IDB WORKING PAPER SERIES Nº IDB-WP-01024

Productivity and efficiency in grassland-based livestock production in Latin America

The cases of Uruguay and Paraguay

Alejandro Nin-Pratt
Heber Freiría
Gonzalo Muñoz

Inter-American Development Bank
Environment, Rural Development and Risk Management Division

October 2019

Productivity and efficiency in grassland-based livestock production in Latin America

The cases of Uruguay and Paraguay

Alejandro Nin-Pratt
Heber Freiría
Gonzalo Muñoz

October 2019

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library
Nin-Pratt, Alejandro.
Productivity and efficiency in grassland-based livestock production in Latin America: the cases of Uruguay and Paraguay / Alejandro Nin-Pratt, Heber Freiría, Gonzalo Muñoz.
p. cm. — (IDB Working Paper Series ; 1024)
Includes bibliographic references.
1. Livestock productivity-Uruguay. 2. Livestock productivity-Paraguay. 3. Beef cattle-Feeding and feeds-Uruguay. 4. Beef cattle-Feeding and feeds-Paraguay. 5. Pastures-Uruguay. 6. Pastures-Paraguay. I. Freiría, Heber. II. Muñoz, Gonzalo. III. Inter-American Development Environment, Rural Development and Risk Management Division. IV. Title. V. Series.
IDB-WP-1024

JEL Codes: O13, O33, O54, Q51, Q54,Q55
Keywords: agriculture, GHG emissions, livestock production, technical change, total factor productivity, Latin America, Caribbean.

http://www.iadb.org

PRODUCTIVITY AND EFFICIENCY IN GRASSLAND-BASED LIVESTOCK PRODUCTION IN LATIN AMERICA

THE CASES OF URUGUAY AND PARAGUAY

Alejandro Nin-Pratt
Heber Freiría
Gonzalo Muñoz

October 2019

INDEX

TABLES

FIGURES

ABSTRACT

This study looks at the performance of livestock production in Uruguay and Paraguay, analyzing two situations with different implications for development: the displacement of livestock by soybean production as occurred in Uruguay and in the Eastern region of Paraguay, and the expansion of the agricultural frontier in western Paraguay through deforestation. In the case of Uruguay, and despite being displaced to lower-quality land, the livestock sector has seen a historical increase in output and productivity between 2002 and 2006 as the result of rapid growth in beef and milk production and a reduction of sheep stocks to historical lows. This growth was driven by changes in nutrition, mostly due to an increase in the area under cultivated pasture during the second half of the 1990s, the use of grain and supplements associated to dairy production, and more recently, by intensive fattening of cattle. Improved nutrition resulted in a reduction in the slaughter age of steers, an increase in the offtake rate and a larger contribution of dairy to total output. In the case of Paraguay, beef production more than doubled between 2005 and 2016, driven by productivity growth which increased by 70 percent during this period. The expansion of soybean production in the Eastern region after 2006 displaced livestock to the Western Region of Chaco. In this new environment, the adoption of high yielding varieties of tropical pastures together with improved animal genetics were the main factors behind increased productivity. Despite these positive developments, livestock sectors in Uruguay and Paraguay still face major challenges to sustain growth in the future. In the case of Uruguay, the challenge is to accelerate and sustain TFP growth, which stagnated again after 2006. For Paraguay, challenges for future development are those related to the environment, as future expansion of production will continue to take place into forest land in the Chaco region. Although the introduction of cultivated pastures has increased productivity and reduced emissions per unit of output both in Uruguay and Paraguay, in the case of Paraguay, increased production, a growing animal stock and deforestation will continue to increase GHG emissions and will require greater control in the use of natural resources and new technological developments to increase environmental efficiency of livestock production.

JEL Codes: O13 O33 O54 Q51 Q54 Q55

Keywords: agriculture, GHG emissions, livestock production, technical change, total factor productivity, Latin America, Caribbean.

1. INTRODUCTION

Grazing of livestock is the largest single land use activity, creating income and nourishment for more than 1.3 billion people globally, making up for 17 percent of the total global energy intake, and allowing for utilization of land that is not suitable for other food production. In the light of the projected population and income growth, global demand for livestock products is expected to further increase until 2050, opening opportunities for additional global expansion and development of livestock production systems. In this context, expansion of livestock production is important for Latin America (LA) given the role this sector plays in the economy of several countries in the region. According to Graesser et al. (2015), from 2001 to 2013, 17 percent of new cropland and 57 percent of new pastureland replaced forests throughout LA. During this same period, cropland expansion was less (44.3 million hectares) than pastureland expansion (96.9 million hectares), and it mostly occurred within core agricultural regions of Argentina, Brazil, Bolivia, Paraguay, and Uruguay. On the contrary, pastureland largely expanded at agricultural frontiers, as in central Brazil, western Paraguay, northern Guatemala and eastern Nicaragua. These trends have different implications for future livestock development and emphasize the importance of distinguishing between the pasture and crop expanding systems as they vary in land use intensity and efficiency, while facing different challenges for their expansion. Some of these challenges are the lack of adequate technologies to expand production in grassland-based frontier systems; the expansion of export crops that bound livestock production to marginal lands, like in Argentina, Uruguay and Paraguay; and the lack of infrastructure and adequate, policies and institutions as is the case in Bolivia, Nicaragua and Paraguay.

Within livestock production, ruminant systems (cattle, sheep and goats) are important because they play an essential role in global GHG emissions. In LA, these systems generate higher levels of GHG emissions than livestock production systems with higher quality diets. Furthermore, the expansion of ruminant production systems is frequently associated to deforestation, and degradation of soil and natural pastures. At the same time, increasing food production from grasslands by increasing feeding conversion ratios or land-use expansion relates to massive trade-offs, such as carbon emissions and biodiversity losses. These trade-offs need to be tackled in any future development of the livestock sector in the region.

This study focuses on the technical and environmental efficiency of grazing-livestock systems in Uruguay and Paraguay, looking at recent performance, developments and trends in production with the goal of contributing to a better understanding of the challenges faced by

grassland-based livestock systems in these countries. This is achieved by analyzing production performance in two situations with different implications for development. A first situation is that of core agricultural regions in Eastern Paraguay and in Uruguay, where expansion of soybean production displaced livestock from some the most productive lands. The second situation is that of expansion of the agricultural frontier in western Paraguay through deforestation and increased area under pasture. The study is organized as follows. Section 2 presents the conceptual framework; section 3 describes data needs and data sources used, while sections 4 and 5 present results of the study for Uruguay and Paraguay, respectively. Section 6 looks at policy changes associated to the improved performance of the livestock sector in the analyzed countries. The final section concludes.

2. CONCEPTUAL FRAMEWORK

An indicator of performance of the livestock sector that provides a comprehensive depiction of the efficiency of resource use with present technology and its environmental impact, is used to measure past performance and present situation of livestock production. In what follows we briefly describe the proposed methodology.

The study applies the framework developed by O'Donnell (2017) that uses index numbers together with data envelopment analysis (DEA)[1] to estimate levels of productivity and efficiency and to decompose changes in productivity into measures of technical change (measuring movements in the production frontier); and measures of technical efficiency change (movements towards or away from the frontier).

Total Factor Productivity (TFP) of a multiple-output multiple-input production unit is defined as the ratio of an index of aggregated output (*Q*) to an index of aggregated input (*X*):

$$TFP = Q/X \qquad (2.1)$$

O'Donnell (2008) shows that any TFP index defined as a ratio of an output and an input index can be decomposed into a measure of technology efficiency and different measures of efficiency change. In practice, this study will use an additive TFP index that for the case of two outputs and two inputs can be represented as[2]:

$$TFP(i,j) = [a_1\,(q^1_i/q^1_j) \times a_2(q^2_i/q^2_j)] \,/\, [b_1(x^1_i/x^1_j) \times b_2(x^2_i/x^2_j)] \qquad (2.2)$$

This index compares the *TFP* of production unit *i* with TFP of production unit *j* (for a particular period). The weights a_1, a_2 and b_1, b_2 could be defined as average output and input prices of all units in all periods. This index is "proper" in the sense of O'Donnell (2017) as it allows comparisons across production units and across years.

The proposed TFP measure for this study decomposes into efficiency and technical change. All indicators compare input use and output of a production unit (PU) (e.g. farm, district, province, country) against output and input of other production units.

$$TFP = EFF \times T \qquad (2.3)$$

Efficiency (EFF) compares the maximum proportional reduction of a PU's total input that allows the production of the same amount of output produced by this PU. A comprehensive index of performance of the livestock sector is built by incorporating an environmental efficiency (EE)

[1] DEA is a 'mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations - such as the production functions and/or efficient production possibility surfaces – that are cornerstones of modern economies' (Charnes, Cooper, and Rhodes 1978).
[2] The 2X2 index is shown only for ease of presentation. The extension to *m* outputs and *n* inputs is straightforward.

index in the decomposition of TFP efficiency discussed above. The EE index adjusts the TFP measure for pollution, treating GHG emissions as a by-product of the desired livestock outputs. Desired outputs and pollutants are assumed to be the result of two separate production processes, where pollutants are produced by the polluting inputs (feed, animal stock) used in the production of the desired outputs. The assumption is that the intended-production technology is a standard technology that describes how inputs are transformed into intended outputs, while the pollution-generating technology is defined following the approach developed by Murty, Russell and Levkoff (2012). Under this technology, given fixed levels of some inputs and/or some intended outputs, there is a minimal amount of pollution that can be by-produced by the technology and this pollution cannot be reduced without incurring in extra costs (reduced production of the desired output). The by-production technology is an intersection of the intended-production technology and pollution -generating technology. The implications of the by-product production process are that it is not possible to reduce pollution without decreasing output, given the available technology. Given that this is a production process of a "bad", we refer to the most efficient PU as that producing the less pollution per unit of input.

Under the proposed approach, the overall efficiency, which we will call production efficiency (EFF), results from the average of technical (TE) and environmental efficiency (EE), where a low environmental efficiency "penalizes" the measure of productivity: the highest efficiency results from PUs that produce the highest amount of desired output per unit of total input while generating the minimum level of GHG emissions per unit of polluting inputs, given the available technology. Notice, however, that pollution is an externality for producers, that is, a consequence of livestock production that affects other parties without this being reflected in the private cost of production.

GHG emissions were calculated following the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories based on collected data on livestock categories and feed. The main features of our estimates of GHG is that we use Tier 2 methodology. The IPCC has classified the methodological approaches in three different Tiers, according to the quantity of information required, and the degree of analytical complexity (IPCC 2006). Tier 1 employs default emission factors and other parameters provided by the IPCC using simplifying assumptions about some carbon pools. Tier 2 on the other hand, uses a similar methodological approach than Tier 1 but applies emission factors and other parameters which are specific to the country and more highly stratified activity data to correspond with country-specific emission factors and parameters for specific regions and specialized land-use categories. For the IPCC, progressing from Tier 1 to Tier 2 generally represents a reduction in the uncertainty

of GHG estimates, though at a cost of an increase in the complexity of measurement processes and analyses.[3]

Data on prices of inputs and outputs are used to calculate the TFP index. Prices of different types of pasture were determined using standard costs per hectare. The frontier and associated measures of efficiency were calculated using DEA. For example, the LP problem for measuring technical efficiency is:

$$\text{TEo} \underset{\lambda,\theta}{=} \min \theta$$

$$\textstyle\sum_{k=1}^{K} \lambda^k y^k \geq y^o \qquad (2.4)$$

$$\textstyle\sum_{k=1}^{K} \lambda^k x_n^k \leq x_n^o \theta \qquad \text{n = \{inputs\} and k= PUs}$$

Technical efficiency of PU "o" (θ) is the minimum proportional contraction of inputs x^o used by this PU given output y^o subject to constraints that define the technology. The environmental efficiency as developed by Murty, Russell and Levkoff (2012), is obtained by solving the following optimization problem:

$$\text{EE} = \min_{\mu,\gamma} \gamma$$

$$\textstyle\sum_{k=1}^{K} \mu^k Z_r^k \leq Z_{ro} \gamma \qquad \text{r =\{pollutants\}} \qquad (2.5)$$

$$\textstyle\sum_{k=1}^{K} \mu^k x_s^k \leq x_{so} \qquad \textit{k = PUs, and s = \{polluting inputs\}}$$

LP (2.5) calculates the minimum amount of pollution that can be produced given the amount and combination of polluting inputs used by PU "o". The overall efficiency is calculated as the average of the technical (ET=γ) and environmental (EE=θ) efficiency:

$$EFF = \frac{1}{2}(\theta + \gamma) \qquad (2.5)$$

[3] Recent studies have hypothesized that carbon gains and losses in grazing lands are not in balance as assumed by the IPCC methodology but rather that carbon gains tend to be higher than losses at low livestock densities. For example, Viglizzo et al. (2019) show that grazing lands generate carbon surpluses that could not only offset rural emissions but could also partially or totally offset the emissions of non-rural sectors. Even though the potential of grazing lands to sequester and store soil carbon could be reconsidered in the future, in this study we stick to the IPCC methodology as the standard and accepted approach for international comparisons. If this different way of considering carbon balance in grazing lands is incorporated in the methodology to estimate emissions, it could change the view that we have at present of the role of livestock as a source of carbon emissions in agriculture.

3. DATA

Sub-national level data was collected from government agencies, including data on animal stock, sales, number of animals slaughtered, inputs, capital, land and labor use. The information collected in Uruguay and Paraguay includes highly disaggregated secondary data from different sources. The core of the dataset and key inputs for the proposed analysis are the following:

- Animal stock and stock composition and categories
- Animal movements and number of animals slaughtered
- Land use and suitability for different agricultural activities including land allocated to crop, mixed crop-livestock systems and land under cultivated forests.
- Inputs used in livestock production (capital, labor), with special emphasis on animal feed quantity and quality: natural and cultivated pastures, hay, and silage and stored fodder

A key element of the analysis is the characterization of feed quality and consumption by different livestock categories. This is important because GHG emissions are calculated based on diets in different production systems using technical coefficients by animal category and feed class. Notice that data on pastures used for productivity analysis includes information on hectares of natural and cultivated pasture, land quality as measured by CONEAT[4] index of land quality for livestock production (for Uruguay), and dry matter production of natural and cultivated pastures in different regions. This information was used to calculate the metabolizable energy (ME) provided by different pastures (in MJ) and this available ME from different sources (natural and cultivated annual and permanent pastures, grains and silos) is used as input of the production process instead of the most frequently used number of hectares of pastures or kilograms of grain fed. This approach also has the advantage of controlling for the quality of natural resources as it considers yields and digestibility of pastures.

Uruguay

The country is divided in 19 departments (departamentos) and each department is subdivided into several police jurisdictions (seccionales policiales). There is a total of 252 jurisdictions in the country and their number varies by department. Of these, 207 were used to build our

[4] The CONEAT index in Uruguay is used to define the current capacity of the country's land, determined on the production of beef and ovine meat and wool. The quality of the soil of all rural lots of land in Uruguay has been analyzed and classified according to its livestock production potential. The index was developed with a scale ranging from 0 to 236, being 100 the national average which is the average of the country's land.

dataset after eliminating semi-urban jurisdictions and others with small number of animals. Information obtained came from National System of Livestock information (SNIG) of the Ministry of Livestock, Agriculture and Fisheries (MGAP). This is a major source of information for this study as it reports data on animal stock and stock composition; movement of animals at the jurisdictional level by destination; land use and land quality measured by the CONEAT index, providing information on land suitability and production potential. All 252 jurisdictions in the country have been classified per this index. Information from the Agricultural Census is available for the years 2000 and 2011 from the Statistical Division of the MGAP. This is the main source of information on machinery and labor allocation. Detailed reports on animal slaughter, by period and category were provided by the National Institute of Meat (INAC). This information was complemented by specific labor surveys and technical coefficients from different sources.[5]

Information on technical coefficients of livestock production that complements the use of pastures in different livestock production systems were obtained from expert opinion and data available in different institutions; mostly from the Office for Agricultural Planning and Policies (OPYPA) of the MGAP, and the Uruguayan Federation of CREA Groups (FUCREA).

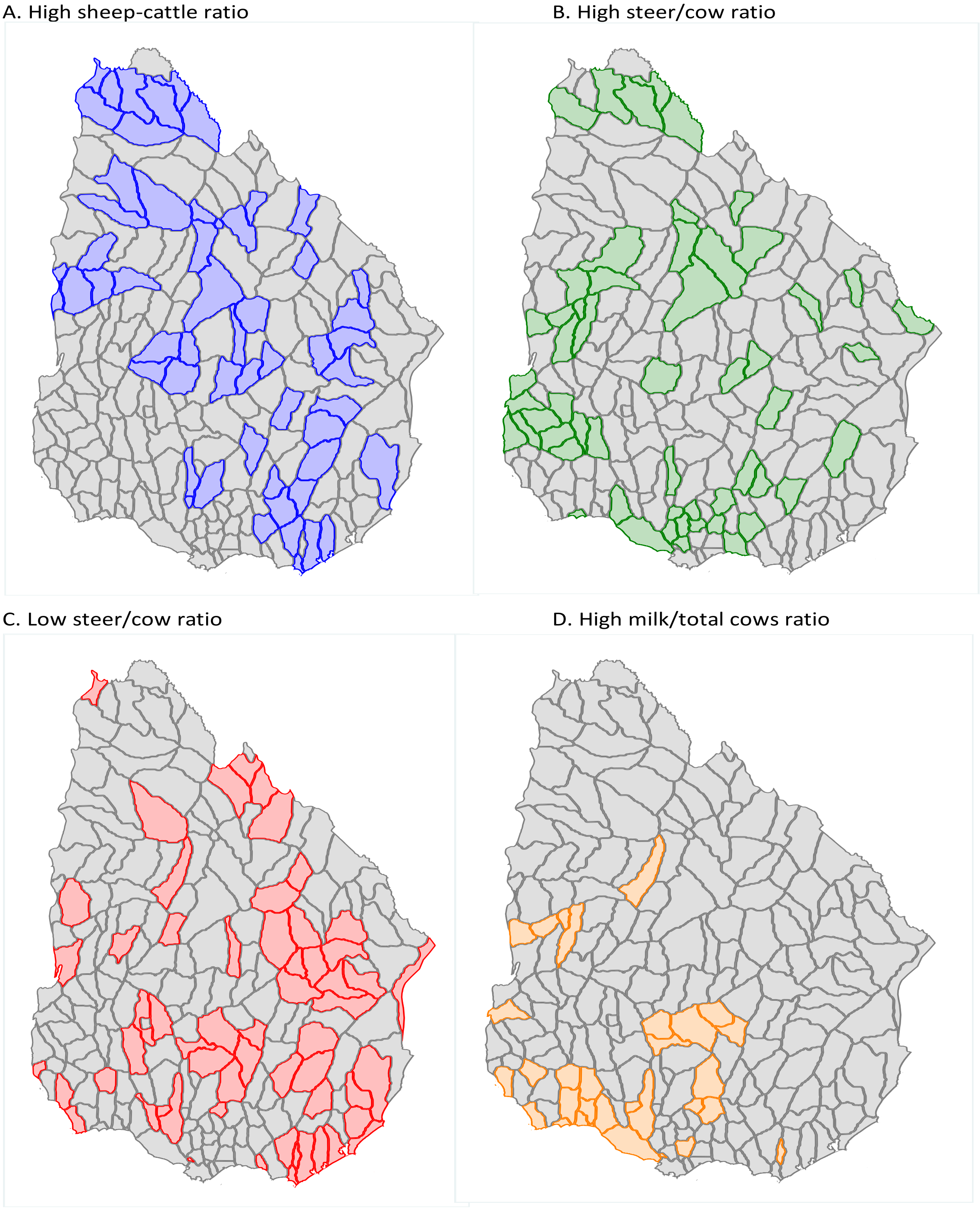
FAO (2018) has a summary description of the main characteristics of livestock production in Uruguay which we summarize here. Most of the beef herds are kept in pasture year-round subject to different forage availability due to the grass production seasonality and they consist of pure breeds mainly from European (Bos taurus) origins. Herds normally calve in determined breeding seasons of three months (between July and September). Artificial insemination is used in more intensive systems like dairy production. In typical herds, 15 to 25 percent of the cows are replaced each year and replacement heifers are raised on the same farm as the cows. Male calves and extra female calves are sold at weaning (5 to 7 months) and 140 to 160 kgs. Culled heifers and cows are sold from the beef herd (mainly after weaning) or fattened in the farm for use in beef production. During the rearing phase, animals can receive supplements to improve growth performance and shorten slaughter age. Usually daily weight gain can vary in a large range from 300g/day in natural grasslands to 900g/day in cultivated pastures with supplements. Feedlots are used mainly during part of the year (late autumn to end of winter) for fattening cattle that goes to slaughter (average between 100 to 120 days). Beef herds in feedlots, which supply 20 percent of animals slaughtered annually, consume 10 to 15 kgs of DM/head/day depending upon their breed, size and age. Diets consist of 20 to 30 percent

[5] Information from all these sources was compiled and made available by OPYPA from MGAP.

forage with the remainder being maize grain, soybean meal and other energy and protein feed and byproducts.

Figure 3.1 shows how different stock compositions reflecting different production systems distribute spatially. The jurisdictions with high sheep/cattle ratios are in general those with low production potential and combines sheep and breeding cattle. Many of these jurisdictions overlap with those in Figure 3.1C of low steer/cow ratios, mostly cattle breeding areas. The jurisdictions with high steer/cow ratios on the other hand are in general areas of high production potential combining agriculture and fattening. Finally, dairy production is concentrated in the south-southwest, originally near the capital city and expanding west and north of the capital driven by growth in exports.

Figure 3.1– Sheep, steer, cow and milk ratios showing spatial differences in stock composition



Source: Elaborated by authors based on data from SNIG - MGAP

Note: Sheep/cattle ratio >0.55 in A; steer/cow ratio>0.45 in B and <0.30 in C; liters of milk produced per cow in stock (including beef cows)>1.8.

Paraguay

The country is organized in 17 departments, three of which constitute the Western Region of the Chaco (the agricultural frontier) and 14 the Eastern Region, the core agricultural region. Departments are organized into districts (distritos) and these into municipalities (municipios). Some of the information needed for the study is available at the municipality level, but most relevant variables are only available at the department level. For this reason, the department is used as the basic unit of analysis.

