Soy in Uruguay from 1961-2016: How the adoption of soy has influenced Agricultural Production Systems and Land-Use

by

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Summary

The focus of the research reported in this thesis is on the consequences of the significant growth in soy production in Uruguay since the 1990s and its impact on agricultural production systems and land use in the country. To the author's knowledge it fills a lacuna in the research literature on soy in South America, particularly in the context of land systems science.

The thesis comprises eight chapters. The first chapter introduces the contexts for the research, it introduces the research themes, and provides important background material on Uruguay.

The second chapter, which reviews relevant research literature, is written in the form of an essay on the evolution of soybean from a regionally important crop in north east Asia to one of the world's major traded commodities. Emphasis is placed on its expansion into South America, and in particular Uruguay, and its roles in stimulating land-use change.

The third chapter introduces the research project design, sampling and methods used in interviews and land-use surveys.

In the fourth chapter time-series of economic data are modelled to explain the growth of soy from a minor crop to the most important export crop in Uruguay. The time-series data include macroeconomic data, export and imports, and soy production and areas from 1961-2016 for the main soy exporting and importing nations. The modelling technique used is Temporal Causal Modelling (TCM), which was released in SPSS in 2016. It is a form of time-series modelling based on Granger causality. This chapter introduces Granger causality, reviews the data used in the modelling (and the decisions behind the model choice and data inputs), explains how TCM operates in SPSS, and presents the results. To the author's knowledge this

is the first application of the SPSS model to agricultural economic data, and the first application of any Granger causality model in land systems science.

Significant soy production models in Uruguay between 1961 and 2016 from TCM are discussed in Chapter 5, along with the main reasons behind the arable land-use regime shift that occurred in the 1990s. The main reasons being the outbreak of a fungal disease that devastated the sunflower crop, the influx and capital and technical knowledge from Argentina during its 1990's economic crisis, increasing demand for soy from China and the EU, and the role of MERCOSUR.

The introduction of soy-based rotation systems is described in Chapter 6, along with a discussion of the development of the actors, processes and infrastructure that make the contemporary soy supply-chain from farm to export market in Uruguay.

Predicted land area under soy in Uruguay between 1961 and 2016 are analysed and discussed in Chapter 7. As was the case with Chapter 5, this uses data acquired from government departments and semi-structured interviews key stakeholders in Uruguay. In addition, a land-use survey of summer crops in the main soy growing provinces was carried out in February 2016. This chapter also analyses how the growth of soy in Uruguay from the 1960s to the 1990s replaced other crops, and how, since then expansion and later contraction of the area under soy has impacted pastures used for beef and dairy production in the country.

The final chapter reviews the findings and presents a conceptual model of soy-pasture dynamics for Uruguay. Limitations and their potential impacts on the research are discussed. Finally, contributions to knowledge in three areas are outlined: the agricultural geography of Uruguay, land systems science, and the application of TCM to land-use change studies.

Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and believe it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed:________________________ Date: 19th August 2018

(Ingrid Tejada)

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Vivere est esse simpliciter

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1 INTRODUCTION

1.1 Background and context

In their 1972 book, *The Limits to Growth*, Denis Meadows and his co-authors warned that during the next century, the world's physical resources would become increasingly scarce and as a consequence economic prosperity would be limited by an increasing global population (Meadows et al. 1972). They also argued that arable land would likely run out by 2000 given population growth projections. So far, however, global food output has kept up with population growth. This, in part, has been due to a dramatic rise in agricultural productivity in the last few decades, and nowhere has this been more dramatic that the emergence of soy as a major global commodity and its expansion in South America. The rise in agricultural productivity has mainly been attributed to the development and adoption of new varieties of existing crops through crop breeding programs and genetic modification; an increase in the use of pesticides, fertilisers and other agrochemicals; improved access to irrigation; and farm mechanisation (Hertel and Baldos 2016; McAlpine et al. 2009; Lambin and Meyfroidt 2011; Verburg et al. 2015; Gershon et al. 2010).

Since the start of this millennium price spikes across a wide range of commodities including metal, oil and staple foods have occurred primarily as a result of increasing demand from emerging market economies. For example, the prices of soy, wheat and maize have increased by more than 25% since early June 2012 and all three have reached historic high prices in recent years (Central Bank 2012). Such events, have refuelled the concerns expressed in *Limits to Growth* about the capacity of modern agriculture to feed the world in the coming decades. But agricultural growth has also led to new challenges in global land-use systems; in particular agricultural expansion onto native vegetation, such as forests and grasslands. Recent research has revealed that drivers of land-use change that transcend spatial, temporal and institutional scales influence land-use policy regulations and may lead to geographical displacement of land conversion (Seto et al. 2012; Friis et al. 2015; Liu et al. 2015). These are distant drivers, in that they start in places that are nowhere near where the resulting land-use occurs (Liu, Hull, Batistella, Defries, et al. 2013).

