating productivity performance within a broader developmental trajectory shaped by deep-seated structural features. Rather than focusing on recent trends, the goal is to uncover the historical processes and deal with some of the structural determinants that have shaped productivity outcomes over time. Such a perspective allows us to better understand the constraints and opportunities faced by Uruguayan agriculture, and its role in the country's long-term economic development.

After this introduction, the paper is structured as follows. In Section 2, we present a literature review considering three major analytical and policy domains related to agricultural TFP: improvements in its measurement, the understanding of technological diffusion mechanisms, and the incorporation of climate change as a structural factor shaping productive trajectories. Then, in Section 3, we provide a historical overview of agriculture in Uruguay, offering the necessary context to formulate our working hypotheses. In Section 4, we present our conceptual framework –based on the standard growth accounting approach– and outlines the empirical strategy used to test those hypotheses. A significant part of our efforts has been devoted to the construction and compilation of a dataset of relevant variables and coefficients, the details of which are described in Section 5. Section 6 discusses the main results, focusing on growth rates of inputs and TFP, contributions, trends and cycles, considering subperiods analytically

relevant, and differentiating between subsectors (livestock and crops). Finally, Section 7 presents some concluding remarks.

This paper makes three main contributions. First, it provides a homogeneous and consistent estimation of TFP for the Uruguayan agricultural sector over the very long run, covering the period 1870–2016. This allows us to overcome the temporal and sectoral fragmentation of the existing literature and to establish a robust benchmark for the historical analysis of productivity. Second, the study disaggregates agricultural TFP into crop and livestock production, making it possible to identify differentiated productivity trajectories, technological regimes, and efficiency dynamics within the agricultural sector. Third, the paper integrates long-run TFP measurement with a historical interpretation, linking quantitative results to technological, institutional, and international integration processes, and thus relating productivity dynamics to key episodes of modernization, stagnation, and reconfiguration in Uruguayan agriculture.

## **2. Literature review**

TFP has become the most appropriate indicator for assessing the performance of the agricultural sector, as it overcomes the limitations of partial indicators such as yield per hectare or output per worker. TFP measures the relationship between total output and a weighted aggregate of the inputs employed in the production –land, labour, capital, and materials– thus offering a comprehensive assessment of efficiency (Kryszak et al., 2021; Koç et al., 2023). In Latin America and the Caribbean, TFP growth has been a key determinant of agricultural expansion and of the generation of income and skilled rural employment. However, recent studies warn that, despite persistent increases in output, productivity dynamics show signs of deceleration and a growing dependence on input-intensive production, raising concerns about the sustainability of the prevailing growth model (Martín-Retortillo et al., 2022; Salazar et al., 2024).

The recent literature identifies three major analytical and policy domains related to agricultural TFP: improvements in its measurement, the understanding of technological diffusion mechanisms, and the incorporation of climate change as a structural factor shaping productive trajectories. These three dimensions intersect, forming a contemporary agenda that seeks to reconcile efficiency, equity, and environmental sustainability in the regional agri-food systems.

The first area, related to productivity measurement, has experienced significant methodological advancements. The traditional growth accounting approach (GAA) remains the most widely used, as it enables international comparability by estimating TFP as the residual between output growth and the growth of a weighted index of inputs, typically computed using Törnqvist or Fisher indices. Nevertheless, this approach relies on assumptions of perfect competition and constant returns to scale that are rarely satisfied (Bureau & Antón, 2022) in Latin American agriculture, which is marked by pronounced structural heterogeneity (Solbrig, 2006). Alternative approaches such as Data Envelopment Analysis (DEA) allow for the estimation of efficiency frontiers without imposing specific functional forms, while Stochastic Frontier Analysis (SFA) provides econometric estimates that distinguish inefficiency from statistical noise (Kryszak et al.,

2021). In contexts as diverse as those of Latin America, methodological choices entail a trade-off between microeconomic precision and macro-regional comparability.

One of the most significant transformations in the recent literature is the incorporation of environmental dimensions into productivity measurement. The traditional concept of TFP, focused solely on marketed outputs, can be insufficient in a context of ecological limits and environmental degradation. This has led to the development of “Green TFP” or “Sustainable Productivity Growth” (SPG), which internalizes environmental impacts and incorporates undesirable outputs such as emissions or waste (Bureau & Antón, 2022; McLaughlin et al., 2024). Methods such as the Luenberger–Hicks–Moorsteen (LHM) productivity indicator and its environmental extensions allow these by-products to be explicitly integrated into performance assessment (Ang & Kerstens, 2017; OECD, 2025). From this perspective, increases in output do not necessarily imply improvements in efficiency if they occur at the expense of ecological deterioration.

Technological heterogeneity and its incorporation into productivity analysis have also gained central importance. Meta-frontier models and related approaches that account for heterogeneous technologies enable the estimation of TFP in settings where different scales and technological levels coexist. In regions where highly capitalized commercial farms operate alongside subsistence-oriented family units, these methods are useful for avoiding biased comparisons (Battese & Rao, 2002; Battese et al., 2004). The recent literature also stresses the relevance of adjusting input measurement for quality changes –particularly for land and fertilizers– and of exploiting panel data to distinguish persistent inefficiency from unobserved heterogeneity (OECD, 2025).

A more precise and comprehensive measurement of TFP is a necessary, though insufficient, condition for improving sectoral performance. Productivity growth depends on the effective diffusion of innovations, a process shaped by institutional, economic, and social factors. Evidence highlights that institutional and regulatory changes are fundamental determinants of productivity, especially in emerging economies where adequate regulatory frameworks can either unlock or constrain growth potential (Kryszak et al., 2021). Two mechanisms have received particular attention: access to modern markets and access to finance. Integration into agro-industrial value chains facilitates technology adoption by providing standards, information, and stable contracts; similarly, credit and agricultural insurance are indispensable for overcoming investment barriers associated with new technologies. Public extension systems and technical services remain central for translating research and development (R&D) efforts into adoption at the farm level (Anderson & Feder, 2007).

Investment in R&D continues to be the main driver of technological progress. However, the literature emphasizes that the expansion of private R&D does not substitute for public research, especially in areas related to public goods or activities with limited commercial profitability, such as technologies for smallholders or marginal areas. Public policy therefore plays a critical role in guiding the spatial and sectoral distribution of R&D spending to avoid reinforcing inequalities (Kryszak et al., 2021; Alston et al., 2010). Access to technology does not guarantee its effective use: human capital and extension services determine the speed and breadth with which innovations translate into

productivity gains. In Latin America, rural educational gaps and the weakness of extension systems continue to constrain this process.

Even when innovation ecosystems function effectively, agricultural TFP faces a structural threat from climate change. Global warming alters temperature and precipitation patterns, reduces water availability, and modifies the incidence of pests and diseases, directly affecting yields. Empirical evidence is strong: anthropogenic climate change has reduced global agricultural TFP by approximately 21% since 1961, and by between 26% and 34% in warmer regions such as Latin America and the Caribbean (Ortiz-Bobea et al., 2021). This accumulated deterioration is equivalent, in productive terms, to the loss of several years of technological progress. In this context, investment in adaptation-oriented R&D –such as the development of resistant varieties, improved water management, or regenerative agricultural practices– becomes an important component of resilience strategies.

Recent literature underscores that the transition toward a sustainable and resilient agriculture requires a comprehensive public policy approach. According to the OECD (2025), this involves combining economic incentives (subsidies for sustainable practices and payments for ecosystem services), investment in knowledge and extension, rural infrastructure, and regulatory frameworks for land use, water, and agrochemicals. Yet the magnitude of the challenge surpasses traditional instruments: although agriculture accounts for more than 20% of global greenhouse gas emissions, it receives only a small fraction of available international climate finance. The mismatch between the sector's contribution to climate change and the resources allocated to mitigation efforts represents one of the most salient tensions on the contemporary agenda: building resilient agrifood systems (FAO, 2021).

The three major areas –measurement, technological diffusion, and climate change– are not separate spheres but interdependent dimensions of a single problem. Accurate productivity measurement is required to identify the true sources of growth and to value environmental services; technological diffusion amplifies the impact of innovation; and climate-change adaptation strategies depend on both. The central challenge for Latin America is therefore to integrate these elements into a coherent strategy that simultaneously promotes economic efficiency, social equity, and environmental sustainability.

Yet, in analytical terms, any examination of these interrelations must begin with a robust and comparable measurement of TFP. Establishing a standard benchmark is not simply a technical exercise: it provides the empirical foundation upon which the influence of technological diffusion can be identified and through which the magnitude and direction of climate-related shocks can be meaningfully assessed. Without a clear baseline, neither refinements in measurement nor broader interpretations of productivity dynamics are possible. Therefore, the first step in this process is the construction of a reliable and comparable TFP metric in the long-run. This is the aim of our paper.

We are not innovating by moving in this direction, as several previous studies have already addressed this issue. In the case of Uruguay, the estimation of TF in the agricultural sector has a number of relevant antecedents, although these remain

fragmented in terms of sectoral coverage, time span, and methodological approaches. Among the earliest systematic contributions, Arancet & Calvete (2003) estimate agricultural TFP for Uruguay over the period 1960–2001. Their results indicate an average TFP growth rate of approximately 1% per year, with marked fluctuations across sub-periods.

From a longer-run perspective, Moraes (2001) provides an estimation of livestock TFP for the period 1870–1970, combining physical and monetary indicators. Her results identify two clearly differentiated phases. Between 1872 and 1908, livestock productivity experienced a phase of rapid growth, with TFP increasing at an annual rate of around 2%, reflecting a period of technological modernization and structural transformation. This phase was followed by a marked slowdown between 1908 and 1930, when TFP growth fell to approximately 0.2% per year, signalling the onset of productivity stagnation. For the subsequent period 1930–1970, Moraes estimates average TFP growth of about 1% per year, which she interprets as a phase of “dynamic stagnation”, characterised by mature technologies, institutional constraints, and limited efficiency gains relative to the earlier expansionary phase.

More recently, Bervejillo & Bertamini (2014) analyse the evolution of agricultural TFP since the mid-20<sup>th</sup> century, stressing the deceleration of productivity growth and the increasing reliance on input-intensive production as key structural features of the sector’s dynamics during the first decades of the 21<sup>st</sup> century.

These national-level studies have been complemented by regional comparative analyses that place Uruguay within the broader Latin American and Caribbean context. Within this framework, comparative exercises report moderate rates of agricultural TFP growth for Uruguay, on the order of 0.2–0.3% per year on average during the second half of 20<sup>th</sup> century and the early 21<sup>st</sup> century, highlighting a relatively favourable performance in regional terms, albeit accompanied by substantial internal heterogeneity (Martín-Retortillo et al., 2022). Nevertheless, the existing literature lacks an integrated and consistent estimation of agricultural TFP disaggregated between crop and livestock production over a very long-run horizon. The present article seeks to contribute to filling this gap by constructing a homogeneous and comparable measure of agricultural TFP for the period 1870–2016, enabling a joint analysis of productive performance, technical change, and their underlying structural determinants.

### **3. Historical overview and working hypotheses**

Uruguay specialized early in the production and export of agricultural goods, a trajectory largely shaped by its favourable geographical endowments, temperate climate, and environmental conditions that supported extensive livestock production. Throughout the 19<sup>th</sup> and 20<sup>th</sup> centuries, livestock –first leather and wool and later meat– constituted the backbone of national production and exports, sustained by the predominance of high-quality natural grasslands across most of the country's productive area. In the 21<sup>st</sup> century, however, the rapid expansion of crop farming and the consolidation of the forestry sector have altered the composition of output by activity, introduced new

technological and organizational paradigms, and contributed to a significant diversification of the export basket.

Agriculture has historically played a pivotal role in Uruguay's long-run economic performance. It has ensured the domestic provision of essential foodstuffs for a growing population, generated key intermediate inputs for agro-industrial processing activities, and supplied the foreign exchange required to finance structural change in the broader economy. The evolution of agricultural productivity –driven by changes in factor use, technological adoption, and institutional arrangements– together with fluctuating patterns of domestic and global demand, has been a central determinant of the pace and direction of Uruguay's economic development since the mid-19<sup>th</sup> century.