Main sources of information for this study are the Ministry of Agriculture and Livestock (MAG), which provides information on land use by crop and livestock on a yearly basis through its statistical summary. Information from the Agricultural Census is available for the year 2008 also from the MAG. As in the case of Uruguay, the Agricultural Census is the main source of information of machinery use, labor allocation and land use for livestock production into natural, cultivated pastures and other uses.

The National Service of Quality and Animal Health (SENACSA), is an autonomous institute created by national law with the mission of implementing quality and animal health policies, and reporting regularly on animal stock, animal stock composition and animal movements of different animal categories between departments and destination. Information on animal movements from SENACSA was available for the period 2013-2016 only. Longer series are available for other variables. To complement the secondary information, several interviews with government officials and experts working in the private sector were held during 2017.

There is no formal or official classification of livestock production systems in Paraguay (for example, breeding and fattening systems, or grazing and feedlot systems), however, insights from local experts allow us to present a preliminary classification and geographic location of production systems. Within the Eastern region, the department next to the Parana river (Zone 1 in Figure 3.2) are part of the major crop production region in the country. Expansion of soybean production started after the economic crisis of 2000, triggering the development of agriculture in the Eastern region and increases in land prices.

The departments in a semi-circle to the east of Asuncion (Zone 2) include an area of traditional smallholder agriculture that included cotton production, an activity that has virtually disappeared at present, leaving vast areas of degraded soils. Within this zone, south of Asuncion, and in a stretch of territory east of the Paraguay river, livestock production is mostly specialized in breeding stock, which takes place along with crop production.

North of Asuncion, the traditional livestock production region is in the departments of San Pedro and Concepcion (zone 3). Both breeding and fattening systems are found in this region,

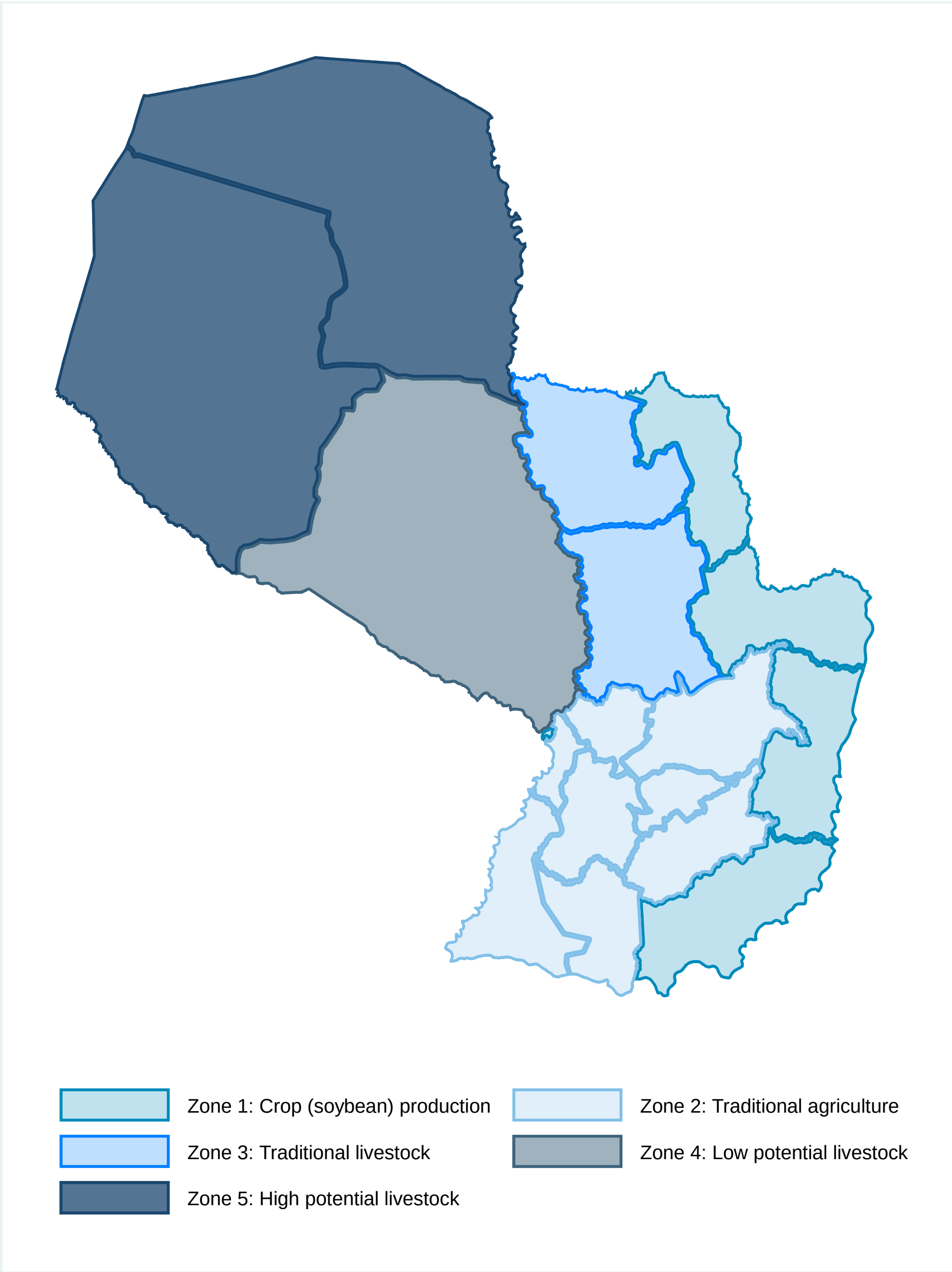
mixed with crop production (soybean and maize), but crop production is less important here than in the east and southeast. Weaning calves from western Chaco and from the south are brought here for growing and fattening. Land prices in this area have also seen significant increases in the last 15 years as the result of the expansion of soybean production as happened in Uruguay and in the southern region of Brazil. Simultaneously with expansion of production into new areas, producers adopted new grass varieties (technology CIAT-EMBRAPA, Bracharia brizantha cv marandu, and Panicum maximum cv Tanzania). These pastures last for 15 to 20 years without further fertilizer application and they can hold up to 0.9 livestock-units (LU) per hectare.[6]

The low-productivity region in the western region of Chaco (Zone 4 in Figure 3.2) is mostly located in the department of Pte. Hayes, an area with lowlands, marshlands, palm trees and natural vegetation, and soils with very low levels of phosphorus (less than 2 ppm). Livestock production in this region specializes in breeding based on natural pastures, with low number of animals per hectare (0.3 LU/hectare, increasing to 0.5-0.6 LU/hectare with cultivated pastures).

Zone 5 (Figure 3.2) includes the Central Chaco, one of the most productive livestock regions in the country, more humid and with soils with high levels of phosphorus (80 to 120 ppm). New technologies were adopted in this area where cultivated pastures of Panicum maximum, cv Gatton are predominant allowing to hold 0.8 to 1 LU per hectare. This is an area with significant presence of Mennonite colonies and includes the southwest corner of Alto Paraguay department, the southeastern part of Boqueron department bordering Alto Paraguay, and the northern part of Pte. Hayes. Further north in department of Alto Paraguay and in Central Chaco, outside the region of the Mennonite colonies, higher precipitation and good quality soils make the region highly suitable for livestock production (0.7 to 0.8 LU/hectare). Despite the high quality of natural resources in this region, the geographic location far from urban centers, poor infrastructure, and poor water quality and availability of water, result in land prices like those of Pte. Hayes and lower than those in the Eastern region. Western Chaco near the Pilcomayo river is also a low productivity region, semi-arid with precipitation below 400 mm per year, and 0.2 LU/hectare.

Livestock units, among which cow-equivalent units is one of the most commonly used, is a measure that makes comparable feed consumption and production of different animal categories. A livestock unit was defined as a dry, empty adult cow of 390 kilograms. For example, steers weighting 450 kilograms represent LU=450/390=1.15 LU.

Figure 3.2– Production zones in Paraguay



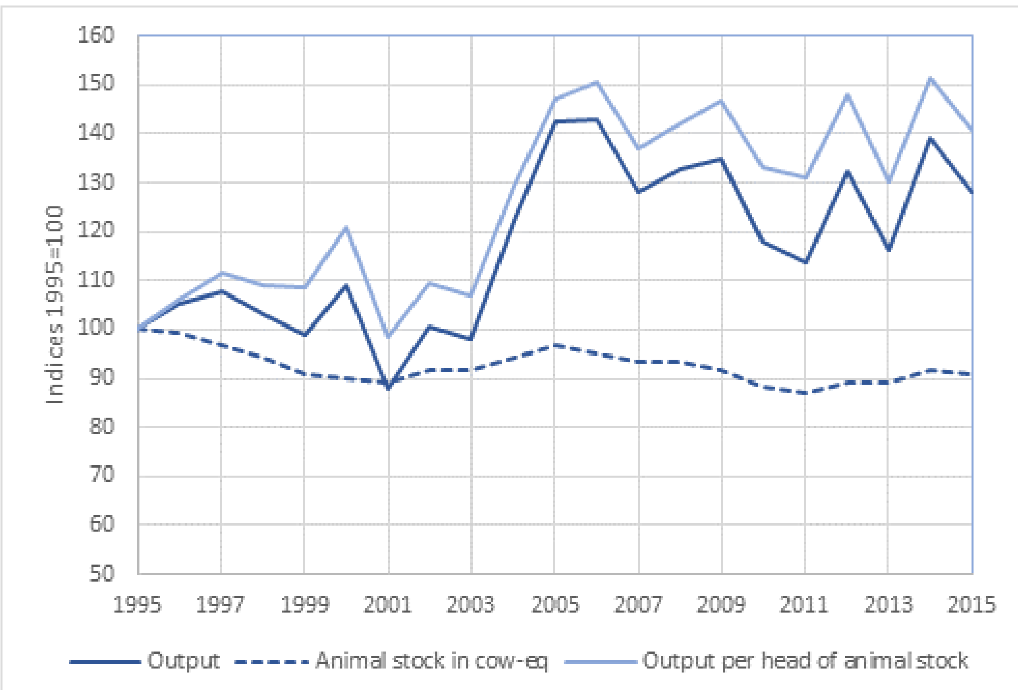
Source: Elaborated by authors based on data from SENACSA–MAG and opinion from local experts.

Note: The map was elaborated using departments as the unit, so the characterization of the regions is a rough approximation. For example, the high-potential livestock region includes significant low-potential areas as explained in the text

4. URUGUAY: RESULTS

Ruminant production in Uruguay (including beef, dairy and sheep) increased by more than 40 percent between 1995 and 2005, to fall again after that year and recover by the end of the period (Figure 4.1). Output per head increased by 20 percent between 1995 and 1999, but the negative impact of an outbreak of food and mouth disease (FMD) and of the regional economic crisis of the early 2000s undid progress achieved in previous years, yielding in 2001 the lowest output value for the period. The overall stock of ruminants did not change during this period (measured in LU units) so by 2015, production per LU was 40 percent higher than in 1995, as shown in Figure 4.1.

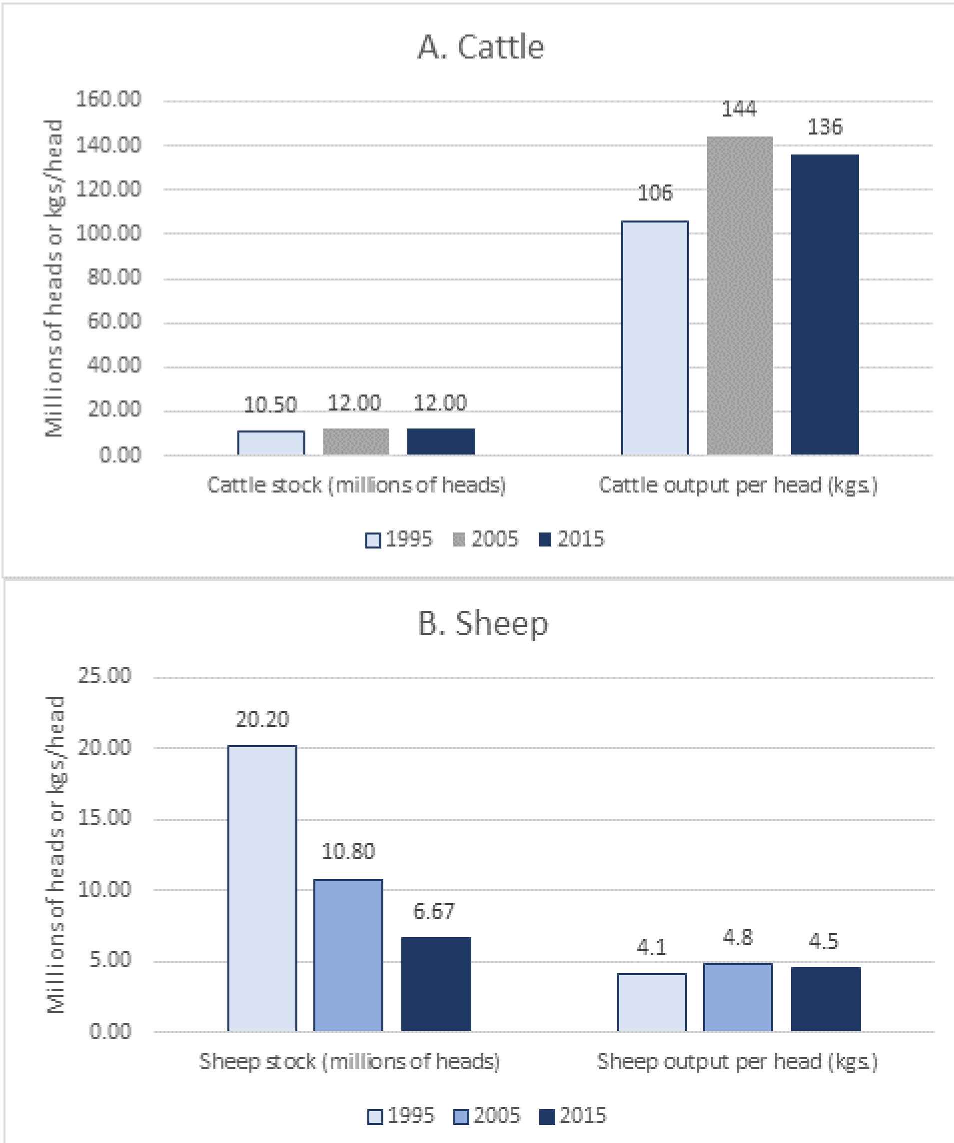
Figure 4.1– Indices of output, animal stock and output per animal, 1995-2015



Source: Elaborated by authors

Significant changes occurred during the analyzed period in the composition of the animal stock. Figure 4.2 shows that the cattle stock increased from 10.5 to 12.0 million heads while the sheep stock collapsed from 20.2 to 6.7 million heads in the same period. These changes occurred simultaneously with an increase in output per head in cattle from 106 in 1995 to 144 and 136 kilograms in 2005 and 2015, respectively.

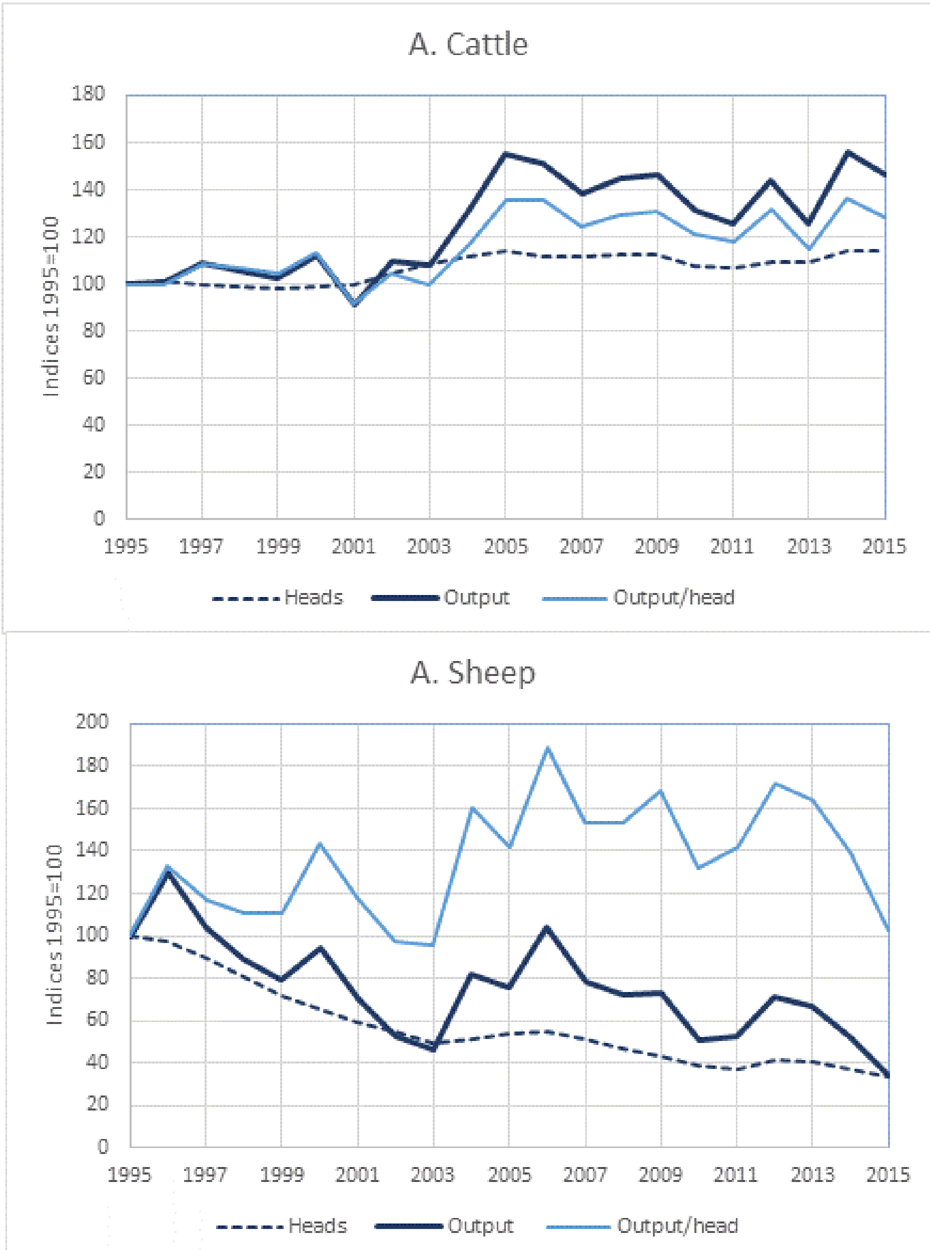
Figure 4.2– Levels of cattle and sheep stocks and output per animal for selected years



Source: Elaborated by authors

Figure 4.3 shows the evolution of animal stock, output and output per head for cattle and sheep separately. Total output from cattle increased 50 percent between 1995 and 2015, while output per head increased 30 percent approximately. Total output from sheep declined together with animal stock, while output per head increased on average by approximately 50 percent after 2003 when compared to its level in 1995, although with large fluctuations during the period.

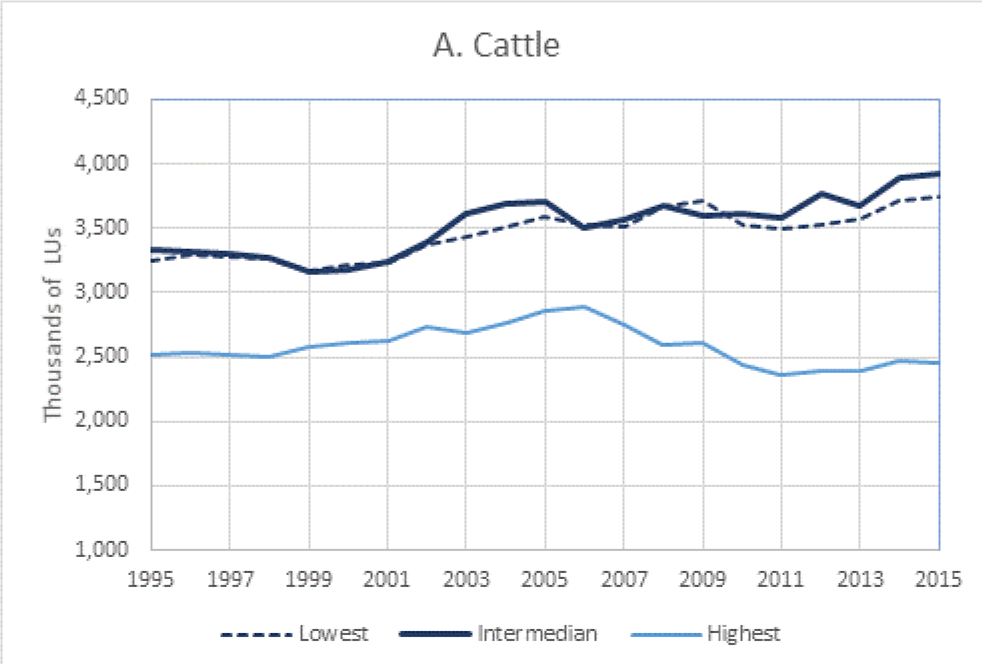
Figure 4.3– Indices of output, animal stock and output per animal for cattle and sheep, 1995-2015

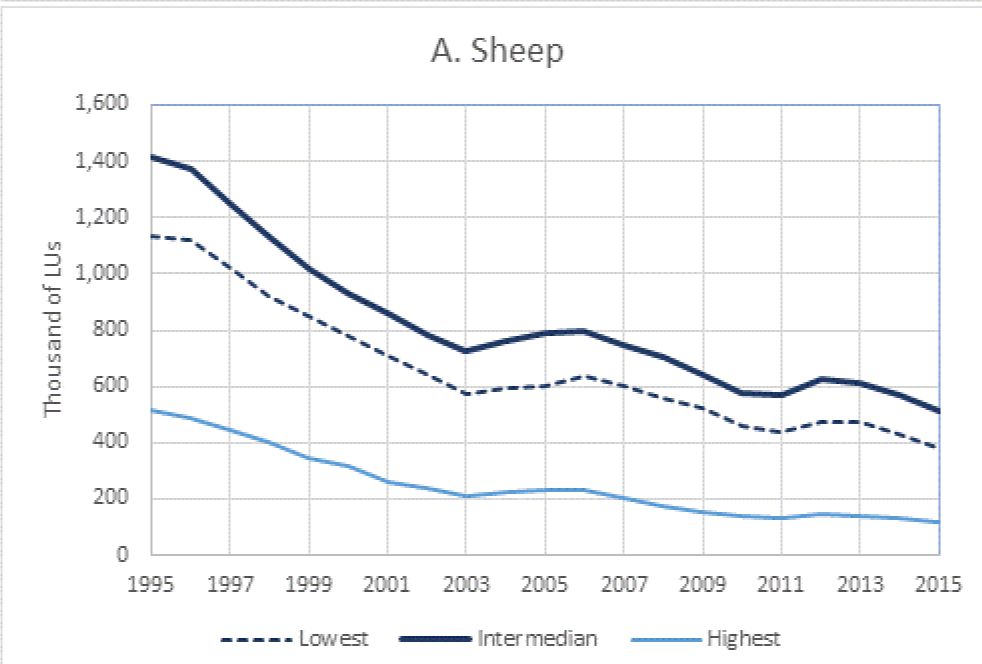


Source: Elaborated by authors

Growth in the stock of cattle is associated to land quality (Figure 4.4). The expansion of the stock occurred in the 2/3 of jurisdictions with lowest value of the land quality index. In the jurisdictions with the highest land quality, the number of cattle decreased after 2005, associated to the expansion of soybean production. Figure 4.4 also shows that most of the observed growth in the number of cattle is inversely related to changes in the number of sheep.