Based on recent studies (Álvarez Scaniello et al., 2024; Castro Scavone & Willebald, 2025), in this section we examine the main productive, technological, and institutional transformations of the agricultural sector across three analytically distinct periods: the phase of rural modernization (1870–1930), characterized by the diffusion of new production techniques and the consolidation of the export-led growth model; the long era of dynamic stagnation (1930–1990), marked by reduced technological progress, policy instability, and declining productivity; and the structural reconfiguration of recent decades (1990–2020), during which regulatory reforms, capital-intensive technologies, and new global market relationships reshaped the sector's productive structure. With these elements we elaborate our main working hypotheses.

### ***Rural modernization, boom and crisis of the agro-export model (1860-1930)***

The period between the mid-19<sup>th</sup> century and the early 20<sup>th</sup> century marked a profound transformation of Uruguayan agrarian economy. The expansion of livestock production, the diffusion of new technologies, relevant institutional changes and the growing integration into international markets shaped a model of agro-export growth that delivered substantial productivity gains.

Key innovations –such as fencing, improvements in herd management, the spread of wool sheep, and the consolidation of large estates as “modern” production unities (*estancias*)– enhanced land and labour productivity and helped integrate previously marginal areas into national and global circuits (Barrán & Nahum, 1978). Fencing expanded during the 1870s, particularly under the dictatorship of Lorenzo Latorre (1876–1880). The consolidation of state authority and the introduction of new legislation aimed at promoting private property (Jacob, 1969). Established in 1871, the ARU (*Asociación Rural del Uruguay*) soon emerged as a key actor. The organization was supported by immigrant landowners and by local ranchers connected to commerce and finance, and it played a central role in drafting the 1875 Rural Code and the 1877 law that created the General Office of Trademarks and Signs (Millot & Bertino, 1996).

The articulation with world markets strengthened as external demand for wool, hides, and later refrigerated beef expanded. Technologies such as the railway and refrigeration, alongside the emergence of meat-packing plants, were critical in diversifying and

upgrading exports (Finch, 1981; Bértola, 2000). These developments supported a sustained phase of growth, consistent with the broader pattern of primary-export expansion across the Southern Cone (Bértola & Ocampo, 2012).

Although structural tensions became apparent in the 1920s –linked to supply constraints (restrictions derived from natural grasslands), distributive conflicts (confrontation between urban interests and rural proprietors), and the disruptions of World War I (WWI)– the overall productivity trajectory maintained positive.

In a long-run perspective, the historical evidence suggests that this phase was associated with TFP acceleration driven by both organizational and technological changes in livestock production and relevant institutional transformations.

### ***Continuities and changes in the long period of “dynamic stagnation” (1930–1990)***

The crisis of 1929 led to the breakdown of the agro-export model and the transition toward a new development strategy centred on import-substituting industrialization (ISI). While manufacturing expanded under protectionist policies and state intervention, the agricultural sector experienced a gradual decline in relative priority, limited access to investment, and slower technological upgrading (Finch, 1981; Bértola, 1993).

Livestock systems retained predominantly extensive characteristics, reflecting low incentives for modernization and the persistence of productivity constraints associated to natural grasslands. Price distortions, overvalued exchange rates, and regulatory uncertainty contributed to the sector’s reduced dynamism. In crop agriculture, although improvements in mechanization and input use were observed from the 1940s onward, these did not amount to a structural technological shift comparable to that of other Latin American agro-exporters.

This long phase –from the Great Depression to the early 1990s–has been characterized by the literature as one of “dynamic stagnation”; this is a concept that describes a sector that, despite maintaining an overall low growth rate and being heavily dependent on meat and wool production, underwent significant internal transformations that were insufficient to break the inertia of aggregate stagnation (Bertino et al., 2001). These transformations included the expansion of industrial crops, such as wheat, rice, and sunflower; the consolidation of the dairy sector, characterized by a sustained increase in production and the partial adoption of new technologies; and the extension of fruit cultivation, particularly in regions suitable for citrus and vegetables. Taken together, these changes implied a sectoral restructuring, redistributing relative weights among activities and laying the foundation for future improvements in productivity and diversification, even though overall productivity remained limited.

Consistent with this interpretation, the period is associated with TFP deceleration, reflecting both sectoral disincentives and the slow and disperse incorporation of technological advances.

### ***End of stagnation, commodity super-boom and Second Globalization (1990–2020)***

The reforms of the 1990s, together with a new wave of globalization, reconfigured Uruguay's agro-productive system. Trade liberalization, foreign investment, changes in land tenure, and new regulatory frameworks facilitated the rapid dissemination of modern technologies. The diffusion of no-till farming, the adoption of biotechnology packages, advances in animal genetics, and the consolidation of agro-industrial firms altered production structures and boosted efficiency (Arbeletche et al., 2012).

The rise of soybean cultivation –virtually non-existent before 2000– illustrates the scale of transformation. Driven by global demand and technological upgrading, soybean expansion led to major changes in land use and production intensity. In parallel, the livestock sector incorporated new reproductive technologies, improved pasture management, and mandatory traceability systems, enabling access to high-value export markets.

A decisive turning point came with the passage of Forestry Law No. 15,939 in 1987 and its regulatory decree in 1994. Together, they introduced generous subsidies, tax exemptions, and long-term credit lines synchronized with forest-growth cycles, triggering a rapid expansion of commercial forestry.

These processes coincided with the global commodity super-cycle (2003–2014), which enhanced profitability and encouraged significant investment in machinery, inputs, and infrastructure. As documented by comparative studies on agricultural productivity in Latin America, this period witnessed notable gains in efficiency and technological adoption (Nin-Pratt et al., 2015).

Therefore, the phase 1990–2020 can be characterized by renewed TFP acceleration, supported by structural transformation, technology-intensive production, and deeper integration into international value chains.

#### ***Working hypotheses***

Based on the periodization and the historical evidence, the following hypotheses guide the expected evolution of TFP in the Uruguayan agricultural sector:

H1 (1860–1930): TFP acceleration.

Modernization, frontier expansion, technological adoption, institutional change and improved integration into global markets are expected to have generated important productivity gains.

H2 (1930–1990): TFP deceleration.

Natural grassland constraints, structural distortions, weak incentives for innovation, and the relative neglect of the agricultural sector under ISI likely slowed productivity growth.

H3 (1990–2020): renewed TFP acceleration.

Market liberalization, technological upgrading, biological and agronomic innovations, new entrepreneurial frameworks (agribusiness), and favourable international conditions are expected to have significantly raised TFP.

These hypotheses provide a coherent interpretive framework and align with established research in economic history and agricultural development.

#### 4. Conceptual framework and empirical strategy

To assess the sources of output growth in Uruguayan agriculture over the long run, this paper adopts a growth accounting approach, a widely used framework in economics to disentangle the relative contributions of input accumulation and productivity improvements. The underlying premise is that economic growth can be decomposed into a combination of increased use of production factors –typically land, labour, and capital– and gains in efficiency or technical change, captured residually by TFP.

This approach builds on the neoclassical production function formalized by Solow (1957), where output ( $Y$ ) is a function of inputs ( $X_i$ ) and a residual term ( $A$ ) capturing technological progress:

$$Y_t = A_t \cdot F(X_{1t}, X_{2t}, \dots, X_{nt}) \quad (1)$$

Assuming constant returns to scale and competitive factor markets, output growth can be decomposed as:

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + \sum_i \alpha_i \cdot \frac{\dot{X}_i}{X_i} \quad (2)$$

Where:

$\alpha_i$  denotes the share of input  $i$  in total output. Under this decomposition, TFP growth captures improvements in efficiency, technology, and institutional quality, factors not explained by mere input accumulation.

This method has been widely applied in historical and sectoral studies (see Denison, 1967; Jorgenson & Griliches, 1967; Schultz, 1953; Federico, 2005; Martin-Retortillo et al., 2019) and has proven particularly useful for analysing long-term transformations in agriculture (Hayami & Ruttan, 1985). It can allow for a comparative analysis over time and across countries or sectors, revealing the extent to which agriculture contributed to broader economic development through innovation and productivity gains.

Given the historical focus of this study, particular attention is paid to issues such as changes in factor quality (e.g., land improvement, mechanization, labour skills), the introduction of new technologies, shifts in institutional arrangements, and the availability and consistency of long-run data. These factors are critical to interpret our estimates of TFP, especially in contexts such as Uruguay, where agriculture has played a central, though evolving, role in national development.

Therefore, our empirical strategy proceeds in three successive stages:

- 1) Construction of a dataset that includes variables that represent the output and inputs of equation (1):
  - Output.
  - Land.
  - Labour.
  - Capital.

An additional contribution of our approach is the inclusion of both the overall agricultural activity and its two main sub-sectors: livestock and crop farming. This decision is methodologically relevant, as it entails a greater reconstruction effort, and it also provides new analytical insights into the understanding and interpretation of the subject.

- 2) Estimations of the coefficients of equation (1) ( $\alpha_i$ ) that represents the share of each input in the total output and the weight of each one in the sectorial expansion.
- 3) Calculations of results according to equation (2), considering the entire period and different subperiods analytically useful for our interests. We dealt with three sets of analytical-descriptive outcomes: (i) the main results in terms of rates, contributions –by input and TFP– and subperiods; (ii) the time evolution of TFP series –total, livestock, crops– and the main trend derived directly from the data; (iii) the time evolution TFP series, according to moving 5-years averages rates and the identification of cycles of improving efficiency.

## 5. Dataset and coefficients: compilation and estimates

This section describes the construction of the variables and the methodological procedures adopted when data estimation was necessary. Appendix 1 details the variables used in the TFP estimation, their data sources, and their evolution over the period analysed.

### **Output**

Output in the agricultural sector is proxied by gross value added (GVA). For the economy as a whole, we rely on the sectoral series reconstructed by Bértola et al. (2024), which cover the period 1870–2023. These series are based on Bértola (1998), Bertino & Tajam (1999) and Bértola (2016). While this study provides estimates of aggregate agricultural GVA, it does not offer a disaggregation between crops (cultivation of cereals, vegetables, fruits, and other plant products, except forestry) and livestock (raising of cattle, sheep, pigs, and poultry) sub-sectors.

In order to obtain consistent series for crops and livestock GVA, we used the constant-price series originally employed by the authors –reported in Bértola (1998) and Bertino & Tajam (1999)– to compute the relative shares of each sub-sector in total agricultural GVA. These shares were then applied to aggregate agricultural GVA at constant prices, as reported in Bértola et al. (2024), covering the period 1870–1954.

For the subsequent period (since 1955 onward), data availability is more limited,<sup>1</sup> and we proposed a different estimation method. We calculated shares derived from the value of

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<sup>1</sup> Despite the availability of official data from the National Accounts System.

gross production (VGP) at current prices<sup>2</sup> and then applied these coefficients to the GVA at constant prices reported in Bértola et al. (2024).

Moreover, the estimations are restricted to crop and livestock production, excluding the forestry sector. This choice reflects limitations in the availability of consistent historical information that would allow forestry activities to be integrated homogeneously with the rest of the agricultural sector over the very long run. In particular, the expansion of forestry in Uruguay is a relatively recent phenomenon, associated with specific regulatory frameworks, production arrangements, and new forms of capital accumulation, which complicate its consolidation with the historical series of inputs and output available for crop and livestock production. In this sense, the exclusion of the forestry sector aims to preserve the internal coherence and temporal comparability of the productivity estimates.

### ***Inputs***

**Land.** This input is measured through the reconstruction of the area devoted to crops and livestock. For the year 1872, information on crops land is taken from Castro Scavone (2023), while data on livestock land is obtained from Moraes (2001), which allows us to estimate total agricultural land for that year. In the absence of information for earlier years, we assumed the same figures for 1870-1871.

For subsequent years, we rely on benchmark observations of crops land and total agricultural land drawn from population and agricultural censuses and official statistics. These series are completed using linear interpolation for periods without direct information. Finally, land devoted to livestock production is calculated as the difference between total agricultural land and land allocated to crop production.

**Labour.** The starting point for measuring labour input is the rural economically active population (EAP) series estimated by Araújo et al. (2015), which covers the period 1908–2000 and refers to the agricultural sector as a whole. However, the lack of information for the 19<sup>th</sup> century and the need to obtain separate estimates for crops and livestock required extending and complementing this series. In practice, Uruguay’s census periodicity only began to align with international standards in the 1970s, which led us to change our procedure. Up to 1963, we performed the calculations as detailed below, and from that year onward, we relied on linear interpolations between available census data.

For the first period (1870–1963), our primary sources consist of population and agricultural census data. The agricultural census report presents an estimate of the rural labour force for 1963 (155,845 persons), which differs from the corresponding figure in the population census (183,678), and the latter being adopted as our preferred benchmark. We therefore used the crop and livestock labour shares derived from the agricultural census to allocate workers within the population census framework. The remaining available information corresponds to the 1908 population census, and the main challenge lies in interpolating both series between the two benchmarks (1908 and

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<sup>2</sup> This approach does not present major limitations, as the historical estimates previously employed were already based on fixed coefficients linking GVA and VGP.

1963) in a manner that is both historically and statistically consistent. We begin by constructing the livestock labour series.

We require an indicator that captures, at least partially, the main changes that may have occurred in the sector's labour market. To this end, we consider the ratio of grazing land to livestock stock. Specifically, we assume that employment in livestock activities evolved in line with the relationship between land input and accumulated output, which serves as a broad proxy for the sector's technical coefficient. As the total increase of both indicators differ, we need to re-scale the series totally between 1908 and 1963 and partially previously (assuming an annual difference of one percentage point<sup>3</sup>).

Araújo et al. (2015) present agricultural labour data for 1961, 1956, 1951, 1937, 1916, 1908 and 1900, and we account with an additional figure corresponding to 1874 (Willebald, 2015). As we had estimated livestock labour force, we can calculate, for these years, crops labour force as difference. Then, as before, the challenge lies in interpolating the series between the different benchmarks in a manner that is both historically and statistically consistent. To account, albeit imperfectly, for the main transformations in the crops labour market, we rely on an indicator based on the ratio of arable land to tractorization (represented as the total horsepower destined to agricultural tasks; see below). We posit that employment in crops production followed the evolution of the relationship between land input and (accumulated) machinery input, which we use as an approximate measure of the sector's technical coefficient. Since the periodical growth rates of these two indicators differ, the series must be fully rescaled between the corresponding benchmarks.

Since the 1960s, census population data is available periodically (1966, 1970, 1975, 1980, 1985, 1990), and lineal interpolations renders reasonable results according to our objective. For more recent years, we incorporate annual data on agricultural EAP provided by the Central Bank of Uruguay (BCU) for the periods 1997–2005 and for the years 2012 and 2016. This information makes it possible to estimate agricultural and livestock EAP and to extend the series up to 2016 using linear interpolation for missing years. The same procedure is applied to complete and extend the series for the agricultural sector as a whole, ensuring consistency between sectoral estimates and the aggregate.

**Capital.** Capital input is measured through several components reflecting the productive characteristics of each sub-sector. We constructed indicators associated with livestock capital, fertilizer use, and mechanization. While fertilizer use and mechanization are considered relevant capital inputs for crops production, livestock is characterized using livestock capital and mechanization. The need to build long-run series and the limitations of available information required the use of indirect estimation procedures.

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<sup>3</sup> We proposed this adjustment for reasons of historic consistency. With our adjustment, livestock workers would represent almost two third of total occupation in agriculture in the 19<sup>th</sup> century instead of 90%, which is consistent with we know about the sector (see Barrán & Nahum, 1967; Beretta et al., 2011).

Fertilizer use is measured using observed data on fertilizer consumption in crops production. Information for the period 1948–1960 was kindly provided by the authors of Martín-Retortillo et al. (2022) and is complemented with FAO data, allowing us to construct a continuous and consistent series for the subsequent period.

Livestock capital includes the main components of the livestock sector: cattle and sheep. In order to construct a homogeneous series, we follow the procedure used by Araújo et al. (2015), based on the concept of Livestock Unit (LU), which is widely applied in agricultural economics. This approach allows different animal species to be expressed jointly using equivalence coefficients based on their energy requirements and feed consumption, thus enabling the aggregation of cattle and sheep stocks into a single measure of livestock capital.<sup>4</sup>

Mechanization is proxied by an indirect measure of the traction power available in the agricultural sector over the period 1870–2016. Prior to the diffusion of tractors, machinery traction relied mainly on draft animals, particularly oxen. For the entire period, total traction power is defined as the sum of tractor horsepower and the horsepower attributable to animal traction, assuming an equivalence of 1 oxen = 0.5 HP. The contribution of animal traction declines progressively over time and becomes virtually negligible by the 1980s, while the opposite occurs for mechanical traction associated with tractors.

Since tractor power cannot be directly or uniformly assigned to crop and livestock production, the sectoral allocation of mechanization is constructed using province-level information on land use and tractor horsepower. Specifically, total tractor horsepower by province is combined with a land-use typology that classifies each province as livestock-, dairy-, or crop-specialized. Following Castro Scavone et al. (2012), a province is defined as livestock-specialized when beef-and-wool grazing accounts for at least 75% of total agricultural land; as dairy-specialized when land devoted to dairy reaches at least 15%; and as crop-specialized otherwise (i.e., when grazing does not exceed 75% and dairy does not exceed 15%). For each year, we compute the share of national tractor horsepower located in crop-specialized provinces and, analogously, the share located in livestock-specialized provinces; these shares are then used as annual weights to allocate total traction power between crop and livestock production. This procedure yields sub-sectoral indicators of mechanical capital that consistently capture both the temporal evolution of mechanization and the territorial pattern of productive specialization in Uruguay, and the resulting classification is consistent with the historical characterization of the economy.

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<sup>4</sup> The technical coefficient used to convert livestock stocks into homogeneous units –number of sheep equivalent to one bovine– adopts the values reported in Álvarez Scaniello (2014) for specific benchmark years: coefficients of 5 for 1963, 6 for 1979, 6.34 for 1995, and 6.67 for 2012. For 1937, we considered a coefficient equal to 4, taken directly from the General Agricultural Census (1937). For the period prior to 1937, we adopted the value corresponding to the 1937 census, while linear interpolations between benchmark years are used to construct a complete annual series. This strategy follows the approach applied in previous studies on livestock capital in Uruguay (see Araújo et al., 2015).

## **Weights**

Factor weights in the calculation of TFP represent the relative importance of each production factor in the generation of output and are interpreted as their shares in income. Within the growth accounting framework, these weights reflect the fraction of output that remunerates the different inputs under the assumptions of constant returns to scale and perfect competition; accordingly, they are not technological parameters fixed *ex ante*, but rather magnitudes observed or imputed from the distributive structure of the economy in each period.

When this approach is applied to agricultural output in a historical perspective, additional complications arise that qualify this interpretation. Beyond the limitations and heterogeneity of the sources, measuring and valuing inputs is particularly challenging because, alongside conventional physical capital, production relies on land and on the livestock stock, the latter being a form of biological capital that functions as a “machine” with its own dynamics of accumulation, reproduction, and depreciation. Scarce information on factor remuneration hampers the direct estimation of factor shares, while the importance of family labour and mixed income necessitates non-trivial imputations. These issues are compounded by the conceptual and empirical difficulties associated with land rents and livestock valuation –implicit prices, differential returns, and changes in stock quality– as well as by long-term technological and institutional change. In this context, factor weights should be understood as historically consistent approximations, whose credibility rests on the transparency of the underlying assumptions and their coherence with the available agrarian evidence.

Among the studies referring to Uruguay, we consider primarily two contributions. On the one hand, we followed Moraes (2001), from which we adopted the methodological criteria; on the other, we used Martín-Retortillo et al. (2019) as a quantitative reference. The former is a pioneering study in the calculation of TFP, for the livestock sector, for the times of the First Globalization, and provides a valuable guide for the construction of the data set. The second offers a complete set of factor weights –derived from and adjusted on the basis of Argentine case, taking into account some kind of “*Río de la Plata* pattern” shared by both economies– which we consider appropriate for our exercise. This choice ensures a controlled comparison with previous studies, as well as comparability at the Latin American region level and with benchmarks from other parts of the world. In this respect, a substantial part of our contribution focuses on the period prior to the 1950s–1960s, for which there is a complete absence of TFP estimates for the Uruguayan agricultural sector as a whole.

Initially, we follow the methodological approach proposed by Moraes (2001), who values the inputs of livestock production at three benchmarks (1872, 1908, and 1930) using their monetary returns in 1908: land, livestock stock (cattle and sheep as representative of livestock capital), other capital (one third of which is included, according to an assumption she constructs based on other sources), and labour. Factor weights are then constructed according to the share of each factor in total inputs. We apply the same methodology to crop production, following a similar logic and structure, including: land, other capital and labour. All data and sources are presented in Appendix 2; here we also

contrast with Álvarez Scaniello (2020) who presents an estimation since 1930 onwards which presents several consistencies with our approximation.

With more abundant and updated data and recent accumulation in the field, we extended the estimations to an annual base and for the complete period (1870-2016). We are comfortable with our own estimates until de 1930s but, for the second half of the 20<sup>th</sup> century we found some discrepancies. This reinforces our initial decision to change the reference source and to rely instead on studies that propose an alternative set of factor weights.

From 1950 onwards, we rely on the estimates provided by Martín-Retortillo et al. (2019),<sup>5</sup> which, for the agricultural sector as a whole, consider five inputs: labour, land, livestock, machinery, and chemicals. This situation confronts us with a threefold challenge. First, to ensure consistency between both sets of estimates; second, to disaggregate the estimates at the sectoral level in order to distinguish between livestock and crop activities; and third, to “navigate” the 1930s and 1940s<sup>6</sup> so as to construct plausible estimates.

We matched the inputs in our own estimates with those in Martín-Retortillo et al. (2019). While labour, land, and livestock match naturally, consistency between our category of “other capital” and their inputs of machinery and chemicals is not straightforward. Here we made three decisions: first, to treat “other capital” as corresponding to the aggregate of these two inputs; second, to distinguish between them from 1950 onwards (assigning them equal weights); and third, to identify our category, prior to that date, with a broad concept of machinery.<sup>7</sup>

Whenever our estimates for the agricultural sector as a whole around the early 1950s reach levels similar or close to those of Martín-Retortillo et al. (2019) –as is the case for labour and other capital– we simply combine both series. By contrast, when this is not the case –as for land and capital livestock– we retain our estimates up to 1930 and extend them through the subsequent two decades.

**Labor.** Until 1949, we rely on our own estimates for agriculture, livestock, and crops, after which we adopt the series reported in Martín-Retortillo et al. (2019) for the whole sector. Since 1950 onwards, the weights corresponding to livestock and crops are obtained according to our estimates’ structure applied to Martín-Retortillo et al. (2019)

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<sup>5</sup> The 2019 study covers the period 1950–2008, and the authors have shared with us their updated estimates through 2016.

<sup>6</sup> In the language of index number theory, this would involve “linking” or “splicing” series; in the present case, however, it is necessary to account simultaneously for both trends and underlying input structures.

<sup>7</sup> By this we mean a set of non-biological productive assets and inputs that enhance livestock and crop productivity through improvements in management, infrastructure, and control of the production process, rather than narrowly defined mechanical equipment. This broad concept reflects both the historical nature of technological change in production –characterized by gradual, cumulative innovations– and the lack of a clear statistical or functional distinction between machinery and chemical inputs in early periods. Accordingly, these elements are treated as a single, technologically coherent bundle of capital inputs.

considering the average of the triennial before (the relation between livestock and crops weights and our corresponding total).

**Other capital.** The procedure was basically the same that used for labour, considering our category and the aggregate of machinery and chemicals. Previous to 1950, we assimilated our category to “machinery” and, afterwards, we divided the category into machinery and chemicals.