Figure 4.4–Trends in animal stocks by tercile of land quality (in LU)

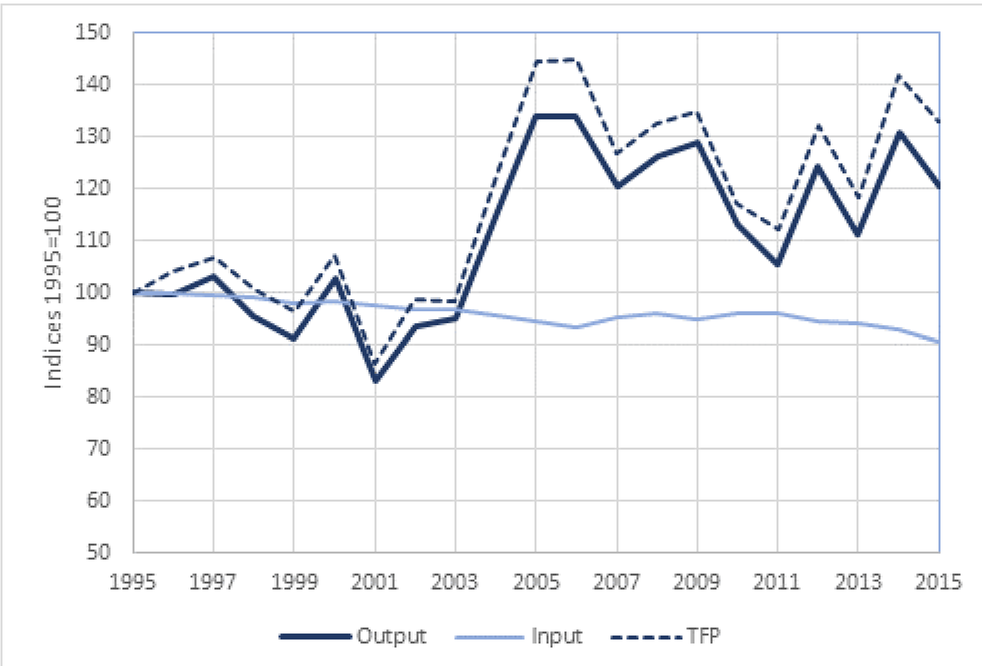




Source: Elaborated by authors based on data from MGAP (SNIG, DGRN, OPYPA).
Note: The group "Lowest" includes the 1/3 of jurisdictions with the lowest CONEAT values, while group "Highest" includes jurisdictions with the highest CONEAT values.

Figure 4.5 displays output, input and TFP indices for the aggregated cattle and sheep sector, showing that TFP growth was driven by rapid growth in output, which by 2005 was more than 30 percent bigger than in 1995. Conversely, the use of inputs in livestock production, measured by the index of total input, decreased by 10 percent between 2005 and 2015 as the result of a reduction in the animal stock and in land allocated to beef production.

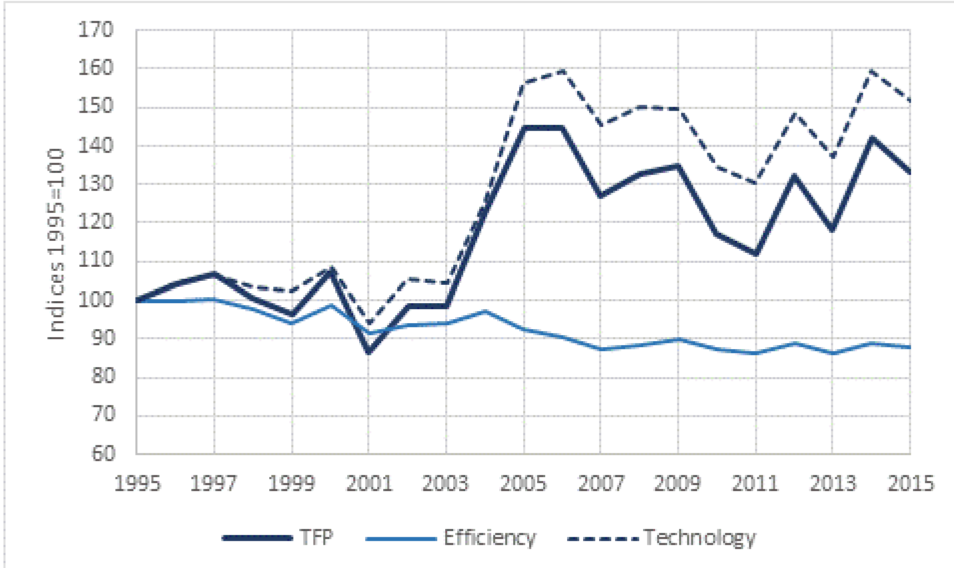
Figure 4.5– Indices of output, input and TFP, 1995-2015



Source: Elaborated by authors

Figure 4.6 shows the decomposition of TFP into production efficiency and technology for the period 1995-2015, calculated at the jurisdictional level in 18 departments. The increase in TFP observed between 2005 and 2015 was driven by technical change, which is reflected in levels of potential output per unit of total input in 2015 that are between 20 and 50 percent higher than in 2005. Technical change takes off after 2001, while efficiency decreased by 12 percent during the period.

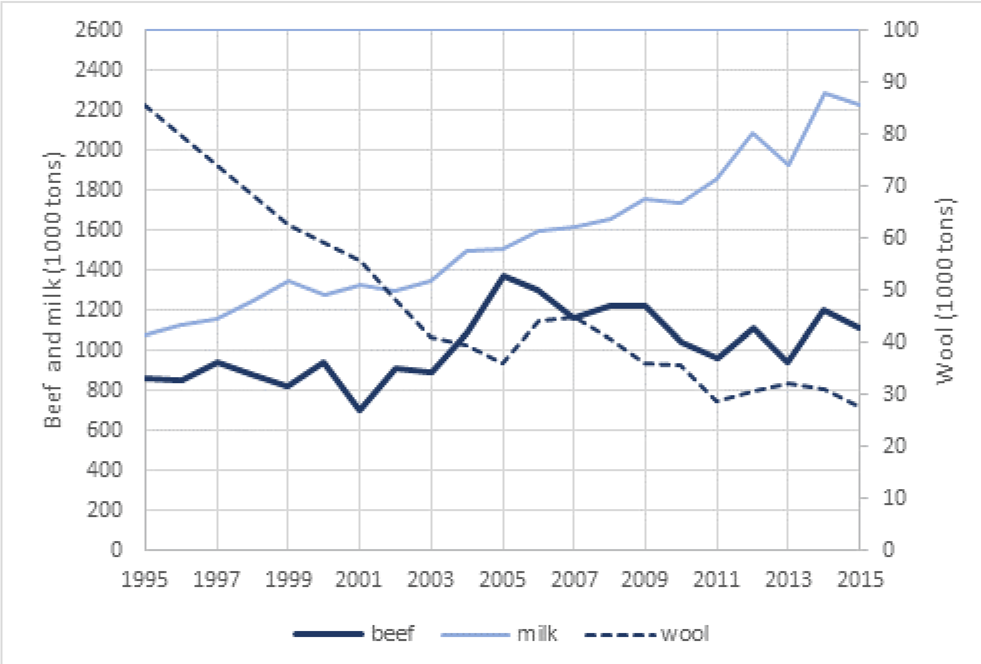
Figure 4.6– Indices of TFP, efficiency and technology, 2005-2015



Source: Elaborated by authors

Results so far have shown that the aggregated cattle and sheep production sector in UDeruguay has seen a historical increase in productivity after 2002, driven by technical change. What changes in production are related to the observed productivity growth? A first major change was the steep reduction in the stock of sheep shown in Figure 4.4, indicating that beef and milk production were the drivers of output and productivity growth. Figure 4.7 shows the evolution of the three major livestock products in Uruguay. Beef production increased 60 percent between 1995 and 2005 but shows a decreasing trend after that year, reaching a total growth of 30 percent for the period. Milk production doubled between 1995 and 2015, while wool production in 2015 was only 32 percent of production in 1995. By the end of the period, beef and milk contributed each with half of the observed growth of the livestock sector, with the share of beef in total output increasing from 57 percent in 1995 to 65 percent in 2016. During this same period, the share of milk in total output increased from 20 to 30 percent, while the share of wool in total output decreased from 20 to 4 percent.

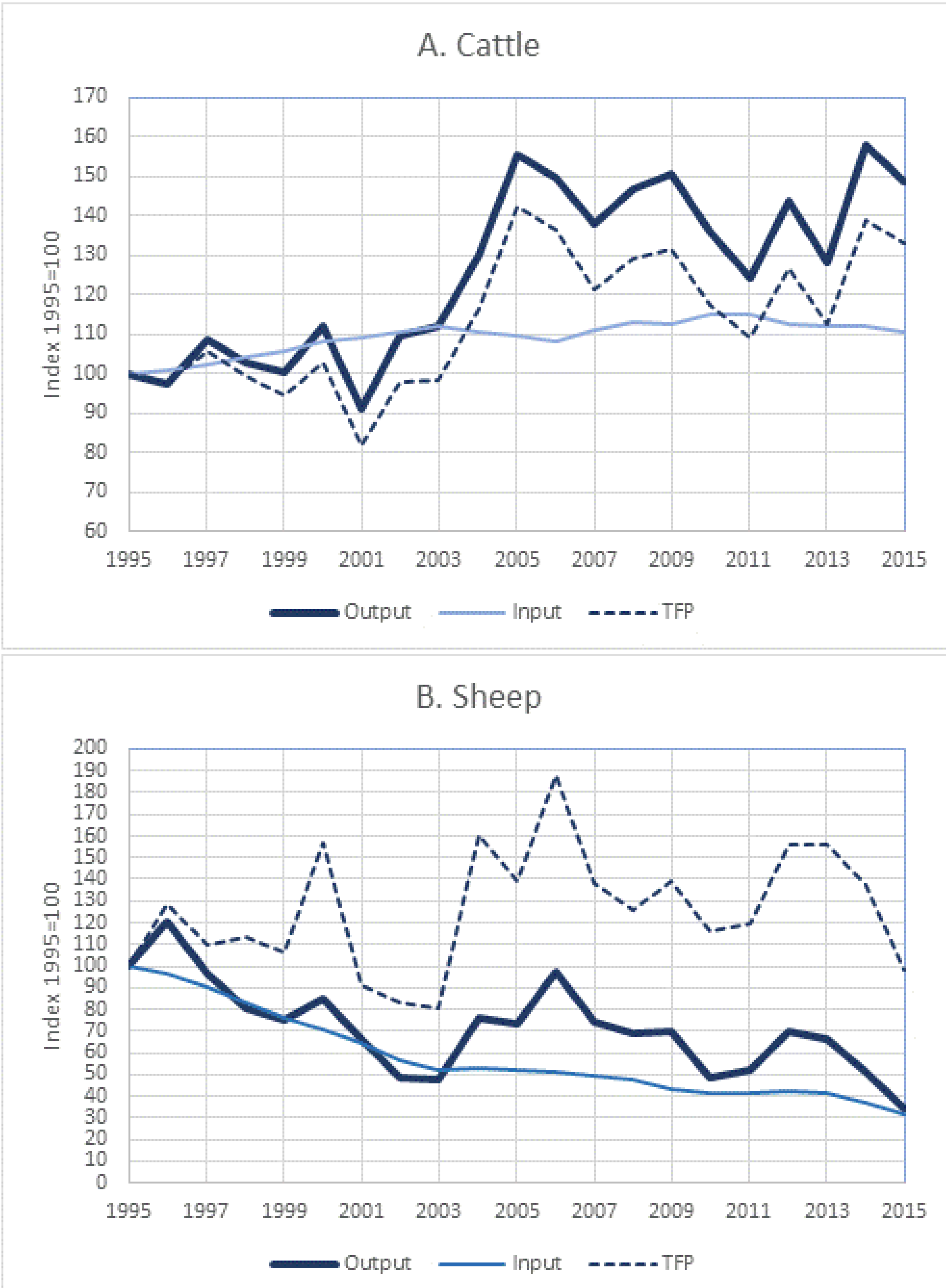
Figure 4.7–Trends in beef, milk and wool production, 1995-2015



Source: Elaborated by authors based on data from INAC and DIEA – MGAP

The patterns of output and TFP growth in cattle production are the same observed in the aggregated livestock sector (Figure 4.8). As no major changes occurred in sheep TFP. Two major changes seem to be driving TFP growth in cattle. The first is a change in the structure of the animal stock, and the second is a change in nutrition, which explains the changes in the animal stock. We look first at the changes in the animal stock (Figure 4.9). The figure shows that the major change occurred in the stock of male cattle, where we observe a reduction in the number of animals of 3 year or older, from almost 40 to 20 percent of the stock, and an increase in the proportion of young steers (1-2 years old) from 40 to close to 50 percent. These changes were driven by changes in nutrition.

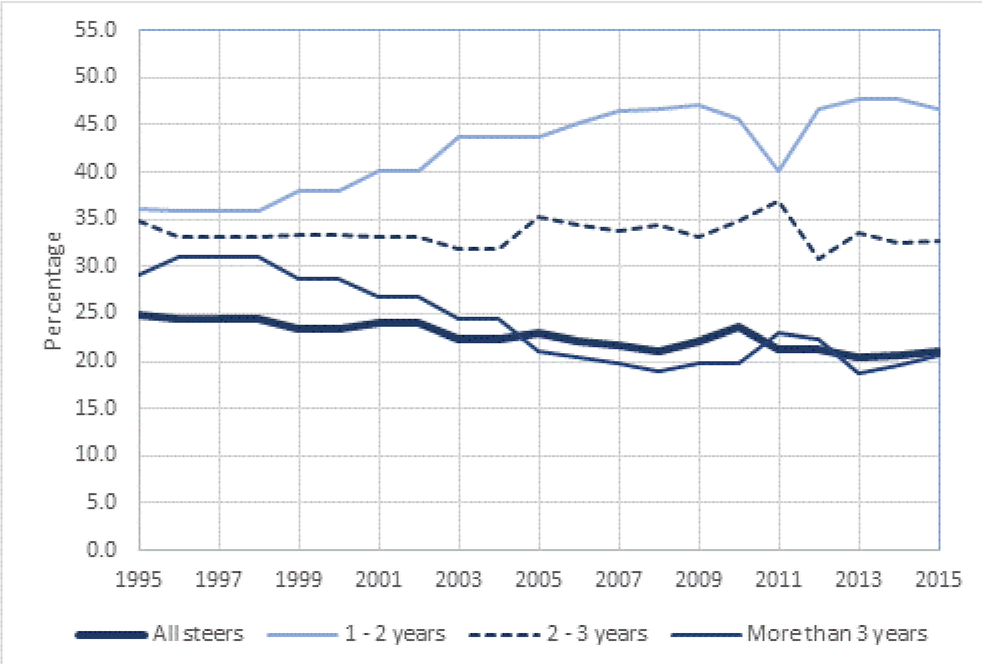
Figure 4.8–Trends in output, input and TFP in cattle and sheep production, 1995-2015.



Source: Elaborated by authors

Note: See appendix for assumptions on input allocation between cattle and sheep production

Figure 4.9– Share of steers in total cattle stock and share of steers of different ages in total number of steers, 1995-2015

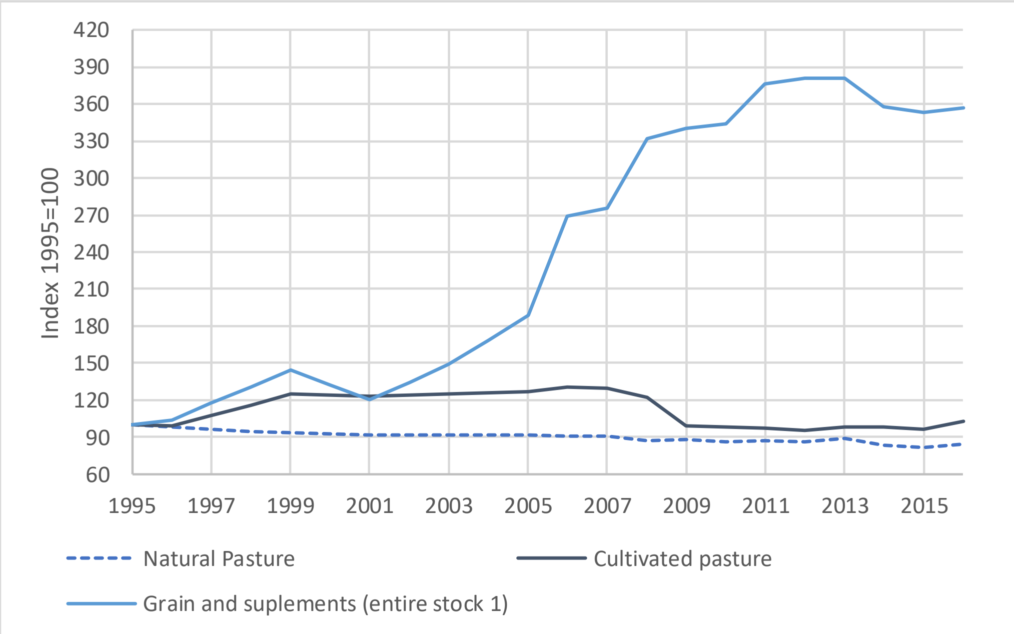


Source: Elaborated by authors

The evolution of natural and cultivated pasture and the use of grain and supplements are shown in Figure 4.10. The area of cultivated pasture increased by 30 percent, but most of this increase occurred during the period that led to the 2002 crisis and to the lowest level of output in the last 20 years. However, this higher area of cultivated pasture seems to be one of the major factors behind the change in the structure of the animal stock and an explanation for the rapid recovery of output after 2002. Also related to improved TFP is the very rapid increase in the use of grains and supplements, which took off after 2003, with the expansion of feedlots and the supplementation of grazing animals with grain. Despite its growing importance, grain is still a very low proportion of the total DM consumed by cattle.

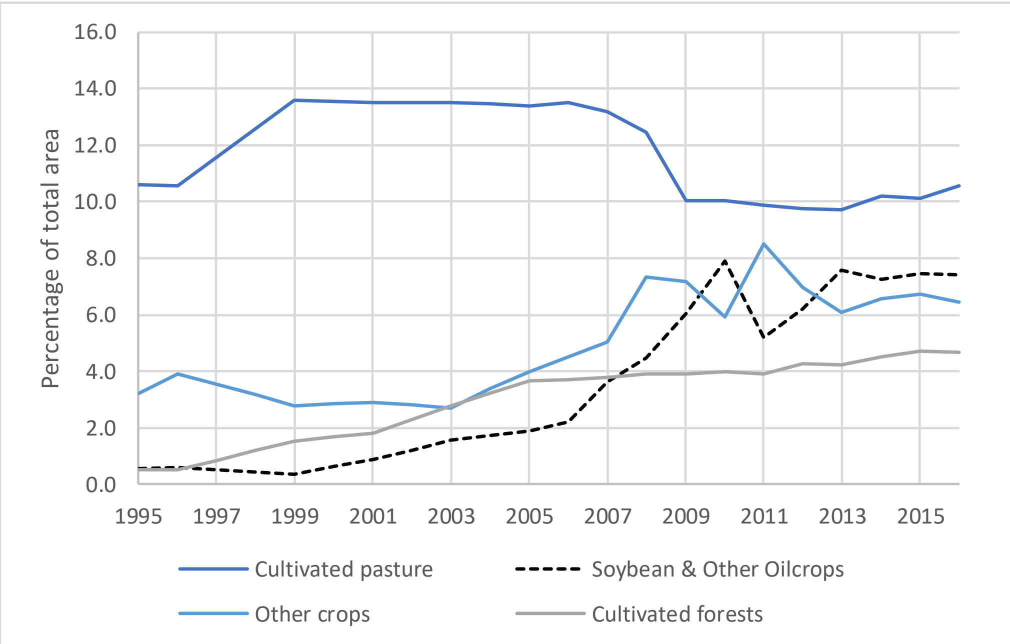
In contrast, the ceiling reached by the area of cultivated pasture coincides with the rapid expansion of the area under crops and the soybean boom that started in the early 2000s (Figure 4.11). The share of cultivated pastures reached 13.6 percent of total area in 1999, a time when the area allocated to crops was below 4 percent. By 2013, the expansion of crop area driven by growth in soybean production had increased total crop area to 13.7 percent of total agricultural area. It is during this period of crop expansion that no further increase in the share of cultivated pasture in total area is observed. The area under forests also increased from less than 2 percent in 1995 to almost 5 percent in 2015.