**Land.** Until 1930, we rely on our own estimates for agriculture, livestock, and crops. Agricultural figures were linearly interpolated between 1930 and 1950, and the corresponding sub-activity weights were obtained following the same procedure as for labour and other capital.

**Livestock capital.** Until 1930, we rely on our own estimates for agriculture and livestock (weight corresponding to crops is zero in this case). Agricultural figures were linearly interpolated between 1930 and 1950, and the corresponding weights for livestock was obtained following the same procedure as before.

The next step is to construct the set of factor weights for the agricultural sector as a whole, as well as separately for livestock and crops, while preserving both trends and structural relationships. By construction, the weights for the agricultural sector in 1870–1930 (our own estimates) and in 1950–2016 (Martín-Retortillo et al., 2019) sum to unity. In contrast, during the 1931–1949 period, when the “splicing” exercises are carried out, an average shortfall of about four percentage points emerges. So, our decision was to proportionally rescale the weights over the period.

Extending the calculation to the sub-sectors poses additional methodological challenges. In a first step, the input structure is modified to reflect production-specific technologies: fertilizers are excluded in livestock activities, and livestock capital is excluded in crop production.

By construction, the sum of sectoral weights equals unity between 1870 and 1930; from that year onward, however, periods alternate in which the sum exceeds or falls short of one. Over the 1931–2016 average, the resulting sum is five percentage points lower for livestock and nine percentage points higher for crops. Accordingly, we proceed in the same way as for the agricultural sector as a whole, proportionally rescaling the weights so as to preserve the underlying structures and maintain long-run trends.

Appendix 2 presents the estimators and an assessment of their historical reliability.

## 6. Results

In this section we present our main results. After we apply equation (2) with our estimates of inputs and weights we present: (i) the main results in terms of rates, contributions –by input and TFP– and subperiods; (ii) description of the time-series of TFP –total, livestock, crops– and the main trends derived directly from the data; (iii) description of the time-series of TFP, according to moving 5-years averages rates and the

identification of cycles of improving efficiency. This section is preceded by a necessary set of limitations and caveats that delineate the critical scope of the analysis.

### ***Limitations and caveats***

The estimation of TFP growth by subperiods entails a well-known methodological challenge: results are highly sensitive to the temporal boundaries selected. In agriculture, this sensitivity is particularly pronounced, as output levels fluctuate sharply due to climatic shocks, agro-sanitary problems, and volatile international prices. As a result, average growth rates calculated for slightly different time windows may diverge substantially.

Moreover, the presence of persistent shocks, structural breaks, and non-linear technological change further complicates the interpretation of TFP dynamics. Short-term variations in yields or input quality may obscure the underlying trend in efficiency, and changes in factor shares can alter the weighting scheme used in index-number approaches.

Nevertheless, we proceed with a periodization of TFP growth rates. The reasons are twofold. First, temporal segmentation facilitates the analysis of long-run productivity dynamics by linking them to identifiable historical phases –such as shifts in land use, technological adoption, or policy regimes– that would be blurred in a single continuous series. Second, this approach enables cross-period and cross-country comparisons that are important for historical understanding, even if the resulting estimates must be interpreted with caution. In this sense, the division into subperiods should not be seen as an attempt to capture short-run fluctuations, but rather as a heuristic device to highlight medium- and long-term patterns of agricultural transformation (our main interest is identifying trends).

### ***Growth rates and contributions***

The adopted periodization is motivated by the need to identify structural changes in productivity trends, avoiding reliance on specific benchmark years and privileging intervals that are sufficiently long to capture long-run dynamics with analytical content. At the same time, the defined subperiods correspond to clearly distinguishable stages of Uruguay's economic development and agricultural production patterns, and display a relatively balanced length, which facilitates comparisons across phases.

The period 1870–1900 is interpreted as representative of the late 19<sup>th</sup> century and of the first major modernizing impulse in Uruguayan agriculture, associated with the consolidation of the agro-export model, the expansion of the productive frontier, and the incorporation of key institutional and technological innovations, particularly in livestock production.

The subperiod 1900–1930 corresponds to the final phase of the classical agro-export model and the period immediately preceding to the Great Depression. It represents a stage of maturation of the productive pattern, characterized by high levels of international integration but also by early signs of exhaustion of the previous

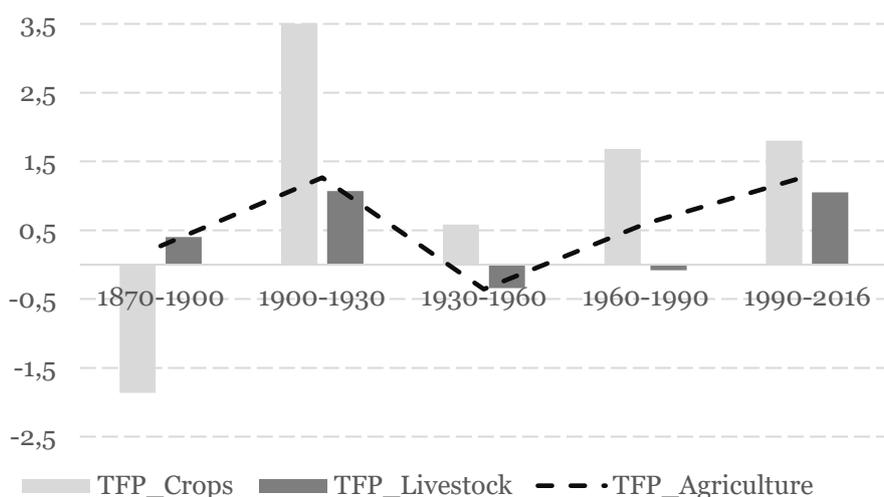
productivity impulses. It is a period that includes, besides, the first great disruption in the international trade of the 20<sup>th</sup> century: the WWI.

The interval 1930–1960 reflects a profound structural change in the Uruguayan economy, marked by the initial collapse of international trade, the reorientation toward the domestic market, and the adoption of the ISI model. In this context, the agricultural sector came to play a subsidiary role within the broader process of structural change, which was reflected in weaker productive dynamics and reduced incentives for innovation.

The period 1960–1990 is associated with the decline of the ISI model and a new phase of structural transition characterized by increasing macroeconomic tensions, productive stagnation, and gradual changes in the organization of agriculture, within a context of partial reforms and a growing, though selective, opening to markets.

Finally, the subperiod 1990–2016 is situated within the framework of the intensification of the Second Globalization, characterized by deeper integration into international markets, pro-market reforms, profound technological and organizational transformations in agriculture, and a renewed productive dynamism, albeit with persistent internal heterogeneity. The decision to close the series in 2016 is not trivial, as it could have been extended to more recent years. However, this cutoff is chosen for two main reasons. First, 2016 is the last year for which homogeneous and comparable information on agricultural labour is available, a prerequisite for the consistent estimation of TFP over the entire period considered. Second, 2016 marks the end of the international commodity supercycle, allowing the analysis to close at a point that represents the exhaustion of an exceptional expansionary phase and avoiding the incorporation of short-term dynamics associated with subsequent shocks.

**Figure 1. Accounting for agriculture TFP: total, livestock and crops, 1870-2016 (percentage per year, %)**



Source: own estimates.

Taken together, this periodization allows the evolution of TFP to be articulated with major shifts in economic, institutional, and productive regimes, while providing a consistent basis for the comparative analysis of different trajectories of growth and stagnation over the long run. In Figure 1 we present the evolution of TFP according to subsectors (livestock and crops) and, in Table 1, we present the variation annual rates corresponding to the total agriculture value-added, each input considered (land, labour, livestock, fertilizers, machinery) and the TFP, as well as the corresponding contributions to the total variation (in percentage points).

The conventional reading of TFP as an indicator of efficiency gains aligns well with what it is known about the sector. Over the entire period, agricultural TFP expanded at an average annual rate of 0.6%, with sectoral rates of 1.3% and 0.4% for crops and livestock, respectively. However, this trajectory was far from uniform over time and across types of production.

**Table 1. Accounting for agriculture growth (percentage per year, %) and contributions (percentage points, pp), 1870-2016**

Year	Output	Land		Labour		Livestock		Fertilizers		Machinery		TFP
	%	%	pp	%	pp	%	pp	%	pp	%	pp	%
1870-1900	2,7	0,4	0,1	1,4	0,3	1,9	0,9			7,7	1,2	0,3
1900-1930	2,1	0,4	0,1	1,7	0,5	0,3	0,1			1,5	0,2	1,3
1930-1960	1,2	0,0	0,0	-0,3	-0,1	-0,4	0,0	9,2	1,0	5,7	0,8	-0,4
1960-1990	0,9	-0,3	-0,1	-0,9	-0,3	0,4	0,1	1,8	0,2	3,0	0,4	0,6
1990-2016	1,2	-0,4	-0,1	-2,7	-1,0	-0,1	0,0	5,8	0,9	1,0	0,1	1,3
<b>1870-2016</b>	<b>1,6</b>	<b>0,0</b>	<b>0,0</b>	<b>-0,2</b>	<b>-0,1</b>	<b>0,5</b>	<b>0,2</b>	<b>3,4</b>	<b>0,4</b>	<b>3,8</b>	<b>0,6</b>	<b>0,6</b>

Source: own calculations.

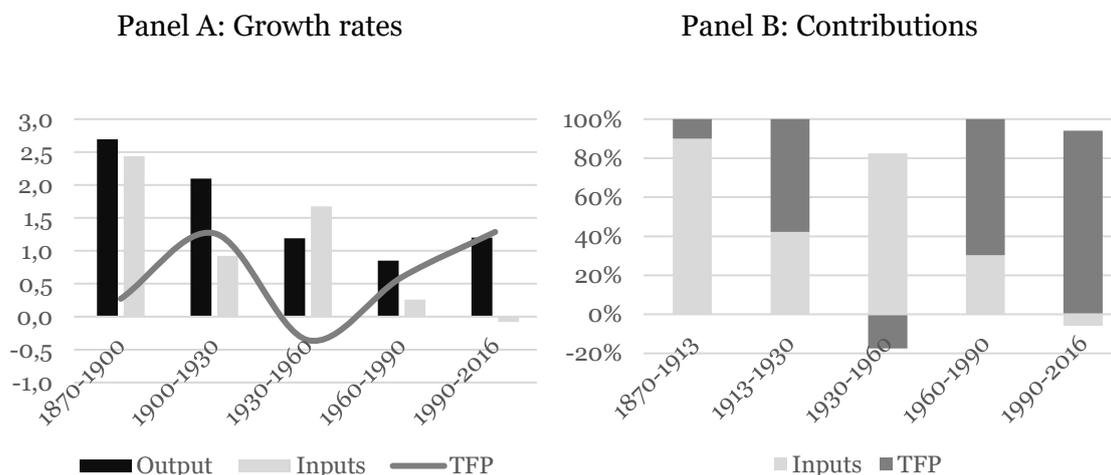
On the other hand, the initial and final subperiods display marked contrasts, though within an articulated long-run logic. The first two subperiods (1870–1900 and 1900–1930) belong to a single cycle associated with the First Globalization and the agro-export model in Latin America, which, although disrupted in the core economies by the WWI, persisted in the region until the Great Depression. Within this cycle, differentiated dynamics can be observed. In the initial phase (1870–1900), agricultural TFP growth was moderate and resulted from contrasting trajectories across subsectors: while livestock production exhibited efficiency gains linked to early international integration, high levels of specialization, and relevant technological advances, crop production showed weaker performance, thereby limiting aggregate productivity growth.

By contrast, during the subperiod 1900–1930, corresponding to the maturation phase of the agro-export model, agricultural TFP accelerated significantly. This performance reflects both the consolidation of earlier gains in livestock and the strong dynamism of crop production, associated with cereal expansion, the adoption of new techniques, higher yields, and a growing articulation between activities.

The phase of agricultural stagnation, extensively examined in the local historiography and spanning from the 1930s to the 1980s, has a clear counterpart in the low rates of efficiency gains, with negative growth rates between 1930 and 1960 (−0.4%) and only marginally positive ones between 1960 and 1990 (+0.6%). Over this long period, a clear contrast emerges between the livestock sector, which recorded negative TFP growth rates, and crop production, which managed to sustain positive and increasing rates.

The final subperiod (1990–2016), framed by the Second Globalization and the most recent commodities supercycle, stands in sharp contrast to the mid-20<sup>th</sup> century experience and represents a renewed break from the earlier stagnation. In this period, efficiency gains and technological change became more generalized across subsectors, resulting in high and relatively balanced rates of TFP growth.

**Figure 2. Accounting for agriculture growth output, inputs and TFP (%), 1870-2016**



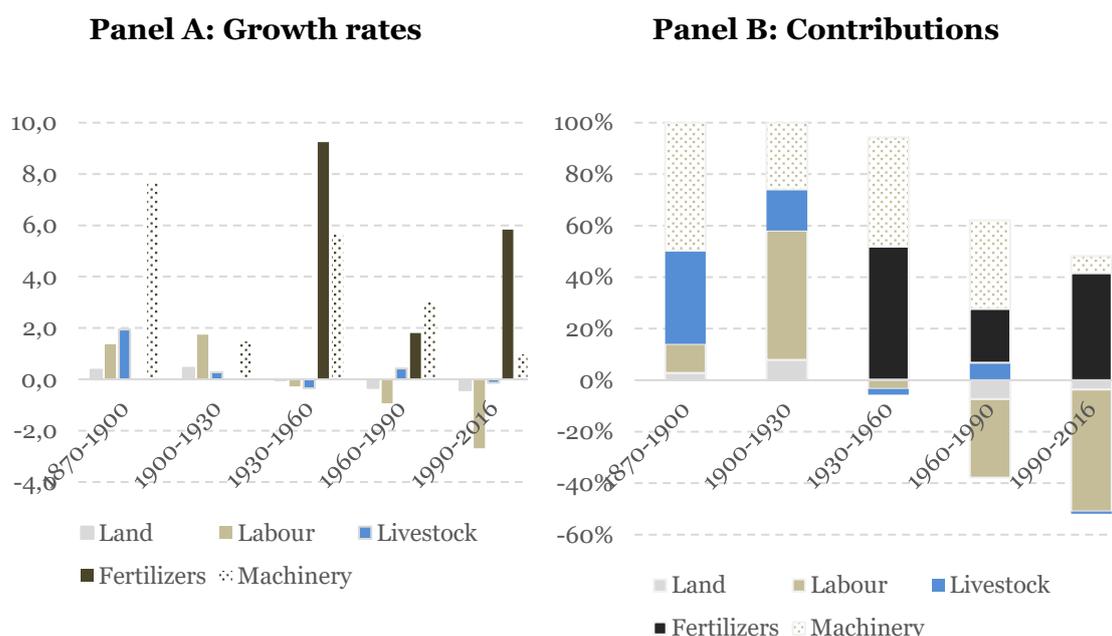
Source: own calculations.

The pronounced deceleration of agriculture was a persistent feature of the Uruguayan economy for more than a century –from the final third of the 19<sup>th</sup> century, when output grew at 2.7% per year, to the 1980s, when production stagnated. This pattern shifted in the 1990s (Figure 2, Panel A), when agricultural output began a sustained recovery, surpassing annual growth rates of 1% and maintaining this trend in the 21<sup>st</sup> century. It is important to underscore that this change in the trajectory of agricultural output was preceded by the recovery of TFP beginning in the 1970s. Indeed, 70% of the sector’s overall expansion resulted from efficiency gains rather than from increased use of inputs (Panel B).

Now we turn to the long-run evolution of agricultural inputs. Uruguay closed its land frontier early, and throughout the 20<sup>th</sup> century the amount of land brought into production was negligible. In the second half of the century, land use even declined as a result of competing uses and urbanization. Labour followed a similar trajectory, although

its decline in both growth rates (Figure 3, Panel A) and contributions (Panel B) was even more pronounced. Livestock was a major input during the agro-export model, but its contribution decreased from the 1930s onward. The counterpart of this process was the persistent positive contribution of machinery and, since the second half of the 20<sup>th</sup> century, the growing use of fertilizers. The contribution of this latter input became particularly relevant in the 21<sup>st</sup> century, when the combination of new technological packages and new crops –especially soybeans– led to a marked increase in fertilizer use.

**Figure 3. Accounting for agriculture growth inputs and contributions (%), 1870-2016**



Source: own calculations.

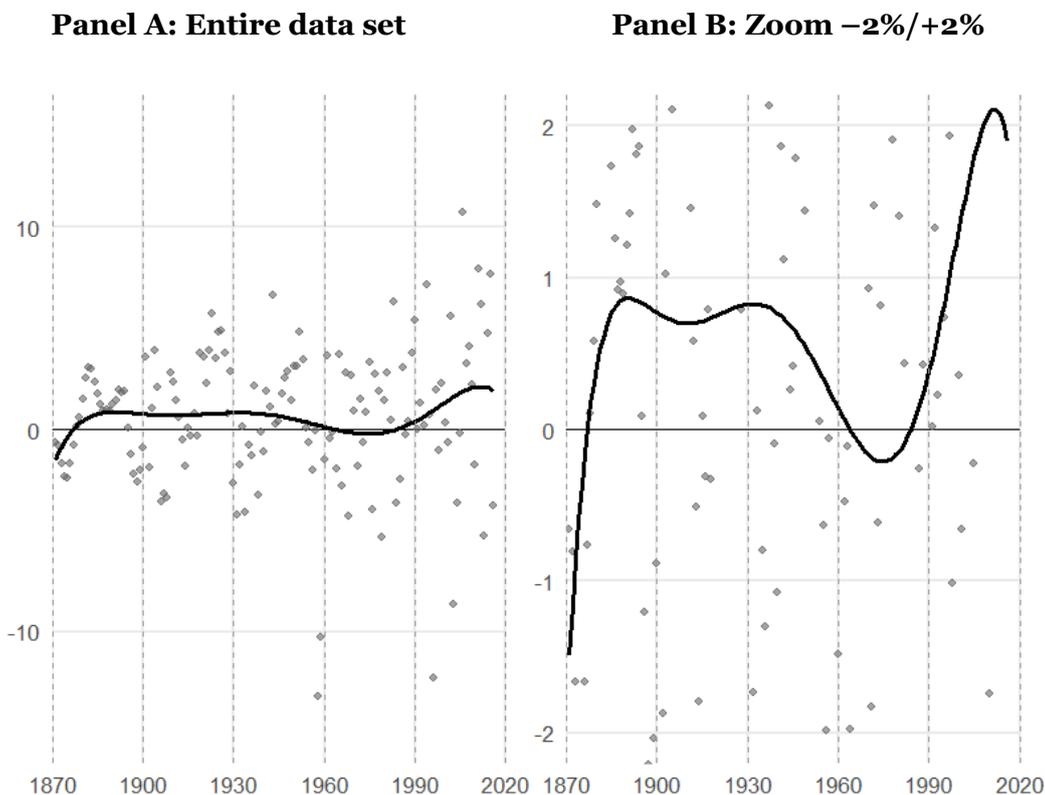
### ***TFP trends (What the data say?)***

One way to overcome the problem of selecting specific years as a reference to evaluate TFP growth is to approximate statistical trends from the data and assess the historical consistency of the resulting trajectories. To do so, we plot the data over time and fit a sixth-degree polynomial function that best captures the underlying trend in the dataset (Figure 4, Panel A). Given the wide dispersion of the data and the likelihood that several observations are outliers, we restrict the range of variation to historically more plausible rates (-2%/+2%) and zoom in on the resulting trend (Panel B).

The fluctuations of TFP in Uruguayan agricultural sector in terms of the efficiency with which labour, capital, and land were combined encapsulate the processes of technological innovation, productive reorganization, and institutional transformation that have defined the national rural economy. Over a century and a half, TFP followed an irregular path, characterized by episodes of rapid advancement and prolonged periods

of stagnation. Its evolution reveals a dynamic that may be described as one of intermittent modernization: phases of technological incorporation and international integration followed by others of low dynamism and extensive adaptation. This pattern resulted in a modest long-term growth trajectory that likely acted as a brake on broader economic development.

**Figure 4. Agriculture TFP. Annual data (%)**



*Source: own data.*

***First modernizing impulse and expansion of technological frontier (ca. 1870–1910)***

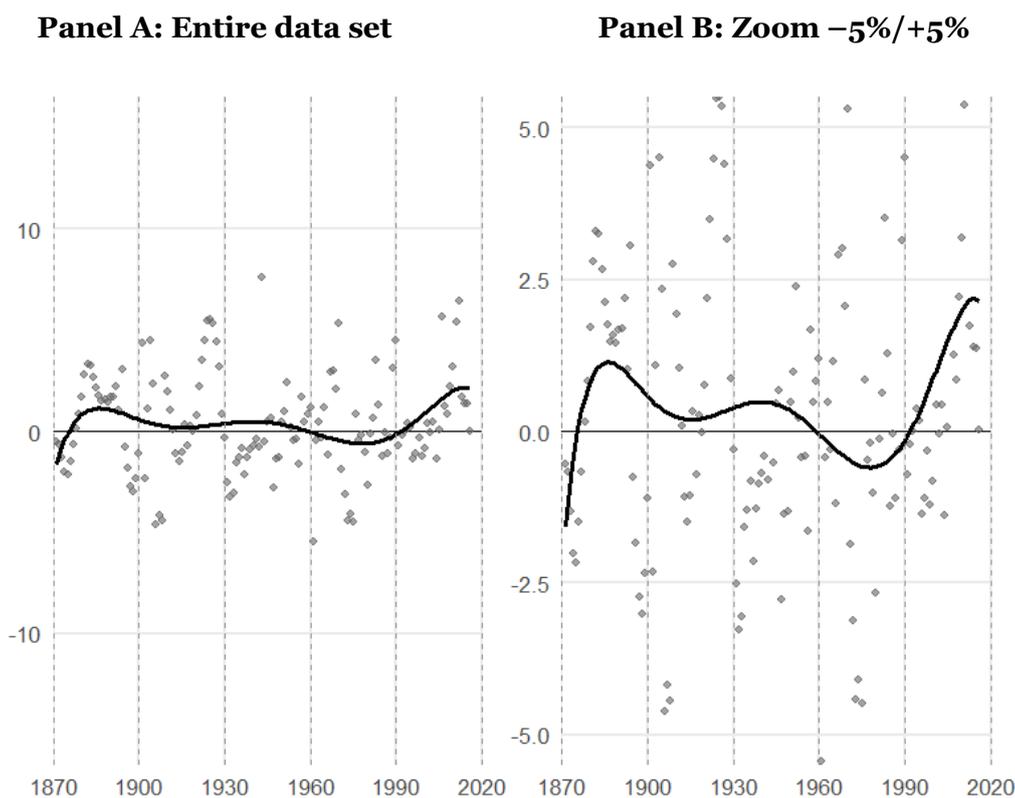
The first major surge in TFP occurred between the late 19<sup>th</sup> and the early 20<sup>th</sup> centuries. Available estimates indicate annual growth rates of around 1 to 1.2 % (averaged over the 1880s–1900s), led by the livestock sector, which acted as the technological and organizational engine of the rural economy as a whole. In this context, the country achieved efficiency levels comparable to other economies on the agrarian periphery.<sup>8</sup>

The productivity cycle responded to the combination of institutional, technical, and market innovations (Moraes, 2001). The consolidation of property rights and the enclosure of land transformed the use of natural resources and enabled a clearer division of rural labour, improved land-use management, and the strengthening of factor

<sup>8</sup> Saini (2016) estimates 1.5% (1910s) and 0.5% (1920s) in Argentina. Robles-Ortiz & Droller (2025) estimate 3% (1890s) and 1% (1900s).

markets. The spread of the “ovine revolution” –based on the introduction of fine breeds in the 1860s– and the articulation between breeders and fatteners in the bovine production latter generated a leap in productivity per hectare and per worker (Millot & Bertino, 1996). The expansion of railway and port infrastructure reduced transport costs and reinforced integration with international markets, where Uruguayan livestock products commanded high prices (Herranz-Loncán, 2011).