Figure 4.10– Trends in natural and cultivated pasture and in the use of grain and supplements in ruminant production, 1995-2015



Source: Elaborated by authors based on data from MGAP (DIEA, DGRN)

Figure 4.11–Share of land under pasture and feed crops, crops and forest as percentage of total agricultural area, 1995-2016



Source: Elaborated by authors based on data from MGAP (DIEA, DGRN)
Note: Share of natural pasture in total area is not shown

Table 4.1 shows the importance of the use of grain in beef production and the evolution of the average live weight of steers. There seems to be a positive correlation between the use of grain as supplement and the final weight of slaughtered animals. A regression of the changes in TFP

against changes in the use of grain plus silo and changes in the share of cultivated pasture in total area at the jurisdictional level (Table 4.2), shows that jurisdictions that increased the area of cultivated pasture and supplements also show higher growth in productivity (TFP).

Table 4.1–Evolution of the average weight of slaughtered steers, total number of slaughtered animals and grain consumption as supplement.

	1997	2000	2005	2010	2015	2016
- Average live weight of slaughtered steers	476.4	469.9	486.3	496.5	506.7	518
- Number of slaughtered animals (millions)	1.93	1.83	2.65	2.25	1.94	2.27
-Slaughtered animals from feedlots (millions)	0	0	0.06	0.12	0.19	0.21
- Animals fattened up in feedlots as proportion of slaughtered animals (percentage)	0	0	2.30	5.30	9.80	9.30
-Percentage of total grain supplied to cattle consumed by different animal categories						
a. Feedlots[1] and by growing steers supplemented with grains (feedlot input)	-	-	39	28	43	49
b. Breeding (calf-cow) systems and mixed systems (both pasture-based)	-	-	10	11	11	11
c. Supplement by pasture based fattening systems	-	-	51	62	46	40

Note: [1] Animals at feedlots are fed with grain the last 100 days before slaughter

Table 4.2– Relationship between changes in TFP and changes in the use of cultivated pasture and grains + silo

	Coef.	Robust Std. Err.	t	P>t	[95% Conf. interval]	
Change in the use of grain and silo	0.004	0.000	8.910	0.000	0.003	0.005
Change in the share of cultivated pasture in total area	22.236	6.698	3.320	0.001	9.105	35.366
Constant	0.762	0.790	0.960	0.335	-0.786	2.310

Source: Elaborated by authors

Summary indicators of efficiency for fattening and breeding in Table 4.3 show a significant reduction in the slaughter age of steers from 4.6 to 3.7 years on average. The overall offtake rate also increased significantly from 0.13 to 0.18 as the result of more efficient fattening, also reflected in the increase in the offtake rate for males (from 0.22 to 0.27). No significant changes are observed in reproductive efficiency according to our data. Most importantly, changes in these indicators occurred between 1992-1995 and 1997-2000. The most significant change after 2000 is the increase in the offtake rate of females which could be related to adoption of new technologies for early detection of pregnancy and other measures improving management of the breeding stock, which allowed culling cows earlier in the year instead of keeping unproductive animals for longer periods.

Table 4.3— Indicators of fattening and reproductive efficiency in beef production

	1992-1995	1997-2000	2002-2006	2007-2015
Slaughter age steers	4.57	3.63	3.57	3.70
Reproductive efficiency'	0.41	0.38	0.40	0.43
Offtake rate	0.13	0.18	0.18	0.18
Offtake rate males	0.22	0.28	0.28	0.27
Offtake rate females	0.10	0.14	0.15	0.17

Note: a. Measured as the ratio of number of calves and number of females one-year or older

The availability of spatially disaggregated information allows, in the case of Uruguay, to decompose the global results and look at how different systems responded to market and policy changes. To that end, police jurisdictions were grouped according to their dominant productive orientation, based on the destination of animal movements, instead of using ratios between stock categories (for example, steer-cow ratios) as in more traditional classifications. The indicator used was the ratio of animals shipped to slaughterhouses, divided by total number of animals shipped, including animals for replacement and fattening. The highest values of this indicator are associated with specialized feeders or fattening systems, and the smallest values with breeders, that is, producers of animals that are replacement or input for other systems. Additionally, jurisdictions specialized in dairy production were identified based on the share of milk production in total output. Note that the unit considered is the jurisdiction and not the individual productive unit, so the levels of identified "specialization" are lower than those observed at the farm level.[7]

Table 4.4 shows that growth in TFP was driven by jurisdictions with mixed production systems. TFP in mix-fattening and mix-breeding systems increased between 1995 and 2005 by 46 and 32 percent, respectively. Specialized breeding systems, located in areas with low production potential, and fattening systems, mostly located in high potential areas, show the smallest increase in TFP: 6.6 and 18.2 percent, respectively. The table also shows that TFP growth recovered in the last five years after showing negative growth in all systems. Table 4.5 shows the share of the area of improved pasture under different production systems. In 1995, two-thirds of the area under improved pastures was under fattening and dairy systems while one-third was under mixed and breeding systems. In 2015, breeding and mixed systems increased their share in total area of improved pastures to 42 percent.

[7] Police jurisdictions were classified as follows based on the ratio animals shipped to slaughterhouses/total shipments: values of the ratio of less than 1.5, Breeders; values between 1.5 and 2.0, Mix-fattening and breeding systems with emphasis in breeding; values between 2.0 and 2.5 Mix-fattening and breeding systems with emphasis in fattening; values of more than 2.5, Fattening systems.

Table 4.4–TFP growth in jurisdictions specialized in different production systems, 1995-2015 (percentage)

System	1995-2005	2005-2010	2010-2015	1995-2015
Mix-fattening	54.6	-17.2	8.6	46.0
Mix-breeding	39.7	-19.5	12.1	32.2
Breeding	21.7	-32.1	16.9	6.6
Fattening	35.8	-28.2	10.6	18.2
Dairy	31.2	-9.4	18.1	40.0

Source: Elaborated by authors.

Table 4.5–Share of area under improved and cultivated pastures across production systems, 1995-2015 (percentage)

	1995	2005	2010	2015
Mix-fattening	10.4	12.5	14.5	14.4
Mix-breeding	16.0	18.1	19.9	20.4
Breeding	6.1	5.6	6.7	7.1
Fattening	25.0	25.1	24.0	24.1
Dairy	42.6	38.8	35.0	34.0
Total	100.0	100.0	100.0	100.0

Source: Elaborated by authors.

Table 4.6 shows the share of cultivated pasture by department classified in three regions that roughly correspond to the high-potential, crop production region, the dairy region around the capital city and the rest, departments that in general have lower production potential and where mostly mix and breeding systems are found. Notice that the two-thirds/one-third share of improved and cultivated pastures repeats here between the crop and dairy production regions (65 percent of total area in 1995) and other departments (35 percent). In 2015, the departments in the “Other” region increased their share in total area of pasture to 50 percent.

Table 4.6–Share of area under improved and cultivated pastures across production systems, 1995-2015 (percentage)

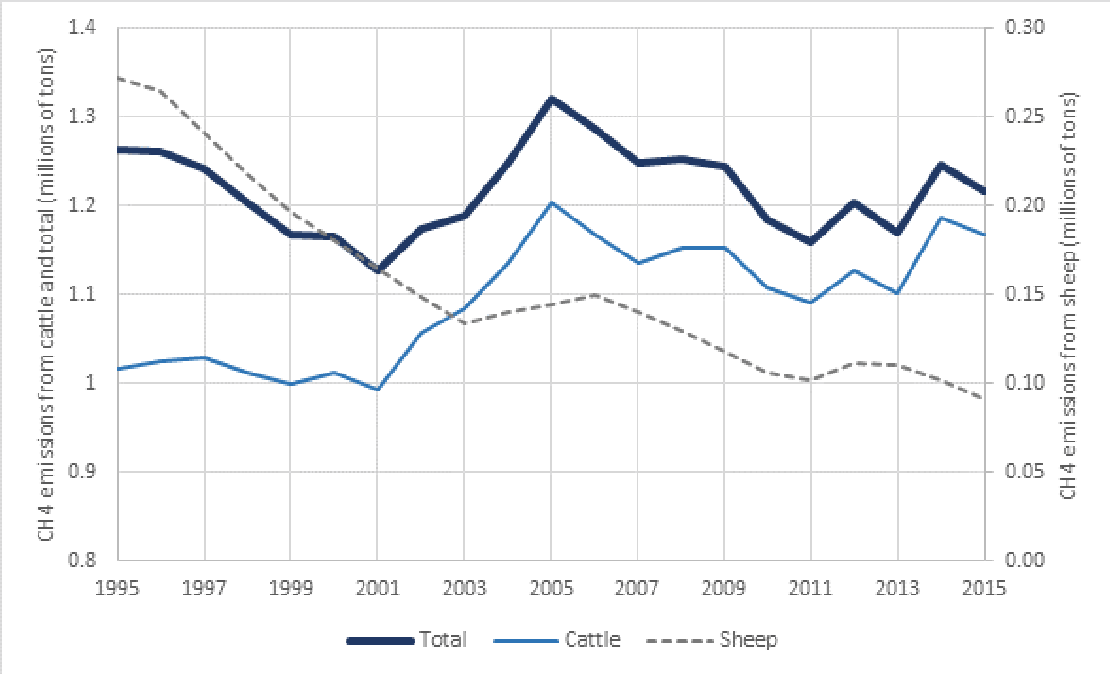
	Department	1995	2005	2015
Crop production region (mostly fattening and dairy systems)	Soriano	13.3	10.7	7.4
	Colonia	12.5	10.4	9.1
	Rio Negro	9.6	7.1	5.0
	Paysandú	9.0	7.1	6.1
	Sub-total	***44.4***	***35.3***	***27.5***
Dairy production	Florida	10.0	13.0	12.7
	San Jose	7.8	7.2	7.3
	Canelones	3.1	3.1	3.4
	Sub-total	***20.9***	***23.3***	***23.4***
Other (mostly mix and breeding systems)	Cerro Largo	4.6	5.6	5.7
	Durazno	4.5	6.4	5.6
	Rocha	4.3	5.7	7.9
	Flores	3.6	4.5	4.3
	Lavalleja	3.4	4.5	4.9
	Tacuarembó	3.2	3.4	5.2
	Treinta y Tress	3.0	3.7	4.9
	Salto	2.7	2.1	2.8
	Rivera	2.5	2.2	3.9
	Artigas	1.6	1.6	1.8
	Maldonado	1.3	1.8	2.0
	Sub-total	***34.8***	***41.4***	***49.1***

Source: Elaborated by authors based on data from SNIG–MGAP

The implications of ruminant production for the environment are accounted by the estimation of GHG emissions from enteric fermentation in cattle. The evolution of GHG emissions between 1995 and 2015 is presented in Figure 4.12. GHG emissions from cattle increased by almost 13 percent between 1995 and 2015. However, when looking at the overall emissions of ruminants we observe a reduction of almost 4 percent. In other words, growth in emissions by cattle were compensated by the reduction in emissions by sheep. The result of these changes is a significant reduction in emissions per unit of output (Figure 4.13), not only for the aggregated ruminant sector but also for cattle, as the observed increase in emissions is smaller than the increase in output. Emissions per unit of output decreased by 25 percent between 1995 and 2015. This reduction is explained almost exclusively by reduced emissions per unit of output in cattle production.

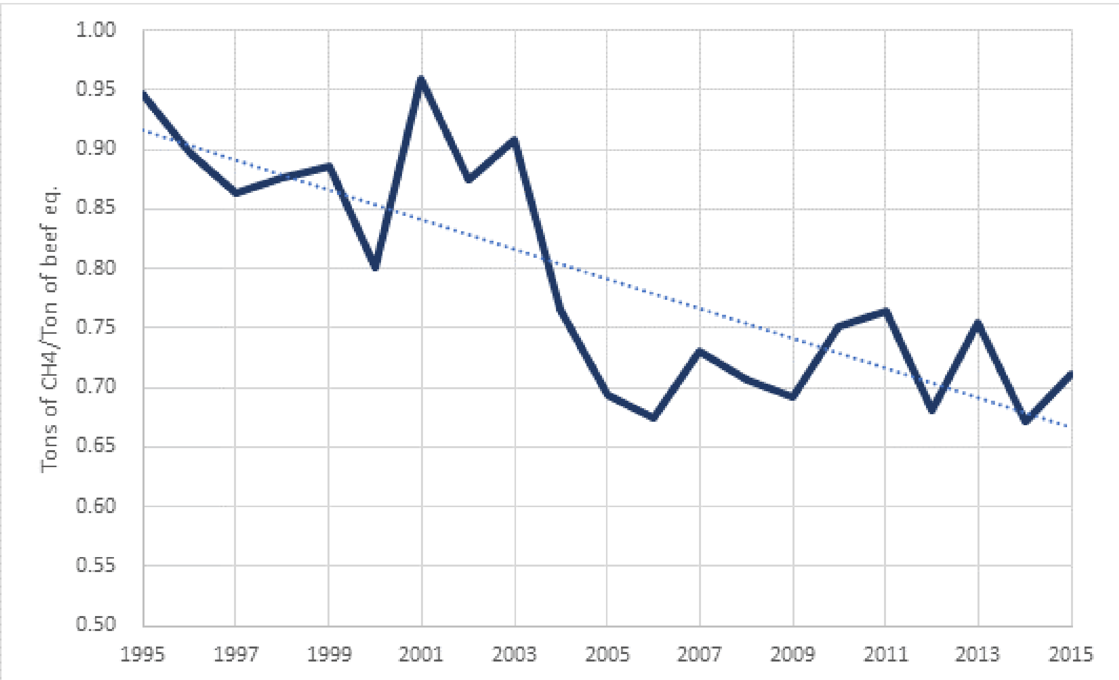
Figure 4.14 decomposes total ruminant emissions into those that result from enteric fermentation and those from urine and dung. Emissions from urine and dung represent approximately 30 percent of emissions from enteric fermentation and emissions from both origins have behaved similarly, changing with changes in output.

Figure 4. 12– Total CH4 emissions, 1995-2015



Source: Elaborated by authors

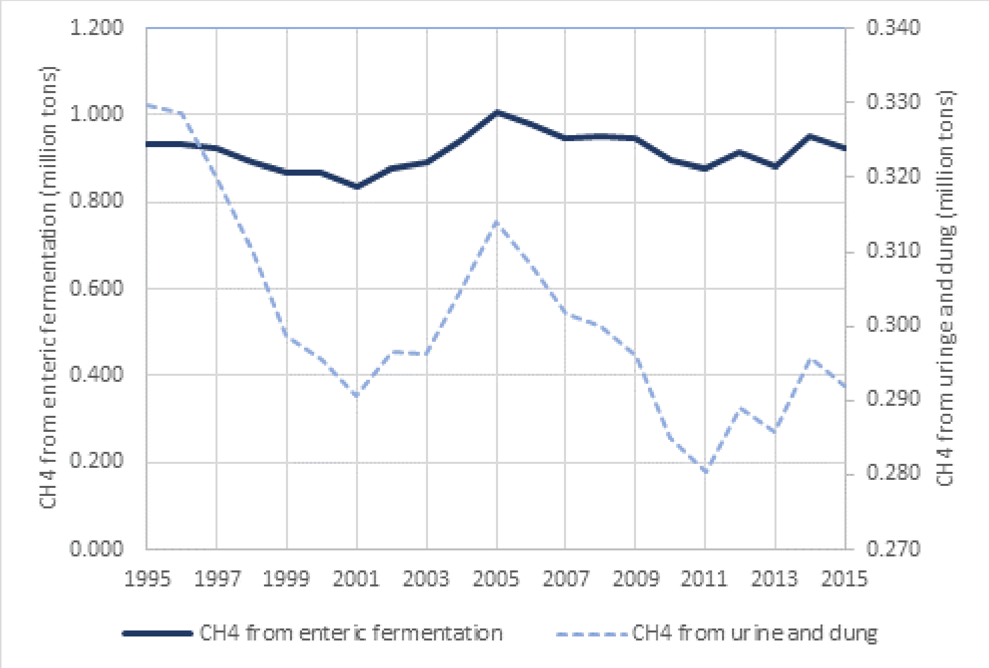
Figure 4. 13– CH4 emissions per ton of output, 1995-2015



Source: Elaborated by authors

Note: All quantities are in tons of beef equivalents, obtained by dividing value of output including beef, milk, wool and sheep by the price of beef

Figure 4.14– CH4 emissions from enteric fermentation and from urine and dung, 1995-2015

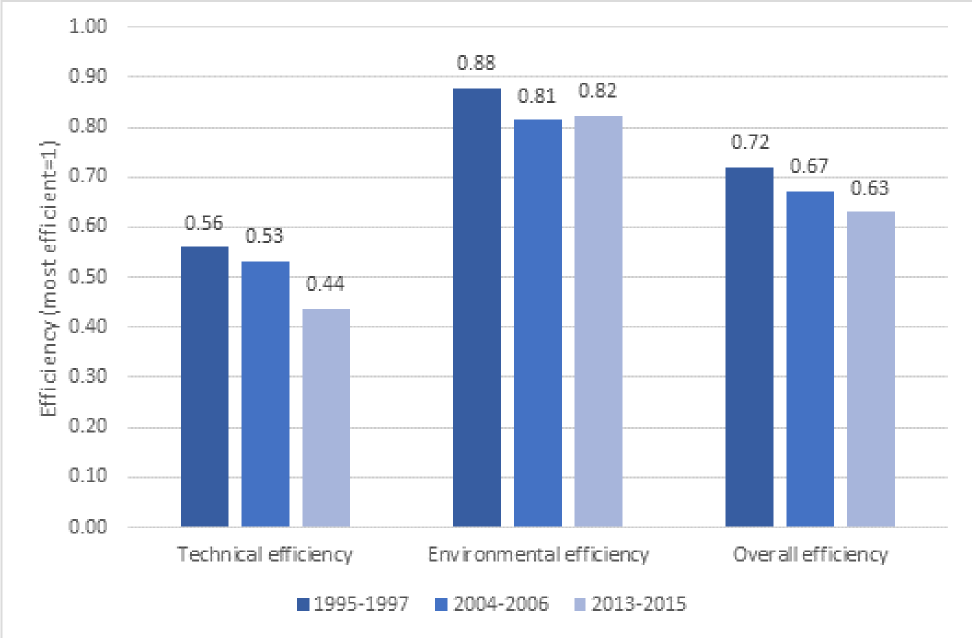


Source: Elaborated by authors

Note: CH4 emissions from urine and dung include emissions from management and from soil nitrification (N2O emissions converted to CH4 equivalents)

The levels of production efficiency and its components are shown in Figure 4.15 while Figure 4.16 shows trends of efficiency between 1995 and 2005. After 20 years of growth, efficiency of livestock production decreased from 0.72 to 0.63. This is the result of a reduction in both technical and environmental efficiency. Technical efficiency decreased from 0.56 to 0.44, while environmental efficiency dropped from 0.88 to 0.82. However, Figure 4.15 shows that environmental efficiency increased after 2005, compensating for the reduction in technical efficiency and keeping overall efficiency constant after that year

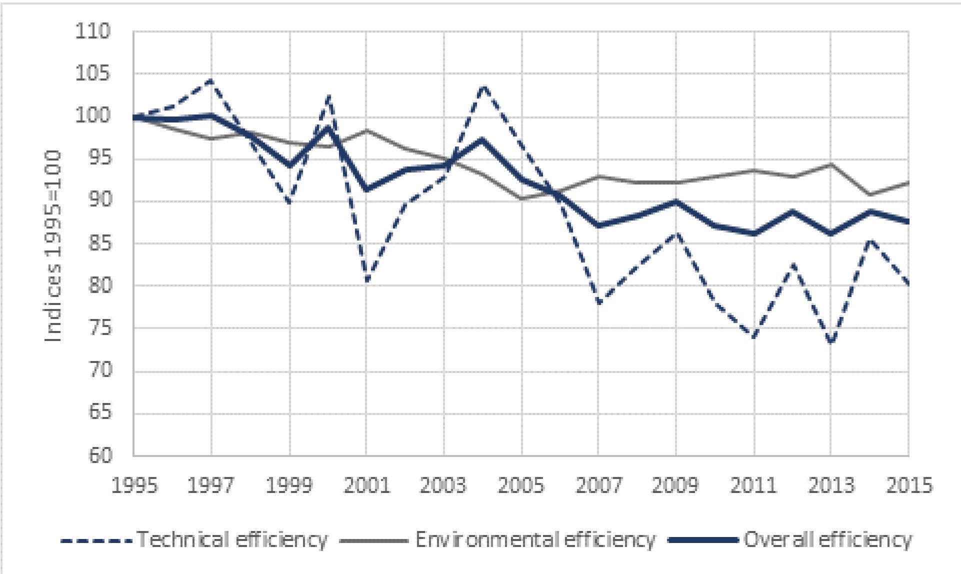
Figure 4.15– Levels of production efficiency and its components (technical and environmental efficiency) for three different years.



Source: Elaborated by authors

.

Figure 4.16– Decomposition of production efficiency into technical and environmental efficiency, 1995-2015.

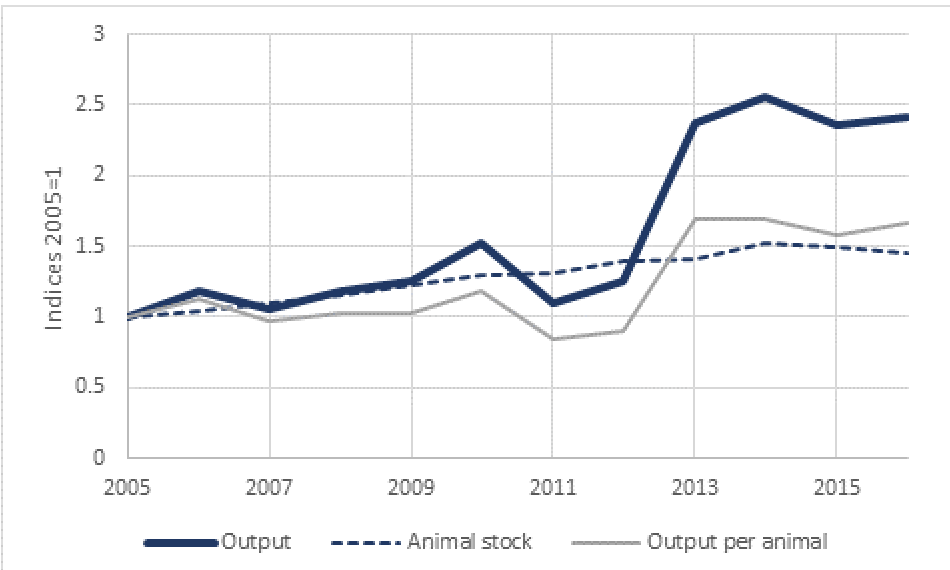


Source: Elaborated by authors

5. PARAGUAY: RESULTS

Figure 5.1 shows a significant increase in beef production in Paraguay between 2005 and 2016. By 2016, total beef production was 2.5 times bigger than in 2005 not only as the result of an increase in the animal stock (45 percent) but also from an increase of 66 percent in output per animal. As shown in Figure 5.1, most of this increase occurred after 2012. Between 2011 and 2016 beef production more than doubled (from a value of 1.1 to 2.42 of the output index), driven by technical change. The sharp increase in output observed after 2011 was calculated using official figures of number of animals slaughtered which increased from roughly a million heads in 2005 to more than 2 million heads in recent years.