**Figure 5. Livestock TFP. Annual data (%)**



Source: own data.

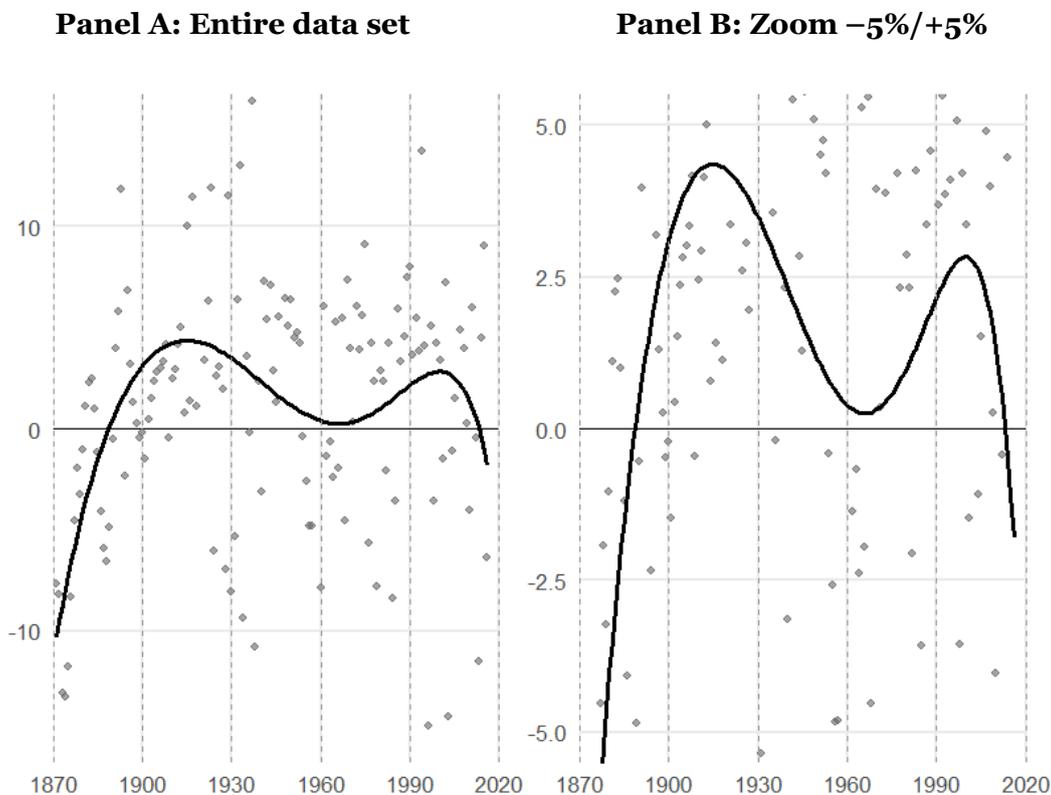
Livestock intensification relied on the more efficient use of natural pastures (Figure 5), without substantially altering the ecological base of the system. Crop farming, by contrast, expanded in area but achieved little improvement in yields; its contribution to overall TFP was thus limited (fundamentally negative; Figure 6). The technological frontier of this cycle was therefore grounded in highly efficient extensive livestock production, organized on large estates, with minimal mechanical traction but with managerial and commercial capacities that allowed it to compete successfully in foreign markets.

***Erosion of dynamism, prolonged stagnation, and decline (ca. 1910–1980)***

Beginning in the 1910s, TFP entered a long phase of weak dynamism, stagnation, and decline, interrupted only by brief sectoral upturns –one of which, in the 1920s, responded to exceptional circumstances, such as the liquidation of cattle stocks and young animals (Bertino et al., 2001). Between the 1910s and the 1980s, average annual

TFP was virtually zero, and even negative in some periods. This long stagnation represents one of the most persistent features of Uruguay's agrarian history.

**Figure 6. Crops TFP. Annual data (%)**



Source: own data.

The exhaustion of the previous impulses had multiple causes. First, the ecological limits of the pastoral model –almost entirely dependent on natural pastures– reduced the scope for further efficiency gains. The expansion of the agricultural area, which could have stimulated productivity growth, faced structural barriers: a highly concentrated land tenure system in a small territory, low investment in physical capital (added to limited financial conditions), and restricted diffusion of modern technology. These constraints quickly dissipated the modest dynamism observed in crop farming in the 1940s and 1950s. The development of dairy farming generated temporary improvements in productive efficiency, representing a potentially virtuous articulation between livestock and crop farming during the 1950s and 1960s, but its dynamism never permeated the sector as a whole.

Second, the international context became less favourable. WWI, the 1929 crisis, and the disintegration of global trade weakened the incentives for modernization. Domestic economic policies, in turn, reinforced the orientation toward the domestic market and transferred resources from agriculture to industry and urban sectors (Bértola, 1991; Jacob, 1981). This bias translated into lower investment and, probably, a gradual obsolescence of agricultural capital. The Korean War and the temporary improvement in

terms of trade of the 1950s briefly halted the decline in profitability of the livestock sector; yet, once the commodity boom subsided, structural trends reasserted themselves.

However, stagnation did not imply immobility. Aggregate TFP conceals a marked alternation between subsectors. While livestock production remained anchored in extensive, low-innovation systems, crop farming gradually incorporated industrial crops and higher levels of mechanization, particularly from the 1940s onward. The coexistence of divergent trajectories –one livestock-based, reliant on the exploitation of natural resources, and another agriculture, based on crops, driven by domestic demand and import-substitution policies– underpins much of the notion of “dynamic stagnation” previously discussed.

During the middle decades of the 20<sup>th</sup> century, the livestock sector partially improved its productivity through the incipient adoption of improved pastures and the modernization of meat-processing plants. Nevertheless, these advances were insufficient to offset the loss of international competitiveness. Overall agricultural productivity remained stagnant: output growth was explained almost entirely by the expansion of inputs –capital and labour– rather than by efficiency gains (see Figure 2, Panel B). Although by the 1960s there were signs of the emergence and gradual articulation of an agricultural innovation system, it had no significant impact on the sector at the time; a couple of decades would pass before such effects became tangible (Álvarez Scaniello et al., 2024).

### ***Intensification of the Second Globalization, modernization, and the productivity leap (1980s–2010s)***

During the 1980s, the first signs of structural change became evident. Following the crisis of the 1960s and the process of economic liberalization of the 1970s, agricultural policy began to reorient toward productive efficiency and trade openness. Reforms in relative prices, market deregulation, and the reduction of state intervention created a new incentive framework. Although the immediate impact on TFP was modest, the institutional and technological foundations for subsequent recovery were established.

The creation and consolidation of scientific and technical organizations—such as *Plan Agropecuario* and the *Instituto Nacional de Investigaciones Agropecuarias* (INIA)—strengthened the agricultural innovation system. These institutions promoted the adoption of improved pasture technologies, animal genetics, and specialized agricultural mechanization. By the early 1990s, the sector was beginning to organize itself around a more business-oriented vision, focused on productivity and export competitiveness.

During these years, TFP displayed a gradual recovery, associated mainly with growth in beef cattle production and rice cultivation –two subsectors with demonstrable technical progress. The transition, however, was gradual and uneven: modernization coexisted with extensive systems that preserved traditional practices.

From the early 1990s onward, Uruguay’s agricultural TFP experienced its most significant expansion since the modernization of the 19<sup>th</sup> century (Figure 5). Average annual growth rates again approached 1 % for the sector as a whole, reaching historically high levels in cropping (around 2%) and livestock (close to 1%). The change was not

cyclical but structural: it involved a profound transformation in the technological base, business organization, and international integration of the sector.

Three processes explain this leap. First, the widespread adoption of practices and techniques near the technological frontier –no-till planting, fertilization, chemical weed control, animal genetics, and intensive pasture management– produced substantial efficiency gains. Second, the expansion of forestry and rainfed crops diversified the productive structure, reducing dependence on extensive livestock production and introducing “new ways of doing things”. Third, the growing articulation with agribusiness and the sustained inflow of foreign investment contributed capital, knowledge, and scale.

Public policy played an enabling role: trade liberalization, the elimination of export taxes, investment promotion, and macroeconomic stability facilitated the renewal of productive capital. At the same time, the maturity of the science and technology system expanded the diffusion of applied knowledge. Producers adopted increasingly sophisticated business practices, including financial planning and risk management.

In livestock production, improvements in animal health and the opening of new markets –together with the growing use of feedlots and cultivated pasture– raised the sector’s overall productivity. In cropping, the expansion of soybeans as the dominant crop transformed patterns of rotation and mechanization, generating remarkable gains in labour and capital productivity.

TFP thus reflected a process of generalized modernization, albeit not without costs: greater land concentration, the displacement of family producers, and rising environmental pressures (Álvarez Scaniello et al., 2024). The productivity surge was driven by the intensification of input use and by deep organizational changes toward network-based production systems reliant on leasing and outsourcing.

It is worth noting that, following the boom of the early 21<sup>st</sup> century, TFP has shown signs of inflection. Since the second half of the 2010s, growth rates have slowed and, in some years, turned negative (more notorious in crops). This does not imply a return to structural stagnation but rather signals the limits of the previous expansion.

In livestock production, the persistence of natural grazing as the primary feeding base for most farms constrains further productivity gains. Modernization is concentrated among a minority of producers adopting advanced management technologies. In cropping, the expansion of soybeans has reached a ceiling due to soil, rotation, and profitability constraints; the decline in international prices after the commodities supercycle reduced investment incentives. Forestry, although maintaining high efficiency, exhibits diminishing marginal returns and reduced employment generation.

Technological heterogeneity has become a structural feature: high-productivity systems coexist with others displaying minimal innovation. This translates into more volatile TFP, increasingly sensitive to international prices and climatic conditions. The recent phase suggests that Uruguay’s agricultural challenge no longer lies in adopting available technologies but rather in ensuring their sustainability and in strengthening the institutional capacity for broad-based diffusion.

### ***TFP trends and cycles (what the data say if we define moving averages?)***

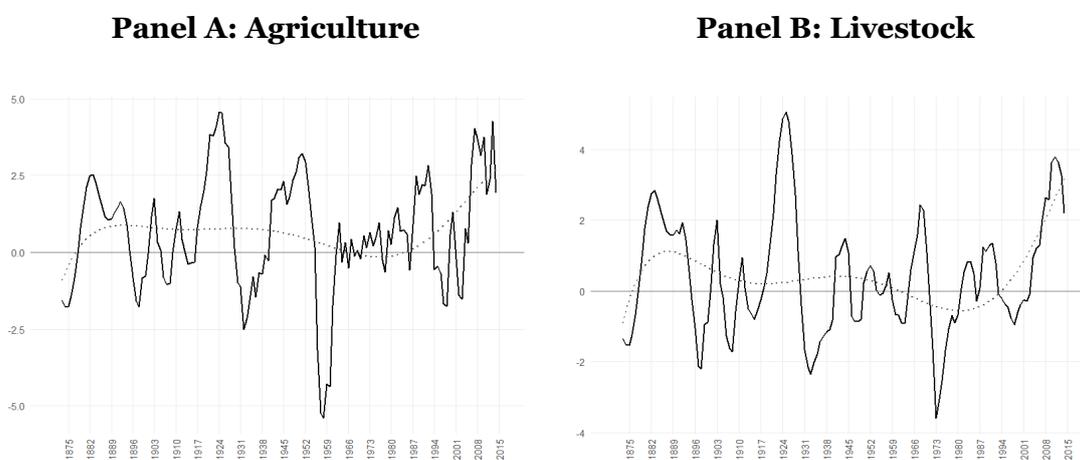
Now, we present a periodization of TFP growth rates based on five-year moving averages. As noted earlier, we acknowledge that defining discrete periods is problematic, but we rely on several considerations to support this choice. First, temporal segmentation helps to analyse long-run productivity dynamics by linking them to identifiable historical phases –such as shifts in land use, technological adoption, or policy regimes– and to cycles inherent to a particularly volatile economic activity. Second, this approach allows for cross-period (and potentially cross-country) comparisons that are valuable for historical interpretation, even if the resulting estimates must be treated with caution.