Figure 5.1– Indices of output, animal stock and output per animal, 2005-2016

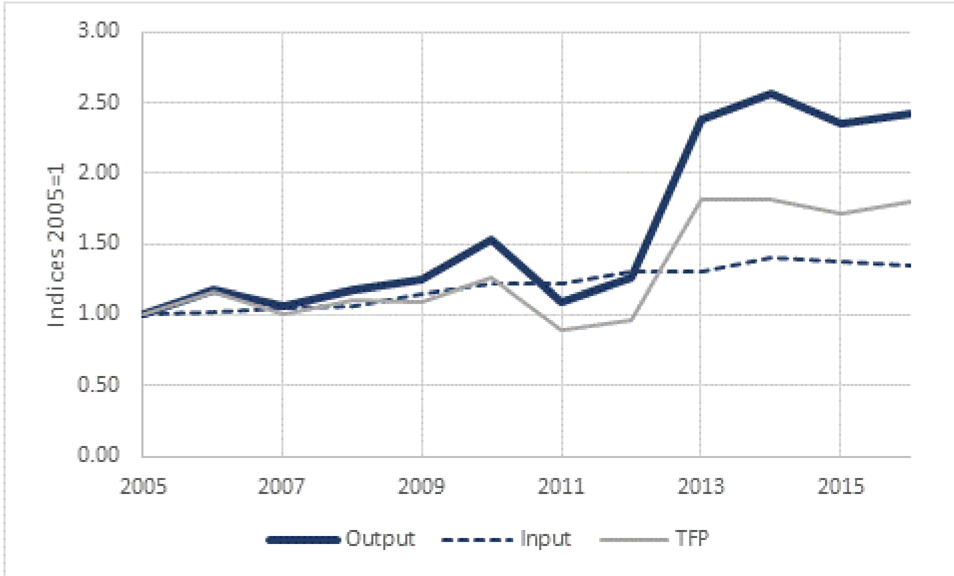


Source: Elaborated by authors

Several circumstances fueled rapid growth after 2011. An outbreak of foot and mouth disease in 2011 might have slowed down growth that started in 2010, probably explaining the rapid come back of production in 2012-2013. Fast expansion of soybean production in the Eastern region after 2006 created the conditions for investments by livestock producers in Chaco, where land prices were still low. Many of these investors came from Uruguay and Southern Brazil. These investments started paying back after 2010.

Figure 5.2 shows the production index from Figure 5.1 but compared to the input and TFP indices. The use of inputs in beef production increased by 37 percent between 2005 and 2015, mainly as a result of area expansion and a growing animal stock below the increase of 242 percent in output during this period. The difference between output and input growth was the result of an 81 percent increase in TFP.

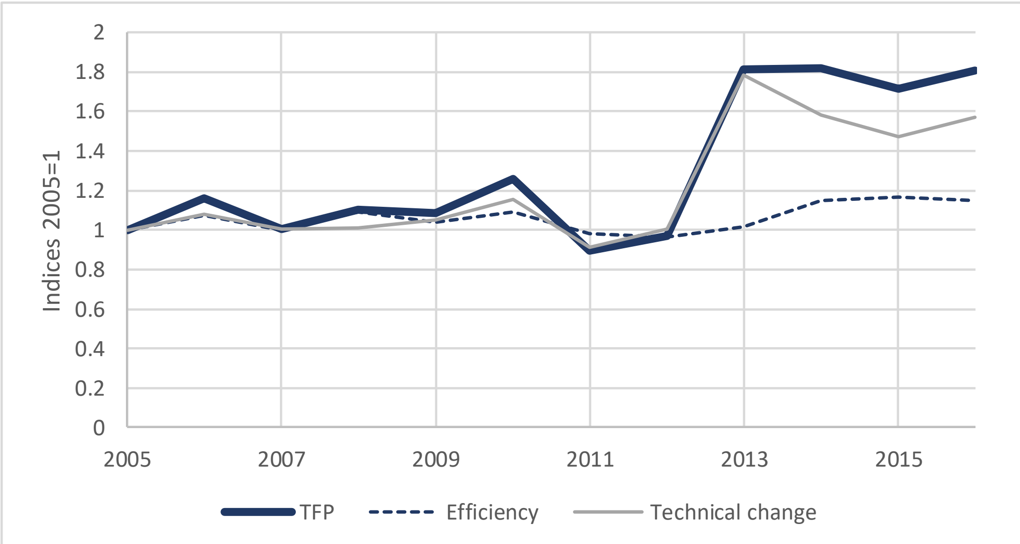
Figure 5.2– Indices of output, input and TFP, 2005-2016



Source: Elaborated by authors

The decomposition of TFP into efficiency and technology (potential output) is shown in Figure 5.3. Technical change has driven growth in recent years, explaining most of the increase in TFP, but efficiency also increased by almost 20 percent in the last five years. This means that the new technology used by beef producers in Paraguay allows them to produce 80 percent more output than the technology used in 2005. Producers are also more efficient than in 2005, which means that on average, production per unit of total input in 2016 was closer to the maximum level of production per unit of input that can be achieved with present technology.

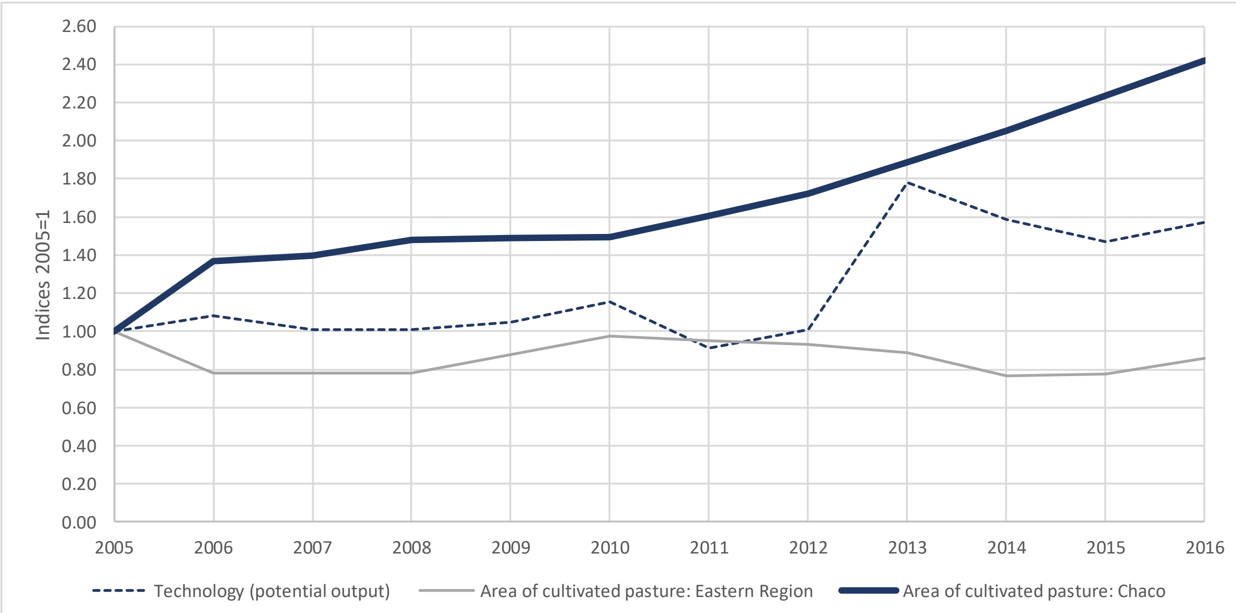
Figure 5.3– Indices of TFP, efficiency and technical change, 2005-2016



Technical change in beef production is directly related to the growing importance of the western region of Chaco in total output, and the increase in cultivated pasture in this region. As shown in Figure 5.4, there is high correlation between technical change, the increase in potential output, and the expansion of the area under cultivated pasture in Chaco. The increase in animal stock is also related to this growth pattern, as the stock in Chaco increased from 35 to 43 percent of total stock.

Table 5.1 shows changes in some indicators reflecting efficiency in fattening and reproduction. Reproductive efficiency remains low and with no sign of change during the analyzed period. Small and non-significant changes are observed in the average slaughter age of males. However, there seems to be an increase in the overall offtake rate from 0.11 to 0.13, which is still low compared to that of Uruguay (0.18 between 1997 and 2015). On the other hand, the offtake rate of females in the stock improved significantly, from 0.08 to 0.17, probably as the result of less unproductive cows kept in the stock, but it is still very low by any standards. Offtake rates of females in Uruguay increased from 0.1 in 1992-1995 to an average of 0.17 in 2007-2015 while offtake in males are still higher than in Paraguay (0.27 on average between 2007 and 2015).

Figure 5.4– Technical change and area of cultivated pasture in the eastern and western regions, 2005-2016



Source: Elaborated by authors

Table 5.1– Indicators of fattening and reproductive efficiency in beef production

	2008-2010	2013-2016
Slaughter age males	4.7	4.2
Reproductive efficiency [a]	0.25	0.25
Offtake rate	0.11	0.13
Offtake rate females	0.05	0.08
Offtake rate males	0.22	0.24

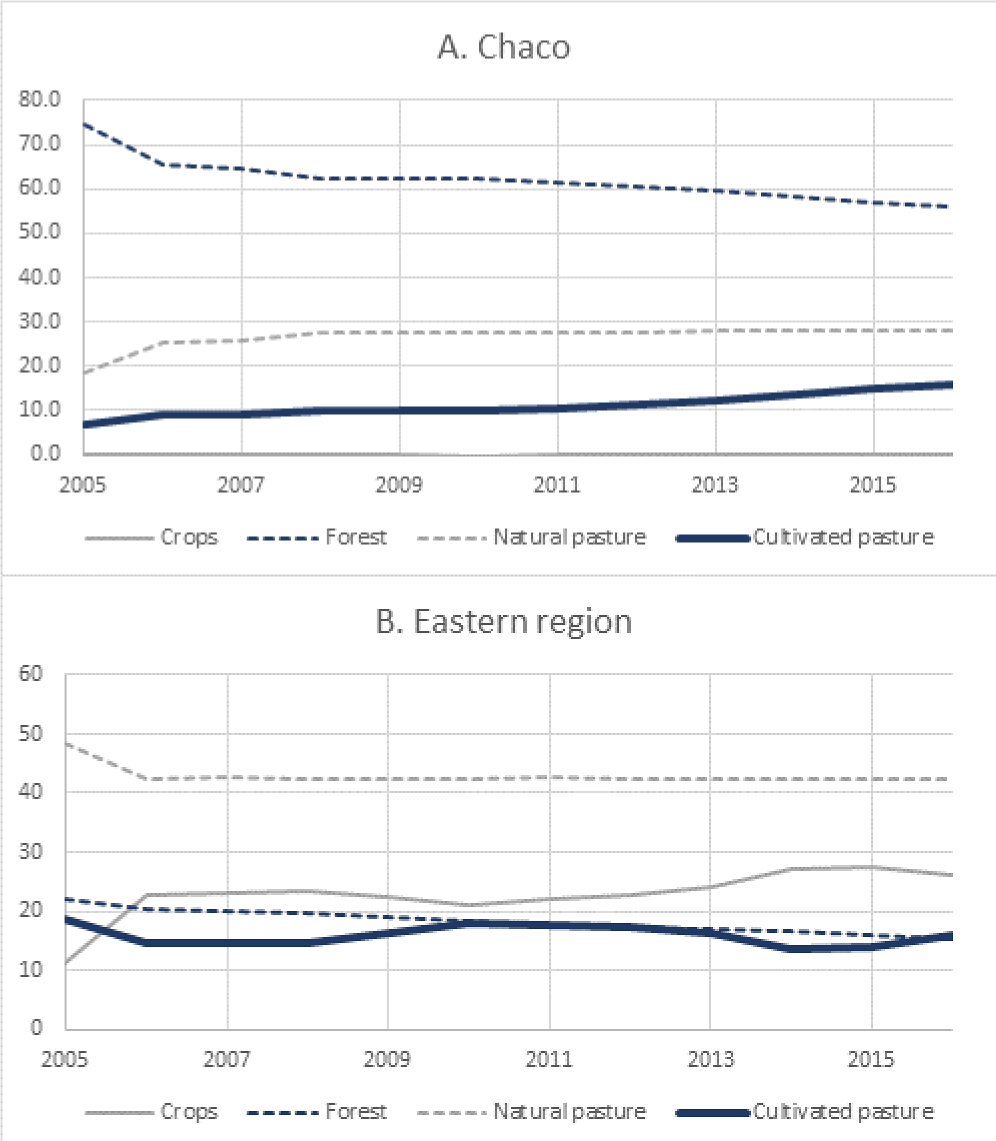
Source: Elaborated by authors

Note: a. Measured as the ratio of number of calves and number of females one-year or older

The observed changes in output production and technology had also implications for the environment. Figure 5.5 shows that the expansion of livestock production in Chaco reduced the share of total area under forest from 75 percent in 2005 to 55 percent in 2016, mostly as the result of an increase in cultivated pasture (Figure 5.5A) which increased from 6 to 16 percent of total area. These changes are in contrast with changes in the Eastern region, where area allocated to forest and pasture decreased in recent years as the result of an expansion in crop area. Notice that by 2016, the share of pasture in total area was the same in both Chaco and the Eastern region (16 percent).

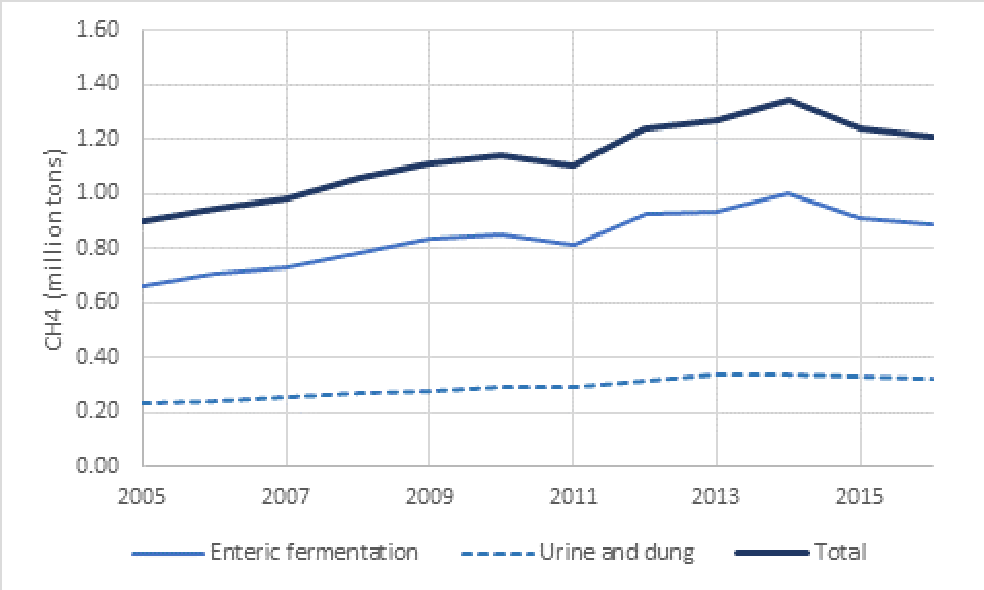
The implications of the expansion of beef production for the environment are accounted by the estimation of GHG emissions from cattle and by the effect of deforestation in Chaco. The evolution of GHG emissions between 2005 and 2016 is presented in Figure 5.6. GHG emissions increased significantly between 2005 and 2016, associated to the rapid growth in production. Total emissions increased from 0.90 million tons of CH_4 in 2005 to 1.21 million tons in 2016, an increase of 35 percent. Total emissions are decomposed into emissions from enteric fermentation and emissions from dung and urine. Of the 0.9 million tons of CH_4 emitted in 2005, almost 0.7 million tons resulted from enteric fermentation while 0.2 corresponded to emissions from dung and urine. By the end of the period, the contribution of each of these sources to total emissions show no major changes. With emissions increasing 35 percent and production increasing 242 percent, the volume of emissions per unit of output and per animal in stock decreased substantially after 2011, the period of strong technical change and output growth in beef production (Figure 5.7).

Figure 5.5– Evolution of land use in Chaco and the Eastern Region, 2005-2016



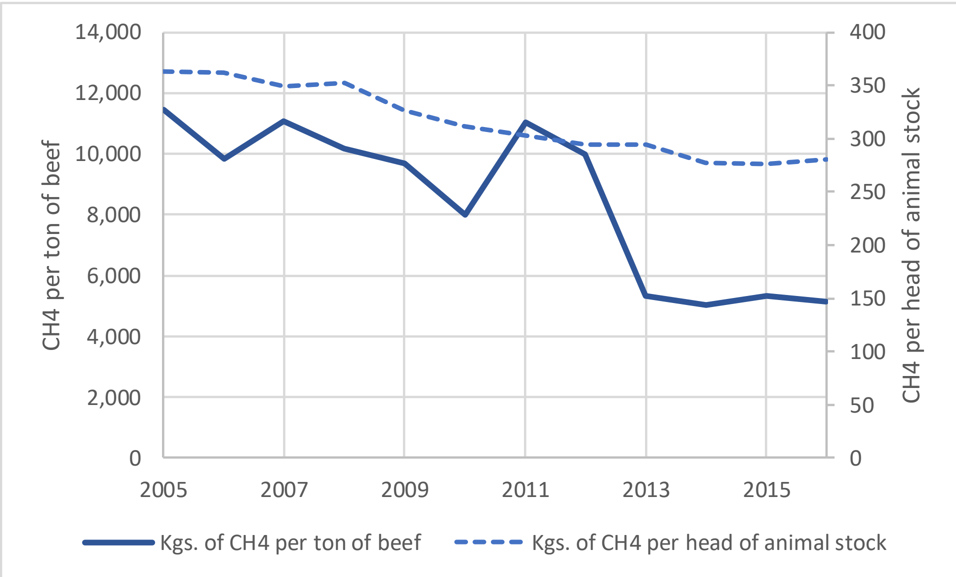
Source: Elaborated by authors

Figure 5.6–CH4 emissions from enteric fermentation and manure, 2005-2016



Source: Elaborated by authors

Figure 5.7–Total CH4 emissions per ton of beef and per head of animal in stock, 2005-2016



Source: Elaborated by authors

Note: Includes emissions from changes in carbon stocks due to deforestation

The reduction in the area under forest and its transformation into pasture also resulted in losses of carbon stocks as carbon is released when the forest is cut. Table 5.2 shows changes in land use in Chaco, and the reduction in the carbon stock that results from shifting land allocation from forests to pasture. Between 2005 and 2016, 2.5 million hectares of forests were converted to grazing land. These changes resulted in a loss of carbon stock (retained by vegetation above and underground) of 23.6 million tons of CH4 equivalents. Considering enteric and manure emissions together with biomass losses (Table 5.3), the overall release of C measured as CH4 equivalents was 37.1 million tons, equivalent to 3.38 million tons per year on average for the period, of which 2.15 result from biomass losses as the result of deforestation.

Table 5.2– Area changes of forests and pastures in Chaco and changes in carbon stocks, 2005-2016

	Forests	Natural pastures	Cultivated pastures	Total
Change in area (mill. Hectares)	-2.5	1.2	1.3	0
Change in biomass (mill. Tons of CH4 eq.)	-29.0	2.5	3.0	-23.6
Annual changes in biomass (mill. Tons of CH4 eq.)	-2.6	0.22	0.27	-2.15

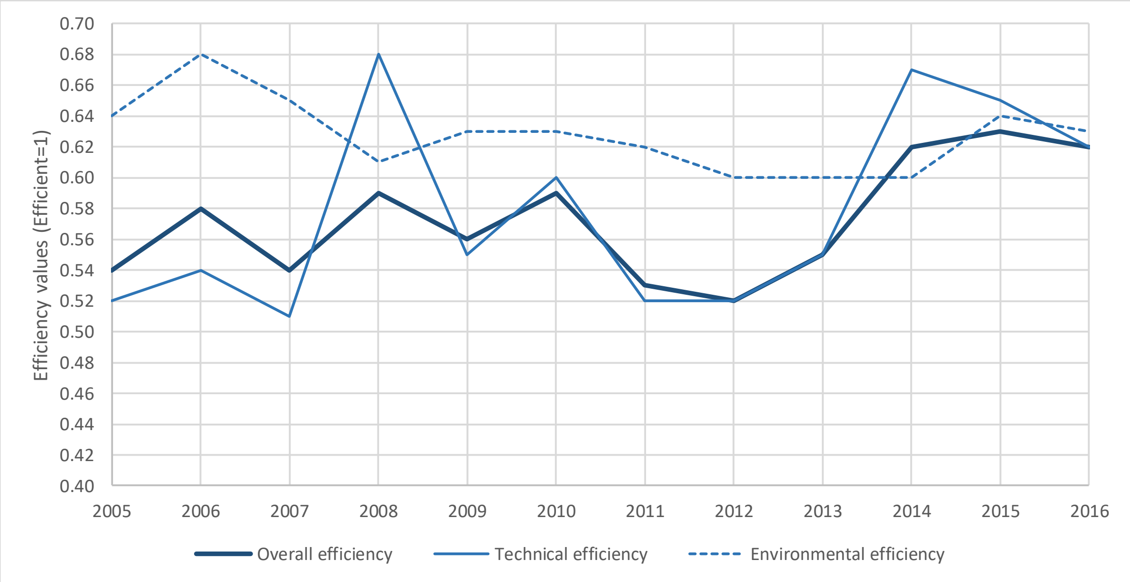
Table 5.3– Total emissions from livestock production, 2005-2016 (million tons of CH4 eq.)

	Enteric CH4	Manure CH4	Manure N2O	Biomass changes	Total
Total emissions	10.0	0.6	2.8	23.6	37.1
Annual emissions	0.91	0.06	0.26	2.15	3.38
Share	27.1	1.7	7.6	63.6	100

More evidence on the environmental effect of beef production and the adopted technology is provided by the decomposition of production efficiency into technical and environmental efficiency. This decomposition is shown in Figure 5.8. Notice that the performance of beef production in terms of efficiency fluctuates over the period. There is no clear trend in overall production and technical efficiency during the first half of the period, but we observe a reduction of environmental efficiency which was equal or greater to 0.64 between 2005 and 2007, falls below 0.62 in 2008 and fluctuates around this value during most of the rest of the period. Losses in efficiency are common during periods of rapid technical change, when adopters of the new technology move the technological frontier outwards and other farmers fall behind to these movements in the frontier. These results indicate that there is a significant margin to reduce emissions under the new technology. An increase in environmental efficiency from 0.63, as observed in 2016, to 0.85 would reduce the 2016 emissions from 1.2 million tons of CH4 to

roughly 0.89 million tons (a 25 percent reduction), which is similar to the level of emissions observed in 2005.

Figure 5.8–Decomposition of production efficiency into technical and environmental efficiency, 2005-2016.



Source: Elaborated by authors

6. LIVESTOCK, POLICY AND THE ENVIRONMENT

The performance of the livestock sector in Uruguay and Paraguay can be tracked back to specific changes in sectoral policy influenced by macroeconomic policy changes and changes in global markets. We identify four major periods during the last four decades, with different implications for agricultural and livestock development. Until to approximately the mid-1980s, the import substitution industrialization model, followed by most countries in LAC, was blamed for the poor performance of agriculture as it discriminated against it through exchange rate overvaluation, export taxes, protection of the industrial sector and direct market interventions. After the “lost decade” of the 1980s, LAC started a major revamping of its macroeconomic policy frameworks, a drive that was consolidated in the 2000s and that resulted in improved performance of the agricultural sector. Between 2002 and 2008, LAC benefited greatly of the more persistent and intense increase of prices of primary commodities since the 1980s. The commodity boom period lasted until the global crisis of 2008 and the world-wide recession that followed. Even in this last period, some LAC countries still presented relatively high growth rates while commodity prices remained at record levels. In what follows we look at changes in the economic environment experienced by Uruguay and Paraguay during these four periods and their impact on performance of the livestock sector. Appendix B presents an overview of the macroeconomic environment during the analyzed period in the two countries.

Policy changes in Uruguay, started in the mid-1970s and accelerated in the 1990s, a time when external events also contributed to changes in growth. We follow Peyrou et al. (2016), and Ilundain and Lema (2001), to summarize the salient aspects of the performance of the livestock sector in different periods to changes in public policy and to major technological, animal health and commercial milestones.

A key factor behind the improved performance of the Uruguayan livestock sector after 2003 is the change in policies that started in 1990, eliminating regulations and distortions that affected livestock production. During most of the twentieth century, the country followed public policies that transferred resources from competitive activities, such as livestock, to other sectors with the explicit goal of protecting the national industry. Different policy instruments were used for this purpose, some direct, as taxes on exports and the ban on exports of by-products such as hides; and some indirect, such as those used to prevent increases in domestic beef prices (a major staple food in Uruguay). Among the instruments used to control domestic prices was a government-owned and managed slaughterhouse, which was the only authorized supplier of beef to the capital city, where half of the country’s population lived, and the existence of “regulatory stocks" that aimed to prevent the rise in beef prices during periods of scarcity.

These measures discouraged investment in livestock and industrial production and were livestock-specific policies associated to the long stagnation of the sector.

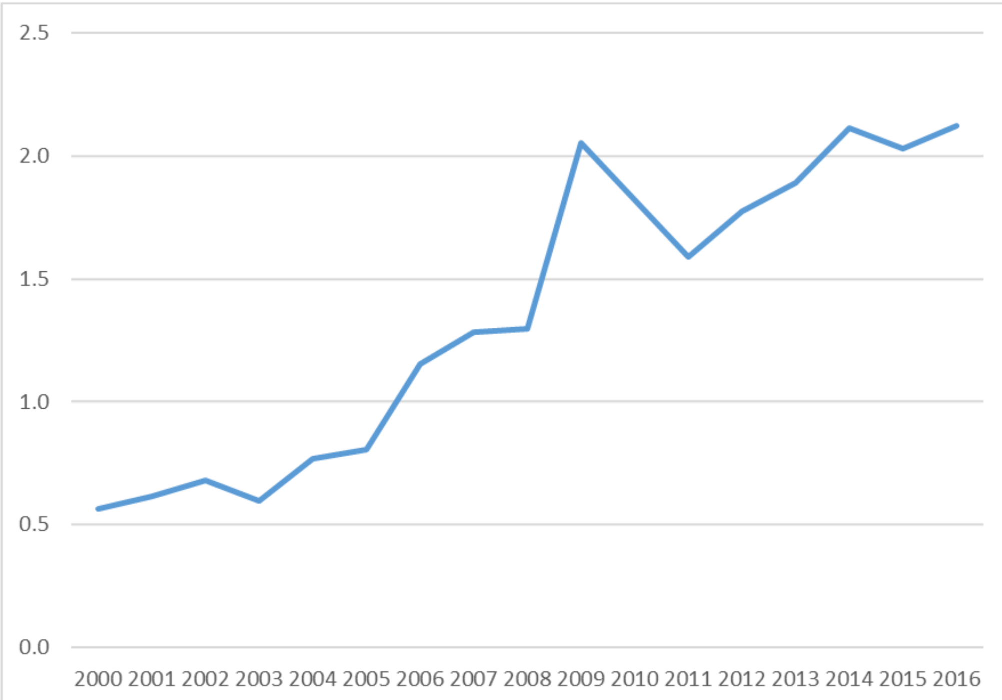
In 1978, the closing of the government's slaughterhouse and the deregulation of the meat processing industry, marked a milestone for the livestock sector and the beginning of a slow process of liberalization that extended until the 1990s. Some of the most important measures implemented during this process were the following:

- Elimination of taxes on beef exports by 1994 (from 15 percent in 1982)
- Introduction of a tax on real income that replaced a tax on presumptive income that operated as an indirect tax to land (1996)
- Elimination of the ban on exports of live cattle (1993)
- Elimination of the meat stock used to regulate the internal market (1993) which encouraged investment in improved pastures and changes in feed quality

These policy changes occurred simultaneously with the closing of the Uruguay Round of trade negotiations that created the World Trade Organization (WTO), incorporating agricultural trade for the first time into a system of multilaterally agreed rules. Changes in global trade rules resulted in an improvement in the commercial climate and had a favorable impact on the performance of the livestock sector in Uruguay.

The set of policy measures of the 1990s, and the expansion of crop production during the 2000s, had an impact on price relationships relevant for different actors in the livestock value chain. On the one hand, the deregulation measures, particularly the authorization to export live cattle, put a "floor" to the price of replacement categories (calves), which are inputs in the fattening process. In addition to the relative price improvement favoring young categories, main product of the breeding activity, the absolute price of the main categories also showed a favorable evolution. Higher prices of livestock products improved the terms of trade of the sector with respect to several inputs, except for fuel and labor which increased significantly during the analyzed period. However, the most relevant change, in terms of price relations and its implications in the competition for the factors, occurred with respect to land. The increased productivity and higher revenue per hectare that resulted from growth in soybean production transmitted to land prices as shown in Figure 6.1. In 2000, one hectare of land could be bought for the equivalent of half-ton of beef. Sixteen years later, the price more than quadruple going beyond 2.0 tons of beef per hectare.

Figure 6.1–Tons of beef needed to buy one hectare of land (national averages)



Source: Author's based on data from DIEA and INAC

Unlike Uruguay, the livestock sector in Paraguay was never a heavily regulated sector. In fact, development and growth of beef production and exports were facilitated by the country's domestic policy environment, with fewer regulations and lower fiscal pressure than in neighboring countries. A high proportion of government's revenue corresponds to indirect taxes, with an overall average tax burden of 11.7 percent, compared to 21 percent in other countries in the region, according to Borda and Caballero (2015). In recent years, the government introduced reforms to improve the design and efficiency of direct taxes, including the introduction of a tax on agricultural income (IRAGRO) that replaced the previous IMAGRO which, as in the case of Uruguay, by taxing presumed income was equivalent to a tax on land, and a very inefficient collection instrument. The new IRAGRO imposes a rate of 10 percent on net agricultural income, lower than that applied to business income in other countries of the region (25 percent in Uruguay, 27 percent in Chile, 35 percent in Argentina and 25 percent in Bolivia).[8] Land taxes are managed by municipalities but collect very low revenues, apparently because they are calculated with

[8] These comparisons are just indicative as we did not consider any differences in deductions, etc.

undervalued land prices. There are no other relevant direct taxes that affect livestock, and the application of export taxes to grains, particularly soybeans, is under discussion. Low taxes and low prices of land in the Chaco region, have been an incentive for investment in the livestock sector during the analyzed period, but the key drivers of the sector were technical change and access to export markets.

Markets and animal Health

Simultaneously to changes in sectoral policies in Uruguay, important changes occurred in market access, largely due to improvements in health status. The major of these improvements was the condition of free of foot-and-mouth disease (FMD) with vaccination achieved by the country in 1993. The government stopped vaccinating animals in 1994, and by 1996 the livestock sector was declared free of FMD without vaccination. This allowed access to major markets, such as a 20,000-ton beef quota to the US, and access to the Korean and Japanese markets. However, these achievements were reversed by the reappearance of FMD in 2000/2001, that hit the Uruguayan economy almost simultaneously with the national and regional financial crisis of 2002. Vaccination was resumed after the outbreak of FMD in 2001, and the status of country free of FMD with vaccination was rapidly recovered and with it, access to several markets, although 90 percent of sales were concentrated in five markets (NAFTA, EU, MERCOSUR, Israel, Russian Federation and China). The status of Uruguay as country free of FMD with vaccination recovered in 2003 continues to this day, while the ability of the country to control and accurately report on its animal health situation, has given Uruguay presence and recognition in livestock trade and health organizations like the World Organization for Animal Health (OIE) and allowed the country to establish agreements with animal health authorities in major markets. One of the main achievements in terms of market access was admission to a new quota (481)[9] in the European market with zero tariff for beef from young animals fattened in feedlots. Although this quota represents only 4.0 percent of total beef exports from Uruguay, it came as a quantitative milestone because it allowed the country to export all beef cuts as part of the quota (unlike Hilton and other quotas limited to specific quality cuts), and because it was a learning-by-doing experience for producers fattening animals with grain.

In the case of Uruguay, the most significant recent changes in the livestock sector are related to access to markets, the strengthening of the public institutions regulating the sector, the promotion of

[9] Access to this quota resulted from a dispute between US and the EU for the European ban on exports from animals raised with hormones. The US won the dispute, so the EU allowed imports from the US under the 481 quota. Later, other exporting countries (Canada, Australia, New Zealand, Uruguay and Argentina) were authorized to supply the EU market through this quota with no tariffs.

livestock products abroad, and the implementation of a universal and mandatory system of individual animal traceability. The responsible entity of animal health is the Directorate General of Livestock Services (DGSG), an executive unit belonging to the Ministry of Livestock, Agriculture and Fisheries (MGAP). The DGSG deals with all aspects of health and safety of commercial animal species (cattle, swine, sheep and poultry), as well as consumer products such as meat and milk. Recently, a national accreditation system was approved by law, which allows the participation of independent veterinaries in the execution of health programs under the responsibility of the DGSG. This represents an innovation in the country, since the public service used to monopolize these services. Public funds to fund the DGSG in 2017 included $40 million directly from government budget and an additional tax of 1 percent, applied to the FOB value of meat exports, designed to fund a Sanitary Inspection Fund (FIS), which is managed by the DGSG.

Quality control and promotion of production and exports are under the National Meat Institute (INAC). From the end of the 1990s, INAC, a non-government public organization that includes representatives of the government and of the private sector, was strengthened financially and institutionally to play more efficiently its role of quality control and promotion of animal products abroad.

The traceability system began with a pilot phase in 2004, became mandatory for all new births in 2008 and for the entire stock in 2010. In addition, the growth of the export supply and access to markets, resulted in changes in the meatpacking industry with investments of major worldwide players, most of Brazilian origin. More recently, Asian capitals from China and Japan also invested in the sector but their share in the industry is still small.

In Paraguay, access to external markets, essential for growth in beef production, had a decisive milestone in the institutional and technical changes linked to animal health, especially to the so-called diseases of trade such as FMD. In addition to improving the health status of Paraguay's cattle stock, the changes resulted in significant improvements in the certification of health status and traceability and control of disease breakouts, all decisive factors in negotiating access to new markets. These changes were the result of Law 2426/2004, which in 2004 replaced the SENACSA (National Animal Health Service), an institution under the central government, creating the "new" SENACSA (National Service for Animal Health and Quality), an autonomous organization under public law, better endowed to provide health services and implement health and quality regulations and policies. The new SENACSA improved the specialization of negotiators and created conditions for an active participation of the private sector in the system. A decisive instance of this participation occurred through the Animal Health Committees, of local conformation, with relevant integration of delegates of producer's associations and unions. Among the functions of these committees are assisting SENACSA and participating in the preparation, supporting and

supervising of vaccination plans. The Inter-institutional Commission for the Eradication of Foot-and-Mouth Disease, which operates as part of SENACSA, collects and manages funds obtained from livestock transactions used to fund vaccination and preventive campaigns. Another area of public-private collaboration is the Meat and Leather Sector Board, under the umbrella of the Investment and Exports Network (REDIEX), an export promotion program of the Ministry of Industry and Commerce.

Paraguay began its foot-and-mouth disease (FMD) eradication program in 1992, achieving FMD free status in 1997, a time when the condition was reported by the countries themselves. After the disastrous appearance of FMD outbreaks in 2002-2003 in the region, the new SENACSA was able to recover the status of free of FMD with vaccination in 2005, a status granted by the OIE, which allowed Paraguay access to new markets. Breakouts of FMD occurred again in 2011 - 2012, but Paraguay recovered its condition of free of FMD with vaccination in 2013.

In terms of export destinations and their evolution, two of Paraguay's most important and consistent destinations for beef exports since 2017 are Chile and Russia, which together account for between 50 and 80 percent of Paraguay's total exports. As beef markets are differentiated by prices, their reputation and the leading effect they have on other markets, access to Chile's market, a demanding market in terms of animal health and quality control of its imports, represents an achievement for Paraguay that can now target major market (it is in talks with the US). The Russian market, on the other hand, less demanding, has represented a first step in access to markets, and is important for the volumes it demands.

One of the constraints for future growth faced by Paraguay is that it has not been able to access the Chinese market because of diplomatic relations with Taiwan, which hinder the possibility of expanding exports to China. Asian markets (where China has the largest share) accounted for 30 percent of MERCOSUR exports in 2013, and 50 percent in the case of Uruguay's value of exports in 2017. On the other hand, Paraguay is currently negotiating access to the USA market, and could access high-value meat quotas in the EU by improving its monitoring and certification processes. Access to the most demanding Asian markets (for example, Japan and Korea) could follow, but will require extensive auditing and certification processes.

Policy and the environment

In 2015, 196 Parties came together under the Paris Agreement aiming at limiting global warming to 1.5 to 2 degrees Celsius above pre-industrial levels. At the center of the Agreement are the nationally determined contributions (NDCs), which embody efforts by each country to reduce national emissions

and adapt to the impacts of climate change, to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of this century. Uruguay presented global 2025 climate change mitigation objectives of its NDC regarding intensity in relation to its gross domestic product and to base year 1990.[10] It also included specific objectives related to Food Production (beef), land use, land-use change and forestry (LULUCF sector) and distinguishes between unconditional objectives and objectives which are conditional on additional specific means of implementation. These objectives cover 99.4 percent of the GHG emissions of the National Greenhouse Gases Emissions Inventory of 2012 (NGHGI 2012). NGHGI 2012 is the latest inventory available and submitted to the Convention.

According to NGHGI 2012, CH_4 emissions in Uruguay account for 43 percent of the total emissions. Additionally, 93 percent (746 Gg) of total CH_4 emissions were generated in the agricultural sector, while the waste sector accounted for 6 percent (47 Gg) of emissions, and the energy sector for the remaining 1 percent (6 Gg). In agriculture, beef production accounted for 83 percent of emissions (622 Gg), which represented 78 percent of the total CH4 emissions. Given the relevance of emissions in beef production, Uruguay must mitigate climate change in a way that does not threaten food production, which means that the national challenge focuses on reducing emission intensity per unit produced.

As part of its commitments to the Paris Agreement, Uruguay set a 2025 unconditional mitigation objective for an intensity reduction (CH4 emissions per unit of beef cattle produced, measured in kg of live weight) of 32 percent compared to 1990 values and an aspirational 37 percent mitigation objective conditional on additional and specific means of implementation (Table 6.1).

[10] This section summarizes main aspects of the First Nationally Determined Contribution approved by Executive Decree number 310 in November 3rd of 2017, in the framework of the Paris Agreement, ratified by Uruguay on October 19th, 2016.

Table 6.1 – Specific objectives for GHG emission intensity regarding livestock production

Unconditional	Conditional on additional specific means of implementation	Food production activity
32% reduction in CH4 emissions intensity per product unit (kg of beef cattle measured in live weight)	37% reduction in CH4 emissions intensity per product unit (kg of beef cattle measured in live weight)	Beef production (33.6% of GHG emissions)
34% reduction in N2O emissions intensity per product unit (kg of beef cattle measured in live weight)	38% reduction in N2O emissions intensity per product unit (kg of beef cattle measured in live weight)	Beef production (17.5% of GHG emissions)

Source: Uruguay: First National Determined Contribution (2017)

The same source indicates that N_2O emissions in Uruguay account for 34 percent of the total emissions of the NGHGI (AR2 GWP100). Additionally, 98 percent (42 Gg) of total N_2O emissions were generated in the agriculture sector, while the waste sector accounted for 1 percent (0.4 Gg) of emissions, and the energy sector for the remaining 0.6 percent (0.3 Gg). In agriculture, beef production accounted for 52 percent (22 Gg), which represented 51 percent of the total N_2O emissions. As in the case of CH4 emissions, efforts to mitigate N_2O emissions generated by this activity have focused on the reduction of emission intensity per kilogram of live cattle produced. The goal is to have a 2025 specific unconditional mitigation objective of 34 percent compared to 1990 values and an aspirational mitigation objective of 38 percent, conditional on additional and specific means of implementation by 2025.

As shown in our results, Uruguay has significantly reduced the intensity of emissions in beef production, and evolution is explained by the increase in productivity thanks to the national and international economic contexts and the implementation of public policies that supported the private sector in the process of adopting productivity enhancing technologies. These actions have been reinforced since 2010 with the implementation of the Climate-Smart Agricultural Policy. It is particularly worth noting those actions that seek to promote the adoption of technologies for forage management in the phases of cattle breeding and raising, based on natural grasslands feeding, as well as cattle management measures,

which improve the efficiency of beef production and, at the same time, eliminate carbon loss from soils, and can increase its stocks. Table 6.2, taken from Peyrou (2016), synthesizes the evolution of livestock performance and related policy changes, identifying three different periods of performance. Notice that Uruguay's reduction in emissions intensity has been related to improvements in the quality of feed. With stagnated area of cultivated pasture and still with a small share of grain-fed cattle, the pace of reduction of emission intensity could be compromised in the coming years.

Table 6.2–Uruguay: Policy, institutional and technical m milestones in the livestock sector

	Stagnation **1935-1990**	Growth **1990-2006**	Slowdown **2006 - Present**
Growth rate	0.10%	3.40%	0.10%
Ratio Export/Output	37% al 39%	39% al 80%	80% al 70%
Technology	Area of cultivated pastures is less than 9% of livestock area	Area of cultivated pastures reaches 16% of livestock area. Use of grain and supplements for fattening, starts	Area of cultivated pastures falls to 12% of livestock area. Expansion in the use of grain and supplements
Industry	Nationally owned, with recurrent financial crises	Increased in foreign investment	Consolidation of foreign investment; introduction of new market institutions like production under contracts; growing number of feedlots
Markets	FMD markets	Access to FMD free without vaccination markets; Loss of FMD free without vaccination status, losing access to markets Recovered FMD free status but with vaccination, and recovered access to markets	Similar sanitary conditions as in previous period. Access to 481 quota for high-quality beef in the EU Access to major markets in East Asia, including China
Policy	Highly regulated and strong government intervention in meatpacking industry	Market liberalization and de-regulation	Market liberalization and de-regulation in place, with partial and heterodoxic interventions

Source: Adapted from Peyrou et al. 2016.

Paraguay has not presented specific NDC goals for livestock but regarding the livestock activity itself, the adaptation of the technology associated with the change of land use with developed and improved pastures in Brazil and Colombia, was the driving force of technical change and the increase in productivity, being accompanied by changes in genetics and management. Because expansion of beef production in Paraguay occurred through increased deforestation, the environmental constraint is one of the major challenges faced by the sector to sustain growth in the future. So far, and despite opposition and complaints from civil society organizations, Paraguay has a regulatory framework in general environmental matters, forest resources and water, mostly designed to attract investments. The Forest law No. 422/73 and its Regulatory Decree 11,681 / 75, more than 40 years old, play a key role in environmental regulation by establishing strong restrictions in some reserve areas, but allowing the advancement of livestock activity, provided it is carried out in accordance with a plan for land allocation, approved by the authority. These plans are required to all farms bigger than 20 hectares, and they need to show land use that keeps a minimum of 25 percent of the original forest area in a single continuous block. If the farm does not reach this percentage when the plan is presented, the owner must replace 5 percent of the total area of the property with forest. In addition, it prevents the removal of surfaces greater than 100 hectares. In this case, frequent in the Chaco, the establishment of forest strips of 100 m wide between parcels and plots is required.