### ***Long-run patterns of productivity: volatility, stagnation, and structural change***

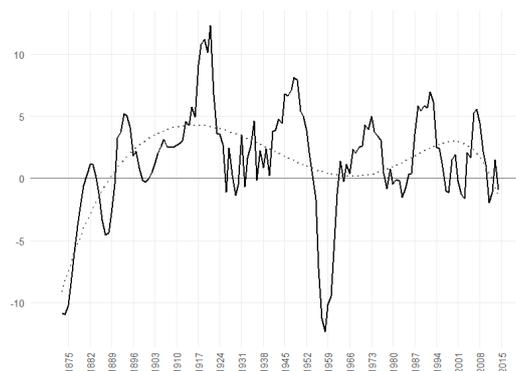
The long-run trajectories of agriculture, livestock, and crop TFP in Uruguay reveal a configuration consistent with broader international patterns of agricultural development: strong cyclical volatility, limited trend growth for most of the 20<sup>th</sup> century (Martín-Retortillo et al., 2022), and a marked acceleration beginning in the early 21<sup>st</sup> century (Salazar et al., 2024).

The pronounced short-term fluctuations evident in all three series –particularly in crops– are fully aligned with the sensitivity of primary-export economies to climatic shocks and global commodity cycles, a feature well documented in the structuralist literature (Díaz Alejandro, 1970; Bértola & Ocampo, 2012). Trend estimates indicate modest efficiency gains between the 1870s and the early decades of the 20<sup>th</sup> century, followed by a prolonged phase of stagnation stretching from the 1910s to the 1980s. This trajectory mirrors the “long stagnation” identified for much of Latin America, shaped by institutional rigidities, limited technological upgrading, and the constraints associated with extensive livestock systems (Solbrig, 2006).

**Figure 7. Accounting for agriculture, livestock and crops TFP. 5-years moving averages and trends (%)**



### Panel C: Crops



Source: own data.

### ***Sectoral contrasts and technological regimes***

The divergence between livestock and crop TFP underscores the structural heterogeneity of Uruguay's agrarian economy. Crop productivity exhibits sharp surges at moments of rapid technological adoption –such as the diffusion of mechanization and improved seeds<sup>9</sup> during the early 20<sup>th</sup> century and, later, the incorporation of no-till practices, biotechnology, and modern input packages after the 1980s –consistent with global evidence on the transformative impact of modern agronomic technologies (Evenson & Gollin, 2003; Fuglie, 2012; Fuglie & Rada, 2018). Livestock productivity, in contrast, evolves through more gradual but persistent improvements related to genetic upgrading, pasture and forage management, health interventions, and feed technologies, reflecting the incremental nature of innovation in pastoral systems described in cross-country evidence (Nin-Pratt et al., 2015). Major troughs in TFP during the 1930s, 1950s and 1970s correspond to episodes of severe droughts, health crises, adverse terms-of-trade movements, and macroeconomic instability, all of which match the timing of shocks documented for Uruguay and the Southern Cone (Bértola, 2008).

### ***A structural break in the 21<sup>st</sup> century***

Across all three series (although shorter in crops), the most striking empirical regularity is the emergence of a clear structural break in the early 2000s. From this point onward, TFP growth turns decisively positive, becomes more synchronous across sectors, and displays fewer deep negative deviations. This shift aligns with Uruguay's transition toward a more knowledge-intensive and technology-rich agricultural model, marked by the increasing adoption of biotechnology, improved genetic and nutritional technologies in livestock, enhanced management practices, efficiency gains from better input use, and

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<sup>9</sup> The *Instituto Fitotécnico y Semillero Nacional* (National Institute of Phytotechnics and Seed), established in 1914 in La Estanzuela, Uruguay, later formalized as an organization by legislation in 1919, was the principal state research center for crop improvement and seed production, and served as the institutional precursor to the modern National Institute of Agricultural Research (INIA).

organizational changes associated with scale, contract farming, and foreign investment. These transformations fit well within broader global assessments of a new phase of agricultural modernization driven by technological intensification and institutional innovation (OECD, 2025; Fuglie & Rada, 2018). Overall, the evidence would suggest that Uruguay has moved from a century-long equilibrium of volatility and stagnation toward a new regime of sustained productivity growth, in line with international experiences of agricultural systems undergoing rapid modernization.

## **7 Final remarks**

From a secular perspective, the trajectory of agricultural TFP in Uruguay can be summarized in three interrelated patterns.

First, the existence of modernization cycles, in which productivity accelerates rapidly through the convergence of technological innovation, external integration, and institutional change. These episodes –at the end of the 19<sup>th</sup> century and during the final decades of the 20<sup>th</sup> century– redefined the efficiency frontier and laid the foundations for new productive equilibria.

Second, the presence of long periods of adaptive stagnation, during which the sector maintained its export relevance through the extensive exploitation of natural resources and the preservation of certain organizational arrangements that balanced domestic supply with external insertion, but without significant efficiency gains.

Third, an underlying tendency toward sectoral diversity, where the unequal diffusion of technology, the persistence of concentrated agrarian structures, and environmental conditions have constrained the sustained expansion of total productivity.

Taken together, TFP grew at an average annual rate lower than 1 percent between 1870 and 2016. This figure encapsulates a history of discontinuous innovation and institutional resilience. Uruguayan agriculture proved capable of reinventing itself in changing contexts, yet its advances consistently faced constraints derived from agrarian structure, dependence on natural resources, and the volatility of international prices. Technical efficiency advanced when institutions, policies, and markets aligned; it stagnated when these conditions became disarticulated.

Rather than a linear trajectory of progress or backwardness, the evolution of TFP reveals a pattern of intermittent learning: a process in which modernization unfolds in waves, each redefining the limits of productivity and reshaping the foundations of long-term agricultural growth.

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## Appendix 1. Variables used in TFP calculation

**Table A.1 Description of variables used for TFP estimation**

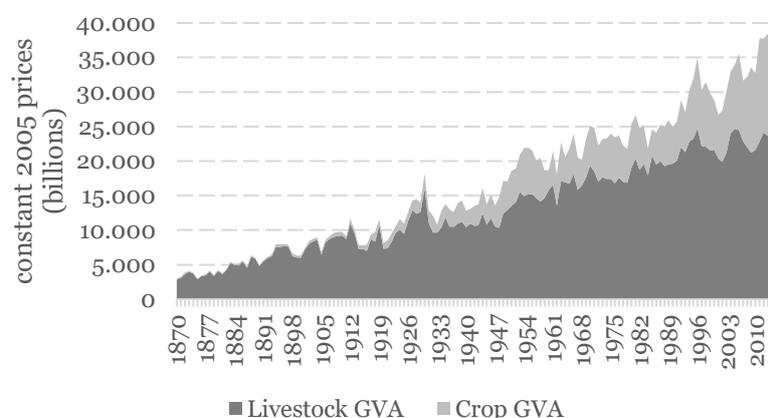
Sector	Category	Variable	Construction method	Source
Crops	Output	Crop GVA (constant prices)	Observed data weighted by the crop share	Bértola et al. (2024)
	Land	Land used for crops (ha)	Observed data and linear interpolations	Castro Scavone (2023); AE (1892, 1900); Nahum (2007); FAO (several years)
	Labour	Economically active population (EAP) in crops	Observed data and linear interpolations	Our estimates for 1870–1963; BCU (1997–2005, 2012, 2016)
	Capital	Fertilizers (since 1948)	Observed data	Martín-Retortillo et al. (2022); FAO (several years)
		Machinery	Traction power (HP) of oxen and tractors, weighted by the crop share	Castro et al. (2012)
Livestock	Output	Livestock GVA (constant prices)	Observed data weighted by the livestock share	Bértola et al. (2024)
	Land	Land used for livestock (ha)	Difference between total agricultural land and crops land	Castro Scavone (2023); AE (1892, 1900); Nahum (2007); FAO (several years)
	Labour	Economically active population (EAP) in livestock	Observed data and linear interpolations	Our estimates for 1870–1963; BCU (1997–2005, 2012, 2016)
	Capital	Livestock stock	Livestock Units (cattle and sheep)	National Census (1860); AE (1884, 1890, 1895); Nahum (2007); FAO (several years)

		Machinery	Traction power (HP) of oxen and tractors, weighted by the livestock share	Castro et al. (2012)
Agricultural sector	Output	Agricultural GVA (constant prices)	Observed data	Bértola et al. (2024)
	Land	Total agricultural land (ha)	Observed data and linear interpolations	AE (1900); CGA (1908, 1916, 1924, 1937, 1943, 1951, 1966, 1970, 1980, 1990, 2000 and 2010)
	Labour	Economically active population (EAP) in agriculture	Observed data and linear interpolations	Araújo et al. (2015); BCU (1997–2005, 2012, 2016)
	Capital	Fertilizers (since 1948)	Observed data	Martín-Retortillo et al. (2022); FAO (several years)
		Livestock stock	Livestock Units (cattle and sheep)	National Census (1860); AE (1884, 1890, 1895); Nahum (2007); FAO (several years)
		Machinery	Traction power (HP) of oxen and tractors	National Census (1860); AE (1884, 1890, 1895); Nahum (2007); FAO (several years); Castro Scavone (2018)

In what follows, we present the evolution of the variables to offer a clearer picture of their respective trajectories over time.

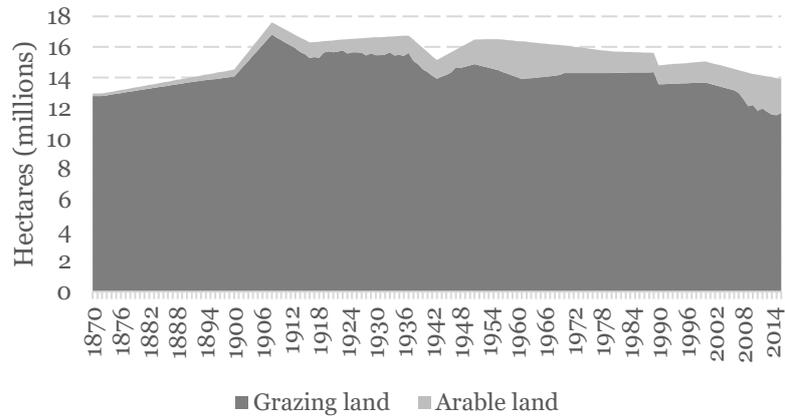
**Figure A.1 Evolution of inputs and output**

**Panel A. Gross Value Added (GVA) in Agriculture**



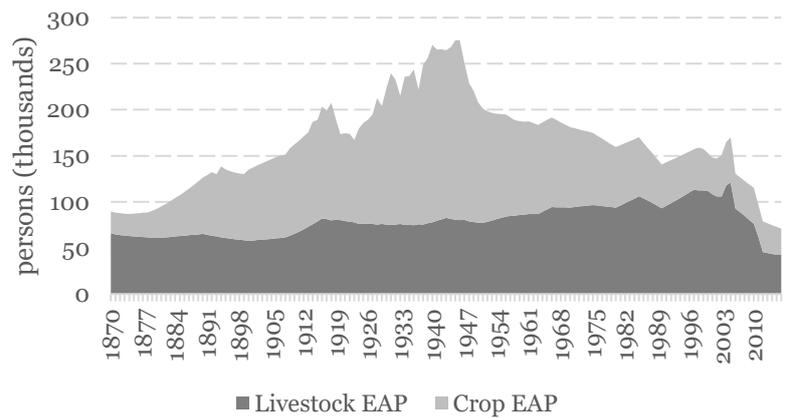
Source: own estimates.