Technology

Cooper, Boston and Bright (2013), group abatement options for livestock emissions into two main categories: new technologies targeting changes in animal metabolism, and farm-management options. Currently, as explained in Cooper, Boston and Bright (2013), the technologies available to reduce livestock emissions are limited. For example, as methane production is affected by the composition of ruminant diets, decreasing the relative proportion of fiber to starches or carbohydrates consumed by animals would reduce CH_4 emissions. However, there are practical economic impediments to changing livestock feed regimes, especially in extensive pastoral systems as those discussed here. Cooper, Boston and Bright (2013) conclude that other options, such as the manipulation of the rumen microbial ecosystem and vaccinations to stem methanogenesis, continue to be researched, but their potential to reduce agricultural GHGs remains uncertain.

According to Rodriguez et al. (2015), climate change research in LAC has focused on the emission and mitigation of greenhouse gases, underscoring the importance of promoting a research agenda that gives greater relevance to issues of adaptation, policy, impacts and food

security. For example, Rodriguez et al. (2015) point out the need to go beyond crop specificities by adopting systemic research approaches that include related human and social aspects and enhance the link between innovation and technologies for adaptation, the measure of the ability of systems to adapt, and the types and the paths of adaptation (Rodriguez et al. 2015).

Pezo et al. (2018) summarize technological options for LAC countries with potential to be used for livestock production intensification that are compatible with climate change adaptation and the mitigation of its effects. The technologies differ in terms of: (i) their current and potential contribution to the adaptation and mitigation of climate change; (ii) the scientific and technical development of the proposals and the degree of validation of their effects; (iii) the feasibility of these technologies and the possibility of adoption at the farm level. Some of these technologies are based on widely proven knowledge and include adaptation to climate change and mitigation of its effects, but others will require more research to determine their technical and economic feasibility.

Among the technologies mentioned by Pezo et al. (2018) based on widely proven knowledge are the rational use of the land and management of cultivated pastures. High production pastures are beneficial because they could lead to a reduction in land use in agriculture; they capture more carbon because of their more developed root systems; and they have higher digestibility and nutritional value, which results in increased livestock productivity while reducing intensity of emissions. For example, In lands with steep slopes, weak soil structure or degraded pastures, techniques that protect plant cover, such as zero-tillage, or temporary relief of grazing pressure using supplementation, are needed to increase productivity of pastures and achieve the benefits associated to this increase. In pastures with high production potential, the first step in the process of rationalization, given available knowledge, is the improved management of inorganic fertilizer. The strategic use of supplements is also recommended to generate a more efficient use of available pasture, reduce productivity losses and the intensity of enteric CH4 emissions. The use of supplements is especially important in pastoral systems facing critical periods of forage supply. Available supplements and their use are technically validated, but there is the need of a greater dissemination of these supplements to better balance diets and fiber concentration. Also needed is the use of some form of food processing (chopping, grinding, "pelleting" or others) that inactivate enzymes or other compounds in addition to improving the intake (Pezo et al. 2018).

In agreement with Cooper, Boston and Bright (2013), Pezo et al. (2018) states that there is a large number of technologies with potential to contribute to a more environmentally efficient livestock sector, but most of them are still in an experimental stage with no definitive evidence on their benefits or their collateral effects. For example, trees and other perennial

woody species can have an important effect in intensifying and diversifying production and acting as buffers for the systems against the risks associated with climate change (silvopastoral systems). There are a variety of systems, tested or in the experimental phase but their results are not conclusive in general, nor its economic feasibility at the farm level.

Other technical options that require more research and validation are: identification and evaluation of forage species that contain bioactive compounds that reduce methanogenic activity; and handling of ruminal fermentation with exogenous compounds like inoculation of various organisms and substances in the rumen that can compete with the producers of CH4. Examples of these substances or organisms are, enzymes, yeasts, ionophores, and other additives to the diet, or the production of vaccines that promote antibodies that inhibit methanogenic microorganisms. However, evidence about magnitude and persistence of the effects of these practices, or of the possibility of negative collateral effects, is still not consistent, and more research to support the feasibility of this mechanism is needed, given the complexity of interactions in the ruminal ecosystem (Pezo et al. 2018).

One of the possible paths to follow in the future is to incorporate the environmental perspective in the process of pasture genetic improvement. The work by Pezo et al. (2018) cites the case of some Brachiaria species (B. humidicola, B. decumbens), which produce biological inhibitors of nitrification and thus reduce N2O emissions. Although recent studies indicate that the effect would be largely neutralized by greater releases of NH3, an eventual precursor of N2O. In addition to the selection of pasture vegetables, there is a promising way forward in the genetic selection of animals. Preliminary work has detected variability in the intensity of emissions although the results are not yet consistent, and cooperative efforts are required to identify the parameters that are key to selection processes.

Additional sources of CH4 associated with livestock production include effluent ponds and manure, both of which are significant sources of emissions from dairy livestock and are also associated with non-ruminant livestock production including pigs and poultry. There are various strategies for dealing with emissions that arise from manure and effluent ponds. Strategies such as improving the utilization of nitrogen, better irrigation or drainage to lower nitrate leaching, use of nitrification inhibitors, and reduced animal grazing during wet seasons could reduce N2O emissions by 15 percent in grazing-based systems and by up to 50 percent in animal housing systems according to Cooper, Boston and Bright (2013). They also cite studies claiming that up to 70 percent of N2O emissions could be eliminated by better management of nitrogen flows, particularly through improved efficiency in applying fertilizers, restricted grazing, and use of maize silage. Combining several of these strategies can lead to significant reduction of overall emissions, although the level of abatement could vary depending on regional differences.

However, many of these options may be of use in intensive livestock operations where the movement of animals is closely managed or housed but are less useful in extensive grazing systems for beef cattle and sheep or in open dairy production (Cooper, Boston and Bright, 2013).

We conclude that there is no clear technology path available for the reduction of GHG emissions from livestock production in LAC. The evidence shown in this study points to the need of improving on the quality of feed and management of different animal categories, reducing the number of unproductive categories in the stock and the amount of GHG emissions per unit of output, which will may only limit, rather than reduce, further increases in livestock emissions. These has been the approach followed by Uruguay in its NDCs, and in which Paraguay has even a larger potential to further reduce emissions per output or animal unit given the existing baseline from which improvements can be made. Furthermore, the major challenge for the region seems to be the deforestation associated to the expansion of livestock production in countries like Paraguay (Bolivia and Colombia), but this problem goes beyond the livestock sector to more general definitions on land use, protection of natural resources and in many cases, effective enforcement of laws and policy measures already in place.

7. DISCUSSION AND CONCLUSIONS

This study looks at recent trends and performance of livestock production in Uruguay and Paraguay, analyzing two situations with different implications for development. The first situation is that of Uruguay and eastern Paraguay, where growth of soybean production displaced livestock from some the most productive lands. The second situation is that of livestock production expanding the agricultural frontier in western Paraguay through deforestation. Results for Uruguay show that the aggregated cattle and sheep production sector has seen a historical increase in productivity after 2002, driven by technical change as the result of the expansion of a more productive cattle stock that drove the stock of sheep to historical lows. Two major changes seem to have driven TFP growth in cattle. The first is a change in nutrition, which explains the second change: a change in the structure of the animal stock. Changes in nutrition resulted from an increase in the area under cultivated pasture and the use of grain and supplements associated to growth in dairy production and to more intensive fattening of cattle. The change in animal stock structure occurred in the stock of male cattle, with a reduction in the number of animals of three or more years of age and an increase in the proportion of young steers (1-2 years old). Also remarkable was the increase in the offtake rate of females as the result of a reduction of breeding age, increase in the number of productive cows in the stock, and improved management of animal stock and pasture improved the performance of the breeding stock. The overall result of these changes was a reduction in the slaughter age of steers (from 4.5 to 3.5 years), an increase in the offtake rate in cattle production and the increased share of milk production in total output, displacing wool as the second major output from livestock production.

In Paraguay, beef production more than doubled between 2005 and 2016, driven by technical change and a significant contribution of efficiency growth. Results show that technical change in beef production was directly related to the growing contribution of the western region of Chaco to total output, and to the increase in cultivated pasture in this region. A major development driving changes in the livestock sector was the expansion of soybean production in the Eastern region after 2006. Rapid growth of soybean production impacted on land prices, creating the conditions for the expansion of livestock production into Chaco's agricultural frontier. The adoption of high yielding tropical cultivated pastures well adapted to growing conditions in the western region, together with improvements in genetics of the animal stock were the main drivers of increased productivity. Our results show that after 2011, the share of cultivated pastures in total area in Chaco went from 10 to more than 15 percent, coinciding with the increase in TFP and efficiency in cattle production at the national level.

A key factor behind the improved performance of the Uruguayan livestock sector after 2003 and a major determinant of technical change is the change in policies that started in 1990, eliminating regulations and distortions that affected livestock production, a process that started in 1978 with the closing of the government's slaughterhouse and the deregulation of the meat processing industry. Simultaneously to changes in sectoral policies in Uruguay, important changes occurred in market access, largely due to improvements in health status. This was achieved by strengthening of the public institutions regulating the sector, the promotion of livestock products abroad, and the implementation of a universal and mandatory system of individual animal traceability. The capacity of the country to control and accurately report on its animal health situation, has given Uruguay presence and recognition in livestock trade and health organizations and allowed the country to establish agreements with animal health authorities in major markets.

Development of the livestock sector in Paraguay was facilitated by the country's domestic policy environment, with fewer regulations and lower fiscal pressure than in neighboring countries. Apart from the technological innovations in livestock genetics and pastures, access to external markets, had a decisive milestone in the institutional and technical changes linked to animal health. In addition to improving the health status of Paraguay's cattle stock, the changes resulted in significant improvements in the certification of health status and traceability and control of disease breakouts, all decisive factors in negotiating access to new markets. The service for animal health (SENACSA), an autonomous organization under public law, improved the specialization of negotiators and created conditions for an active participation of the private sector in the system, and facilitated access of Paraguayan livestock products to markets like Chile and Russia, with the possibility of accessing the US market in the future.

With respect to the environmental impact of the livestock sector, emissions by cattle in Uruguay increased modestly between 1995 and 2015, but this growth was compensated by reduced emissions resulting from the reduction of the stock of sheep. The overall result was a significant reduction in emissions per unit of output, not only for the aggregated ruminant sector but also for cattle. Environmental efficiency in Uruguay is relatively high and has not changed significantly during the analyzed period.

The environmental aspect and the emission of GHG, appears to be more of a constraint for future livestock growth in Paraguay than in the case of Uruguay. GHG emissions from enteric fermentation are high compared to emissions in Uruguay. Emissions were reduced by half with increased TFP and environmental efficiency even decreased, so there is still a wide margin for improvement. Adding to this problem, the expansion of livestock production in Chaco takes place through the expansion of the agricultural area into forest land. As shown before, low

productivity livestock production on natural pasture results in very high levels of GHG emissions per unit of output and will require more area of forest converted to pasture to sustain the same level of output. In a similar line of argument, deforestation of low-quality soils with very low productivity potential and high risk of degradation as in some regions in Pte. Hayes and near the Pilcomayo river is more difficult to justify and could have a high cost for the environment.

Despite positive developments in the last three decades, the livestock sector in Uruguay still faces major challenges to sustain growth in the future. Some of these challenges were already evident in the past ten years. The first challenge for the sector is to accelerate TFP growth. Our results show that TFP increased significantly between 2002 and 2006, experienced negative growth after this year and showed signs of recovery in the last years of the analyzed period, but it is still too early to tell if this recovery will be sustained. Three technical issues are related to stagnated TFP. First, no further reduction in the slaughter age of steers occurred after 2006. Second, no major changes occurred in reproductive efficiency (which remains at about 0.43). Third, the expansion of the area of cultivated pasture occurred during the 1990s, coinciding with a historical increase in the offtake rate and the reduction in the slaughter age of steers. However, future expansion of the area of cultivated pastures will face competition for land from agriculture (soybean), a fight that beef production is unlikely to win given land prices and soybean technology. This could mean that productivity growth based on pastures might have reached its ceiling in 2005, with future improvements in feed quality increasingly depending on the use of grain and supplements. Although this is technically feasible, there is no clear evidence of the economic feasibility of increasing the ratio grain/pasture to sustain productivity growth in different production systems.

As in the case of Uruguay, the livestock sector in Paraguay still faces major technological challenges to sustain growth in the future. A more in-depth analysis is needed to determine the factors explaining the slowdown in TFP and output after 2013, but the information available shows a clear future path to increase productivity. Reproductive efficiency is low and major gains can be achieved by improving management and nutrition of the breeding stock by expanding the area of cultivated pasture and with the strategic use of grain and supplements, as was the case in Uruguay in recent years. There is also a wide margin to further reduce the slaughter age of males and improvements in these areas could result in significant increases in the offtake rate.

In terms of market access, the recently opened Asian markets offer Uruguay potential for very good prices, and product placement (cuts, offal) that in general are worth little in other markets. However, commercial agreements with other suppliers limit the possibilities of effective access to these markets. Without access to markets that pay a premium for high-

quality products, there will be limited possibilities to expand the use of grain as feed in beef production. Conversely, Uruguay has shown that it is possible to access the most demanding Asian markets even with FMD vaccination if the country builds a reputation of adequate food safety control.

One of the constraints for future growth faced by Paraguay is that it has not been able to access the Chinese market because of diplomatic relations with Taiwan, which hinders the possibility of expanding exports to China. On the other hand, Paraguay is currently negotiating access to the USA market, and could increase high-value meat quotas in the EU by improving its monitoring and certification processes. Access to the most demanding Asian markets (for example, Japan and Korea) could follow, but will require extensive auditing and certification processes. Would it be necessary to implement universal and mandatory traceability as in Uruguay? Is it possible for LA countries to follow alternative paths as those of Australia and other exporters by scaling up voluntary and partial systems?

With respect to livestock production and the environment, we found that there is no clear technology path available for the reduction of GHG emissions. There are many technologies with potential to contribute to a more environmentally efficient livestock sector, but most of them are still in an experimental stage with no definitive evidence on their benefits or their collateral effects. For example, silvopastoral systems can have an important effect in intensifying and diversifying production and acting as buffers for the systems against the risks associated with climate change, and there are a variety of systems, tested or in the experimental phase but their results are not conclusive in general, nor its economic feasibility at the farm level.

For now, the path followed by Uruguay in its NDCs for the Paris Agreement, setting mitigation objectives for an intensity reduction of emissions, could be followed by Paraguay and other countries and could be achieved by improving on the quality of feed and management of different animal categories, reducing the number of unproductive categories in the stock and the amount of GHG emissions per unit of output. Paraguay has even a larger potential than Uruguay to further reduce emissions per output or animal unit given the existing baseline from which improvements can be made. Furthermore, the major environmental challenge for the region seems to be the deforestation associated to the expansion of livestock production in countries like Paraguay (Bolivia and Colombia), but this problem goes beyond the livestock sector to more general definitions on land use, protection of natural resources and in many cases, effective enforcement of laws and policy measures already in place.

Finally, the lessons learned from past performance of the livestock sector in Uruguay show that distortions and regulations could affect investment, technical change, growth and development of the sector. Although distortive livestock policies are no longer in place in

Uruguay, there are other policy practices that could have also significant negative effects on development of the livestock sector and other competitive sectors in LA. That is the case of macroeconomic policies that result in real exchange rate cycles, a recurring feature of the Uruguayan economy since the 1970s. The appreciation of the real exchange rate in Uruguay has served to choke off tradable activities, rendering growth less sustainable and more susceptible to negative shocks. Similar patterns on the effect of the exchange rate on growth were observed in Paraguay, with similar consequences on export commodity prices.

REFERENCES

Bervejillo, J. 2013. “Variabilidad regional de la productividad ganadera”. MGAP, Anuario OPYPA 2013. 277 - 287

Borda, D. y M. Caballero. 2016. Eficiencia y equidad tributaria: Una tarea en construcción. *Población y Desarrollo*, 42: 81-91.

Caputi, P. and J. M. Murguía. 2003. “Análisis del Crecimiento Ganadero a Través de un Modelo de Equilibrio.” *Agrociencia* VII(2): 79 – 90.

Cooper, M. H., J. Boston, J. Bright. 2013. “Policy challenges for livestock emissions abatement: lessons from New Zealand.” Climate Policy 13: 110–133

FAO 2018. Reducing Enteric Methane for improving food security and livelihoods. Retrieved from http://www.fao.org/in-action/enteric-methane/challenges-and-solutions/south-america/uruguay/en/

Graesser, J., Aide, T.M., Grau, H.R. and Ramankutty, N., 2015. Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environmental Research Letters*, *10*(3), p.034017.

Hausmann, R., A. Rodriguez-Clare, and D. Rodrik. 2005. “Towards a Strategy for Economic Growth in Uruguay,” Inter-American Development Bank, Economic and Social Study Series, February.

Ilundain, M. y J. I. Lema. 2001. Evolución de la ganadería de carne vacuna en el Uruguay en la década de los noventa. Oficina de Programación y Política Agropecuaria, Uruguay.

Murty, S., Russell, R.R. and Levkoff, S.B., 2012. On modeling pollution-generating technologies. *Journal of Environmental Economics and Management*, *64*(1), pp.117-135.

Pezo, D., y colaboradores. 2018. “Estado del arte de la investigación e innovación para la intensificación sostenible de los sistemas ganaderos y de la adaptación/mitigación ante el cambio climático en América Latina y el Caribe.” Publicación en el marco del proyecto “Mecanismos y Redes de Transferencia de Tecnologías de Cambio Climático en Latinoamérica y el Caribe (LAC)”, implementado por el Banco Interamericano de Desarrollo (BID)

O’Donnell, C.J., 2008. An aggregate quantity-price framework for measuring and decomposing productivity and profitability change. *Centre for Efficiency and Productivity Analysis Working Papers, University of Queensland*.

O’Donnell, C.J., 2017. Estimating total factor productivity change when no price or value-share data are available. *Centre for Efficiency and Productivity Analysis Working Papers, University of Queensland*.

Peyrou, J. et al. 2016. La cadena de la carne vacuna. Universidad Católica del Uruguay. 2016 180 p

Rodríguez, A., López, T., Meza, L. y Loboguerrero, A. 2015. Innovaciones institucionales y en políticas sobre agricultura y cambio climático. Evidencia en América Latina y el Caribe. CEPAL. 133 pp.

Viglizzo, E.F., M.F. Ricard, M.A.Taboada, and G. Vázquez-Amábile. 2019. “Reassessing the role of grazing lands in carbon-balance estimations: Meta-analysis and review.” Science of The Total Environment, 661 pp. 531-542.

APPENDIX A

Ruminant production in Uruguay was traditionally conducted as a mixed system with joint grazing of sheep and cattle. Because of this, it is normally difficult to determine how labor allocates to sheep and cattle production. To the effects of this study, and to be able to measure separately cattle and sheep productivity, we allocate inputs of ruminant production as follows:

- It was assumed that cultivated pastures, grain and supplements were mostly allocated to cattle production as part of the technology package behind TFP growth in production and the displacement of sheep production
- Natural pasture was allocated to cattle and sheep proportionally to the LU of each species at the jurisdictional level.
- A regression of total labor against heads of cattle and sheep, area of cultivated pasture and amount of supplement and interaction terms combining these variables was ran at the jurisdictional level. Estimated coefficients in this regression are used to calculate the amount of labor related to each species. The regression uses a panel of jurisdictions using three years and includes categorical variables to control for fixed effects of years and jurisdictions. The results of the regression are shown below, coefficients of categorical variables are not reported.

Linear regression, number of observations = 808
F(219,588)=159.58
Prob. > F = 0.0000
R-squared= 0.9553
Root of MSE = 58.163

labor	Coef.	Robust Std. Err.	t	P>t	[95% Conf. interval]	
cattle LU	3.10	0.44	6.98	0.000	2.2	4.0
sheep LU	1.35	0.14	9.59	0.000	1.1	1.6
EM from cultivated pastures	0.00	0.00	2.22	0.026	0.0	0.0
EM from grain	0.01	0.00	1.28	0.202	0.0	0.0
Crop area	0.96	0.85	-1.13	0.260	-2.6	0.7
cattle-pasture	-0.001	0.00	-4.46	0.000	0.0	0.0
cattle-grain	0.21	0.05	4.33	0.000	0.1	0.3
sheep-pasture	0.00	0.00	0.93	0.352	0.0	0.0
sheep-feed	-0.13	0.04	-3.06	0.002	-0.2	0.0

APPENDIX B: MACROECONOMIC POLICY AND GLOBAL MARKETS

The 1980s Lost Decade

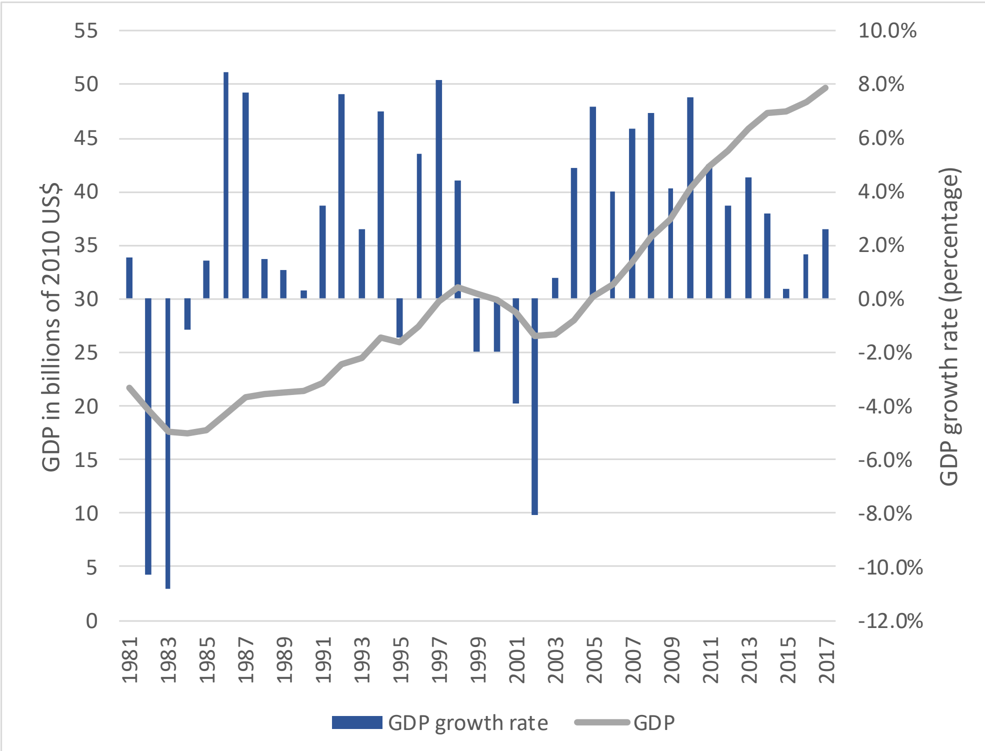
The international economic environment during the 1980s was markedly favorable for LAC countries, with decreasing international interest rates, the improvement in the terms of trade, and the international depreciation of the dollar verified since 1985. However, during this time, the region was still engaged in the implementation of distortive policies that harmed agriculture and other competitive sectors. During this period, Uruguay was still transitioning to democracy after more than a decade of military government (1973/1985)[11]. In March 1985, a new democratic government takes charge of the Uruguayan economy, after the 1982 debt crisis in Mexico triggered the regional crisis that marked the beginning of the end of the military government. The new democratic government redefined the monetary, fiscal and wage policy and brought the economy to a new growth path. However, the international and regional conditions greatly limited economic growth and macroeconomic stability. The Uruguayan economy that started the new democratic period growing at an annual rate of 8 percent, ended up the decade with an average growth of less than 1 percent, high inflation and unemployment (Figure B.1).