### Panel B. Land used in Agriculture



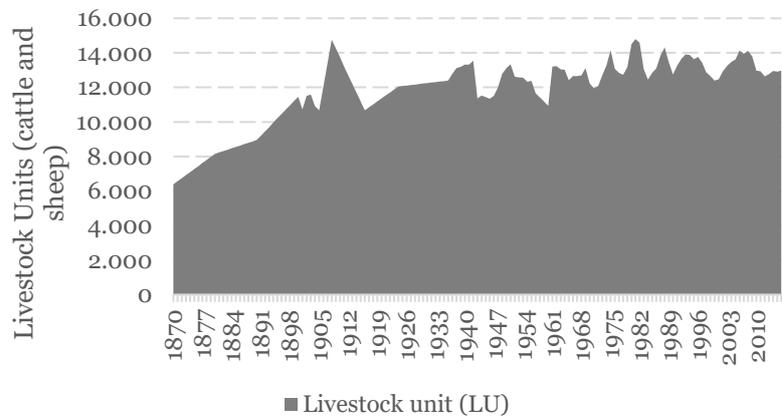
Source: own estimates.

### Panel C. Economically active population (EAP) in agriculture



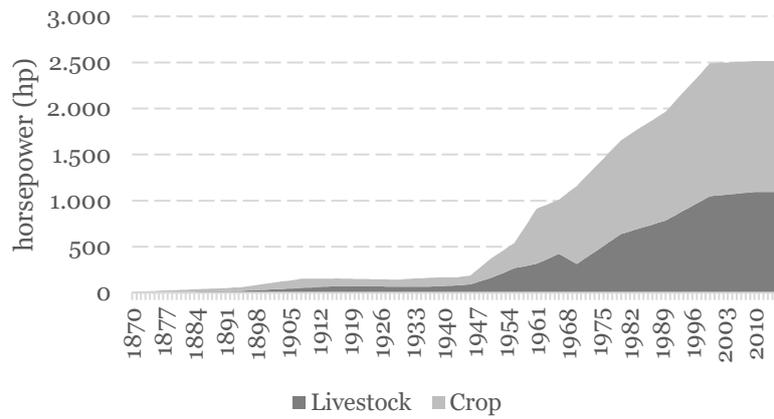
Source: own estimates.

### Panel D. Livestock stock



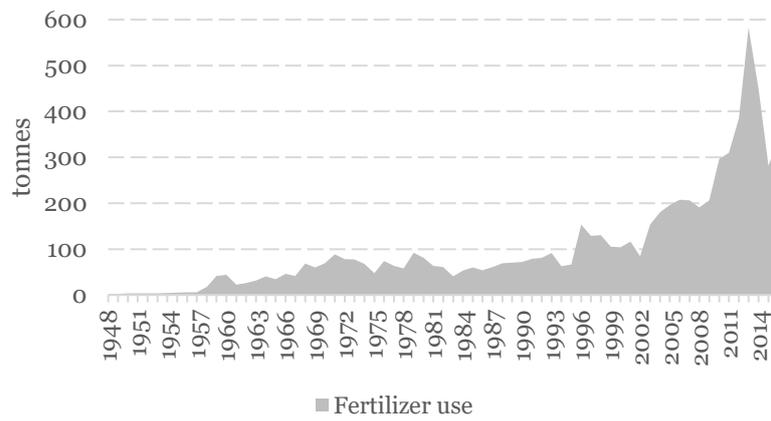
Source: own estimates.

### Panel E. Tractor power in Agriculture



Source: own estimates.

### Panel F. Fertilizer use in Agriculture



Source: own estimates.

## Appendix 2. Weights used in TFP calculation

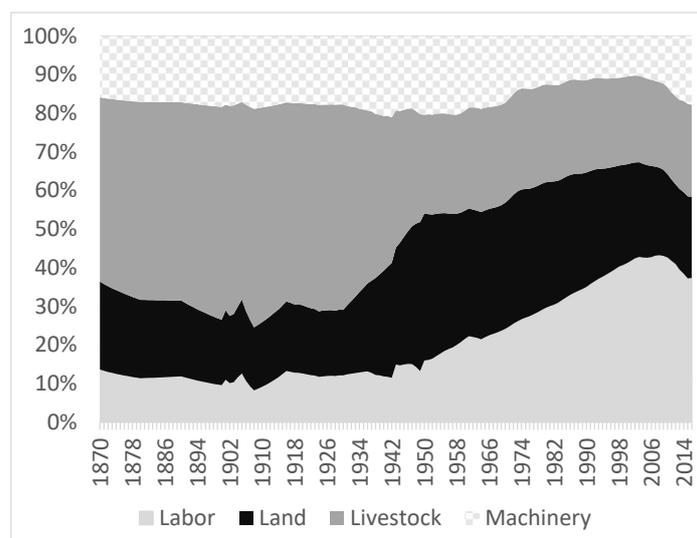
### *Interpretation of factor weights*

The evolution of the factor weights used in the calculation of TFP can, to some extent, be read as an indicator of changes in the technological combination of production factors and, in that sense, as indirect evidence of technical change. However, it is important to stress that, within the growth accounting framework, these weights represent income shares rather than structural technological parameters. Accordingly, their dynamics reflect not only technological transformations –such as mechanization, increasing input intensity, or the incorporation of more productive biological capital– but also changes in relative prices, institutional arrangements, and market conditions that affect factor remuneration. In the agricultural sector, this caveat is particularly relevant for the interpretation of land rents and the valuation of livestock stocks. Consequently, factor weights should be understood as historically contingent magnitudes that are informative about processes of productive transformation, yet whose interpretation requires caution to avoid a mechanical identification with technological elasticities.

### *Evolution of factor weights in livestock production*

Figure A.2 presents the evolution of the factor weights used in the calculation of TFP for livestock production from the late 19<sup>th</sup> century to the early 21<sup>st</sup> century. Overall, the picture depicts a profound yet gradual transformation of the productive structure, characterized by a decline in the relative weight of livestock stock as the dominant factor and by an increasing diversification of the inputs employed in production. The absence of abrupt or erratic changes suggests that the estimates capture long-term historical processes rather than artifacts arising from splicing procedures or ad hoc assumptions.

**Figure A.2. Structure of weights. Livestock (%)**



Source: own estimates.

In the early decades of the period, livestock production is heavily concentrated in the animal stock, which accounts for the bulk of total input. This configuration is consistent

with an extensive system based on the relative abundance of natural resources, low levels of mechanization, and simple management technologies. In this context, livestock simultaneously fulfils the role of productive capital, a means of system reproduction, and the main carrier of technical change, which explains its high share in sectoral income.

Throughout the 20<sup>th</sup> century, a downward trend in the livestock weight can be observed. This should not be interpreted as a loss of productive importance of the animal stock, but rather as the outcome of a process of modernization and intensification. Genetic improvements, advances in animal health, and changes in management practices made it possible to increase output per head, thereby reducing the need for a proportional expansion of the stock. As a result, the relative remuneration of livestock declines vis-à-vis other factors, even though its physical contribution to production remains central.

At the same time, there is a sustained increase in the weight of machinery and, later on, of chemical inputs, particularly from the middle of 20<sup>th</sup> century onwards. This evolution reflects the progressive incorporation of physical capital and complementary technologies –such as infrastructure, equipment, pasture fertilization, and supplementation– which transformed the traditional livestock system into a more intensive and technologically complex one by the early 21<sup>st</sup> century. From the perspective of technical change, this pattern is consistent with a capital-using bias, albeit without fully displacing biological and natural factors.

The weight of labour remains relatively low throughout the period, which is consistent with the historically low labour intensity of livestock production. Nevertheless, its evolution is not monotonic: the modest increases observed in certain phases may be associated with greater complexity in management tasks, sanitary control, and productive organization, suggesting that technical change was not purely labour-saving but also organizational in nature.

Land, for its part, retains a significant and relatively stable share, with fluctuations that appear to respond more to changes in relative prices, market conditions, and institutional arrangements than to strictly technological transformations. In this respect, the evolution of its weight should be interpreted with caution, as it reflects the dynamics of land rents rather than variations in physical land productivity.

A relevant turning point can be identified around the 1940s and 1950s, when the structure of factor weights begins to change more markedly. This shift coincides with the transition to a new phase of modernization in the agricultural sector, as well as with the passage between different information regimes and statistical sources. The fact that this transition takes the form of a gradual change in slopes –rather than an abrupt break– reinforces the plausibility of the estimates and suggests that the splicing of series preserves long-term economic coherence.

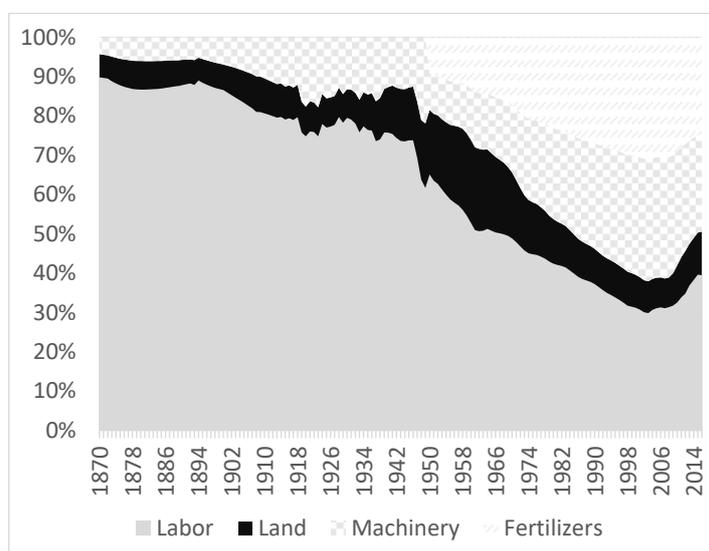
Taken together, the evolution of factor weights reveals a process of structural transformation in livestock production, in which the productive system moves from a strong dependence on biological capital and land toward a more diversified combination of inputs. This dynamic is consistent with the economic history of the Uruguayan and *Río de la Plata* livestock sector and provide a fundamental context for interpreting the

trajectory of TFP: productivity growth cannot be understood without considering changes in the structure of factor remuneration and in the ways that the technological change is incorporated into the production process.

### ***Evolution of factor weights in crop production***

The evolution of the estimated factor weights for crop production displays a pattern that is fully consistent with the long-run technological transformation of Uruguayan agriculture (Figure A.3). In the early decades of the period, production is overwhelmingly dominated by labour, whose weight reaches very high levels, reflecting a labour-intensive production structure based on traditional techniques and limited mechanization. In contrast, capital inputs and modern intermediate inputs play a relatively minor role, in line with a predominantly extensive agricultural system.

**Figure A.3. Structure of weights. Crops (%)**



Source: own estimates.

Over the course of the 20<sup>th</sup> century –particularly from the mid-century onwards– the labour weight declines steadily, while the share of machinery increases markedly. This trajectory reflects the progressive diffusion of agricultural mechanization and the direct substitution of labour by capital, in line with the literature on biased technical change in agriculture. In this sense, the evolution of the machinery weight points to a clearly labour-saving and capital-using pattern of technical change, which appears earlier and more intensively in crop production than in livestock activities.

The fertilizer weight emerges more clearly at later stages and gains relevance during the second half of the 20<sup>th</sup> century, capturing the transition toward more intensive production systems and the adoption of modern technological packages. The growing importance of this input is consistent with a production strategy oriented toward yield increases, based on the complementarity between mechanization and chemical inputs.

The land factor exhibits a more gradual evolution, with an increase in its relative weight during the intermediate period. This pattern can be interpreted as reflecting processes of relative land valorization and changes in agricultural specialization. Unlike livestock production –where land maintains a more stable role– the weight of land in crop production appears to respond more sensitively to technological change and shifts in relative prices.

Taken together, these results suggest that crop production underwent a deeper and more dynamic process of technological transformation than livestock production, characterized by a rapid decline in labour intensity and a rising importance of capital and modern inputs. This differential evolution across subsectors reinforces the plausibility of the estimated weights and provides a consistent framework for interpreting the results of TFP at the aggregate level.