Revamping of Macroeconomic Policy in the 1990s

Starting in 1990, during a period when LAC countries introduced major changes into their macroeconomic policy frameworks, a new elected government in Uruguay established a stabilization plan with exchange rate anchor, labor market flexibility and the goal of achieving fiscal balance. The partial success of the change in policy regimes in the region was reflected in the reduction of inflation, from the hyperinflation of the 1980s to one-digit values in the 2000s. In the case of Uruguay, inflation dropped from a peak of 113 percent in 1990 and an average of 68 percent between 1981 and 1995 to an average of 8 percent between 2004 and 2017 after a sustained deceleration during the 1990s (Figure B.2).

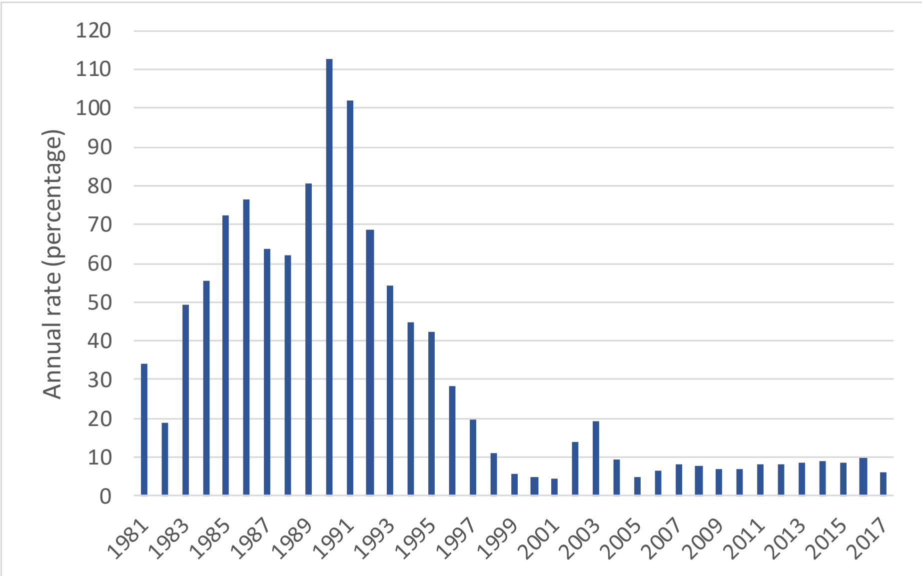
Figure B.1–Uruguay: GDP trends and GDP growth rates

[11] We follow Mordecki (2017) to summarize some of the milestones of macroeconomic policy in Uruguay.



Source: Elaborated by authors based on World Bank (2019).

Figure B.2–Uruguay: Inflation, consumer prices (annual percentage)



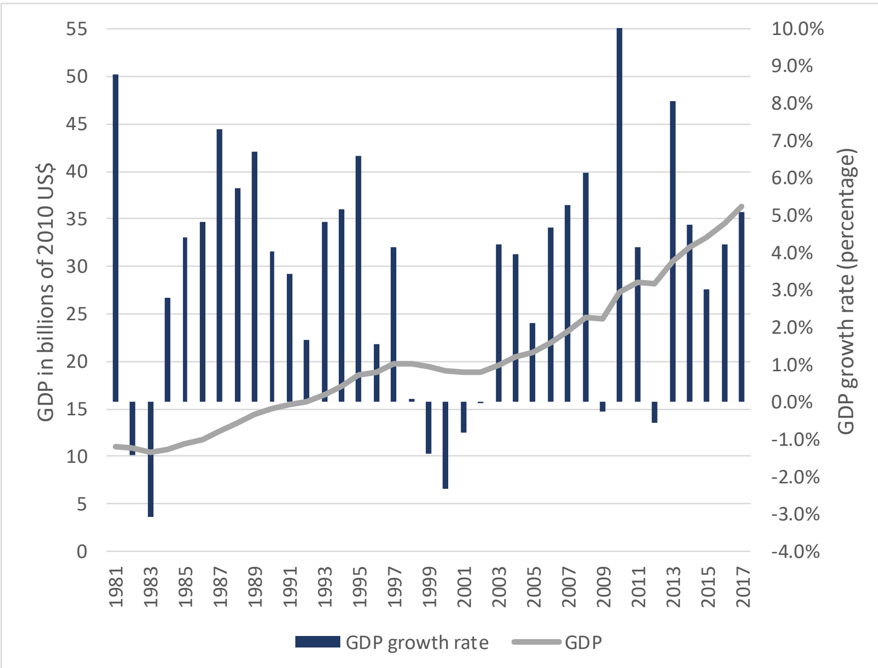
Source: Elaborated by authors based on World Bank (2019).

In Paraguay, the regional crisis of 1982 was also felt (Figure B.3) but it took until 1989 to overthrown President Stroessner, Paraguay's dictator for nearly 35 years. The new government implemented policies that resulted in a more open economy, like those implemented by Uruguay and other countries in the region during the 1990s. The policy changes included the elimination of multiple exchange rates, reduction of the fiscal deficit and a rapid liberalization of interest rates. These changes resulted in a reduction of inflation from 37 percent at its peak in 1990 to one-digit levels after 1997 (Figure B.4). However, Paraguay did not have the regulations in place, nor the capacity to supervise financial markets, so an unregulated and massive capital inflow resulted in a series of financial crisis that recurrently affected the economy from 1995 until 2000. The impact of these policies on the economy are shown in Figure B.3. Between 1990 and 2002, the Paraguayan economy grew at an average rate of 2.1 percent, but the impact of the financial crisis was reflected not in the average growth but in the evolution of the growth rate, that went from 6.7 percent in 1989 to 1.7 percent in 1990, increased to 6.6 percent in 1995 until growth collapsed in 1998. The slowdown of the economy was accompanied by a growing and unsustainable fiscal deficit and external debt.

During this period, and together with changes in macroeconomic policies, LAC countries deepened their trade and financial integration with the world economy, dismantling their massive historical barriers to trade in goods, services, and capital flows and putting in place multilateral and bilateral preferential trade agreements with major world trading partners. By 2010, and according to

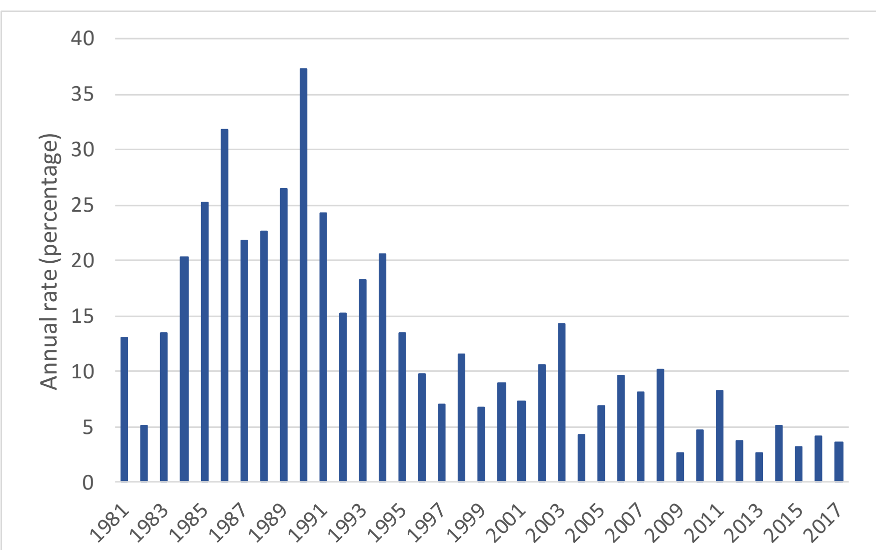
Anderson and Valenzuela (2010), relatively few significant domestic producer subsidies or taxes were still in place in the region.

Figure B.3–Paraguay: GDP trends and GDP growth rates



Source: Elaborated by authors based on World Bank (2019).

Figure B.4–Paraguay: Inflation, consumer prices (annual percentage)



Source: Elaborated by authors based on World Bank (2019).

In the case of Uruguay and Paraguay, integration to the world economy was overshadowed by the creation of the Mercosur in 1991, with these two countries together with Argentina and Brazil as full members. This trade agreement together with Argentinean convertibility policy and Brazil's "Plan Real" generated a high regional dependence of the two smaller economies in the trading block. After the Brazilian devaluation of January 1999, the Uruguayan economy began to shrink, and rushed to another deep crisis after Argentina abandoned convertibility in December 2001. The financial crisis lasted until August 2002, when it was stopped with bank closures and a deposit freeze. The living conditions in Uruguay rapidly deteriorated, with high unemployment and sharp increase in poverty. In Paraguay, the slowdown of the economy in the second half of the 1990s was accompanied by a growing and unsustainable fiscal deficit and external debt. The regional crisis that started in 1999 sent the fragile Paraguayan economy to four years of negative or zero growth (Figure B.3).

The Commodity Boom

The year 2003 marked the start of the most favorable global economic environment of the last three decades for LAC and for Uruguay and Paraguay in particular. For five consecutive years, the world economy grew at rates above the average of the previous 30 years, driven by the US and the strong dynamism of countries such as China and India, whose growth boosted a greater demand for primary products that fueled the rise in commodity prices. The dynamism of the global economy led to a substantial increase in exports, which allowed the region to run positive current account balances, while private investment helped to stimulate growth of domestic demand. In line with the expansion of demand, the volume of world trade during the period grew faster than world production, and commodity prices saw sustained growth since 2003, given this scenario of increased commercial flows. Adding to this, we observe during this period a favorable international financial situation, with large capital inflows to emerging markets, both in the form of direct foreign investment and speculative activities, stimulated by low interest rates due to the expansionary monetary policy applied in high-income countries. In addition, Uruguay and Paraguay benefit from improved performance of the large neighboring economies of Argentina and Brazil. These effects also contributed to the recovery of domestic demand.

In this favorable context, the Uruguayan economy started to recover in 2003, at first by taking advantage of the idle capacity left by the crisis, followed by an increase in total factor productivity, which allowed the potential GDP of the economy to expand, and with favorable international conditions, the economic growth continued for more than a decade. Growth was slowed down in 2008 and 2009 by the

irruption of the mortgage crisis in the United States, but the economy showed resilience facing the crisis, with a fast and solid recovery.

One of the aspects that distinguished this period was a higher contribution of investment to GDP, driven to a large extent by the increase in foreign direct investment. Part of this investment was directed to new production activities modifying the production structure of the economy (paper mills and large-scale soybean production), which was also reflected in exports. However, the country's specialization in exports of primary commodities didn't change. On the other hand, one of the achievements of the period in terms of foreign trade was the diversification of export markets and reduced dependency on regional markets.

Nevertheless, Uruguay's economy started sputtering after 2011. Until then, the government managed to keep the fiscal deficit below 2.0 percent. However, the ability to maneuver public finances and the management of discretionary spending were reduced from there, due to the implementation of health and social security reforms, which meant an increase in the "permanent" expenditures of the public sector and a deterioration of fiscal results. In this context, although inflation remained below 10 percent, it was only occasionally able to fall within the target range established by the Central Bank, showing the existence of persistent inflationary pressures. As shown in Figure B.1, GDP growth after 2011 fall to an annual average of 2.6 percent, compared to 6.0 percent between 2005 and 2011.

In the case of Paraguay, the economy emerged from the 1989-2002 crisis after the implementation of new policy measures that reduced the fiscal deficit and regulated financial markets. Most importantly, the economy benefited from the implementation of a new development strategy that focused on attracting capital investment in agribusinesses and developing the country's infrastructure. The new policies were successful in accelerating growth and stabilizing the economy as can be seen in Figure B.3 and 6.4. GDP growth after 2002 was on average 4.4 percent despite the 2008 global financial crisis and negative weather shocks to agriculture in 2009 and in 2012. This growth is explained in part by the continuity of Paraguay's economic policy despite government changes.

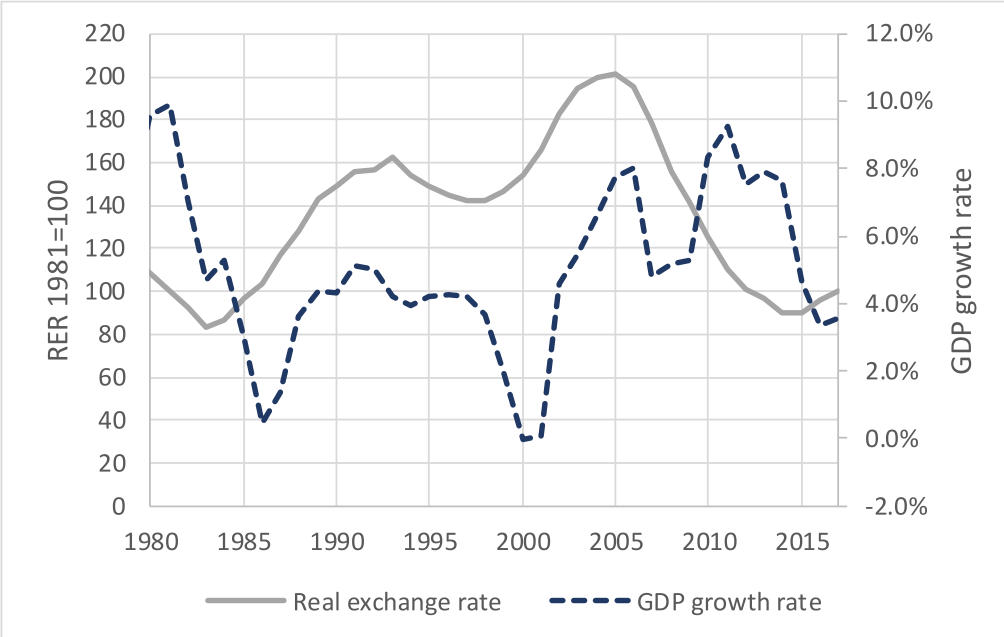
The exchange rate played a major role in the performance of both the Uruguayan and Paraguayan economies during the analyzed period, cross-cutting the different growth periods just described. As discussed in Hausmann, Rodriguez-Clare and Rodrik (2005), real exchange rate cycles have been a recurring feature of the Uruguayan economy since the 1970s. As shown in Figure B.5, the collapse of economic growth in 1982 was followed by the depreciation of the peso. This pattern repeats in the 1990s, when growth acceleration was accompanied by a significant appreciation of the peso. When growth came to an end by the end of the decade, the collapse of the exchange rate followed in 2002. This pattern seems

to be repeating after 2000, with devaluation of the peso and rapid growth after the 2002 crisis, rapid appreciation after 2005 and a slowing down of growth after 2011. According to Hausmann, Rodriguez-Clare and Rodrik (2005), the eventual appreciation of the real exchange rate in Uruguay has served to choke off tradable activities, rendering growth less sustainable and more susceptible to negative shocks. The effect of appreciation of the local currency (pesos and guaranies) is important for livestock growth performance. In Uruguay, the relevant costs of grazing breeding systems are mostly services and "non-tradable" goods (taxes, salaries, fuel, and family consumption).

Figure B.6 shows trends in international beef and soybean prices in dollars and same prices converted into pesos of 2005. High domestic prices in the 1990s resulted in increased investment in pastures, stimulated by liberalizing policy changes and expectations of better export prices. These investments matured, and their fruits were "harvested" as of 2002, the year of the crisis that brought an abrupt increase of the RER, to which was added, from the outside, the beginning of a phase of great increase of international beef prices. But after 2005, growth and the appreciation of the peso had a negative effect on domestic beef prices. While international beef prices increased 90 percent between 2005 and 2014, prices in pesos dropped more than 20 percent during the same period. Notice that soybean prices increased relative to beef prices after 2005 in international markets and in pesos, which could explain the reduction in cultivated pastures in high potential areas specialized in fattening.

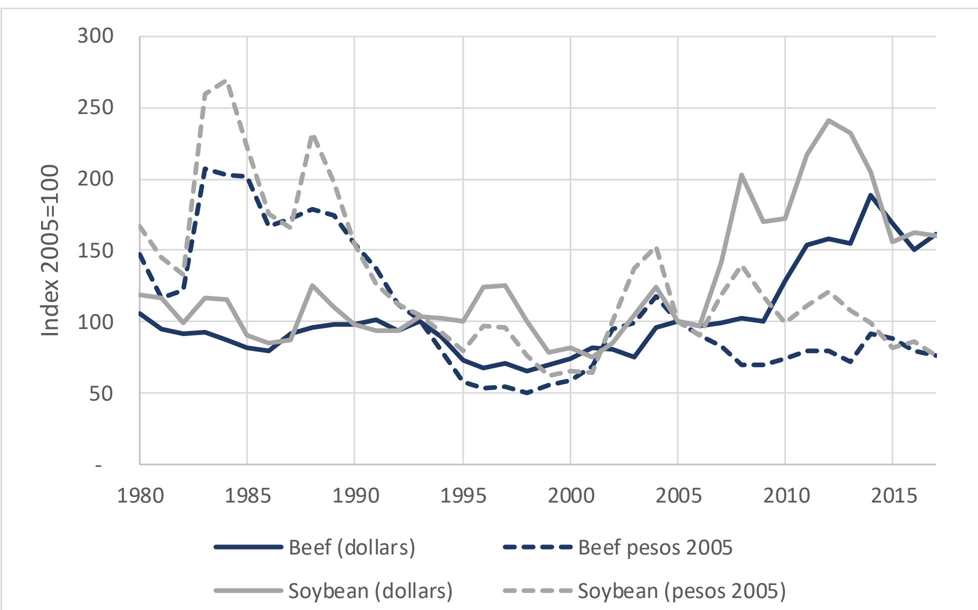
Similar patterns on the effect of the exchange rate on growth are observed in Paraguay, with similar consequences on export commodity prices (Figure B.7). Trends in output and prices are similar, with the fall in output in 2011 associated with the reappearance of FMD. Investments and technical change in the Western region coincided with the increase in international prices, and, until 2005 with the depreciation of the guarani. In this case, expansion of the livestock activity continued in the Western region with no competition of soybeans after 2005, with growth slowing down after 2013.

Figure B.5 Uruguay: GDP growth and the exchange rate



Source: Elaborated by authors

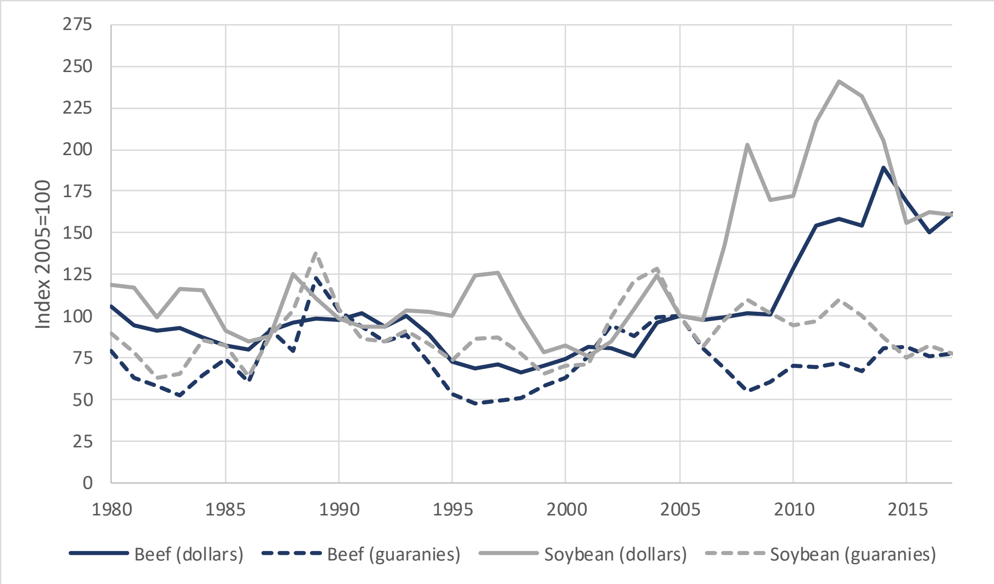
Figure B.6 Uruguay: Indices of beef and soybean prices in current dollars and in 2005 pesos



Source: Elaborated by authors

Note: Beef prices are Australian and New Zealand 85% lean fores, CIF U.S. import price, thousand US$ per ton; soybean prices are U.S. soybeans, Chicago Soybean futures contract (first contract forward) No. 2 yellow and par Prices in pesos are obtained by multiplying dollar prices by the official exchange rate and deflating by CPI.

Figure B.7 Paraguay: Indices of beef and soybean prices in current dollars and in 2005 guaranies



Source: Elaborated by authors

Note: Beef prices are Australian and New Zealand 85% lean fores, CIF U.S. import price, thousand US$ per ton; soybean prices are U.S. soybeans, Chicago Soybean futures contract (first contract forward) No. 2 yellow and par Prices in guaranies are obtained by multiplying dollar prices by the official exchange rate and deflating by CPI.