History tells us that the demand of food has been fuelled by an increase in population, but more recent evidence suggests that increases in incomes and changes in dietary patterns are key drivers of food consumption. Although, on a global scale, population growth is projected to grow at a lower rate than in the past, over the next fifty years, population growth will remain higher in African and Asian countries than other parts of the world (United Nations 2015). China and India are already populous countries playing a major role on these developmetns. For example China has a very pronounced expansion of its imports of soybeans which the country now acccounts for some 50 percent of world imports of soybeans (Fouré et al. 2013). As a result, higher incomes in these regions will continue the trend of change in dietary habits that has occurred in east Asia since the 1980's due to China's large agricultural economic reform and participation in global trade. China's industrial revolution has seen a transformation in income diets and a shift in food consumption patterns especially the consumption of foods that are rich in protein and fat; including meat, dairy and foods that are processed (Gale et al. 2015) (Liu, et al. 2013; Kharas & Gertz 2010; Hoffman, 2014).

To meet this growing and changing food demand industrial crop output will need to increase. To increase production output more arable land will need to be acquired for intensive crop output. We have already seen deforestation and land displacement underway. It is not just the land-use for agriculture but the infrastructure of supply-chains which is fundamental to the transportation of such goods across far distances. Other challenges that will ultimately accompany this growing demand are the limited land resources globally, impacts of globalised trade on biodiversity , water quality , and land quality as well as socioeconomic influences (Meyfroidt et al. 2013a; Newbold et al. 2015).

Consideration of sustainable supply-chains

The rise in meat consumption in some developing economies has increased the demand for animal feed from oil- and protein-rich plant sources. Soybeans have become an important agricultural commodity globally. Since the 1990s global trade in soybeans and other soybean products has risen rapidly, whilst in 2008/2009 it surpassed global trade of wheat and other coarse grains, overall in the last 50 years' soybean production globally has grown from 27 to 269 million tons and it is projected the world trade will increase in soybeans by 22 percent (Tran et al. 2016).

To some extent, supply has been also driven the introduction of genetically modified (GM) soybeans. Several countries in the Southern Cone[1] of South America have become major soy producers globally as a result. GM soybean cultivation has proven to be economically efficient in Latin America, for example in Argentina, the planting and export of transgenic beans has revived Argentina's near-dead economy (Leguizamón 2014), making Argentina the third largest global grower and exporter of soybeans (Newell 2009). The total area of soybean in the Southern Cone now exceeds 1 million km^2 -- the total area of France, Germany, Belgium and The Netherlands combined (WWF 2014). Soybeans are also a major crop in Brazil and Paraguay and, adjacent to these two countries but outside the Southern Cone, in Bolivia. In Uruguay -- the world's seventh largest producer in 2013 of whole soybeans by weight- the expansion of soy and its role in the national agricultural economy has not attracted much research compared to the plethora of studies on Brazil, despite it having had the fastest rate of increase in production over the decade of all the major producing countries. Over 3.5 million ha of natural grasslands has been converted to agricultural cropping systems. Some of the herbaceous cover was natural pasture, by 2009 it was mainly soybeans (Redo et al. 2012; Garrett et al. 2013). Research in Uruguay has lacked in comparison to other countries with the exception of Redo

[1] [1] Southern Cone refers to countries south of the Tropic of Capricorn. In geographical terms the Southern Cone is made up for Argentina, part of Bolivia, Brazil, Chile, Paraguay and Uruguay.

et al. (2012) who discuss the soy expansion in relation to policies and Modernel et al. (2013), who discuss the environmental impacts of grazing in relation to Uruguay.

There are many themes within the research on Brazil's soybean production, but in the context of this research, those that have examined the impacts on land-use and land-cover changes and its environmental and socioeconomic consequences are the most important. (Meyfroidt et al. 2013a; Lambin et al. 2001; Pacheco 2012; Leguizamón 2014).

1.2 Research aims and themes

The overall aim of the thesis is to explore and understand historical and contemporary trends in soy production in Uruguay, and then analyse its impacts on land use in terms of the country's cultivation and pastoral systems. Specifically, it attempts to answer three important lines of research:

1. How and why has soy evolved as the main crop in Uruguay and what factors have led to the growth of soy cultivation in Uruguay since 1961 (this research is reported in Chapters 4 and 5). The time frame of this line of research is from 1961 to 2016;
2. How have agricultural production systems in Uruguay responded to the post-1990s soy boom? (Chapter 5 and 6). The time frame of this line of research is 1990 to 2016;
3. How important has the switch to, and the growth in soy, been in shaping changes in agricultural land use (both cultivation and grazing systems), and how are these changes coupled to global trade and institutions? (Chapter 7). The time frame of this line of research is 1990 to 2016;

1.3 Chapter summaries

Chapter 1 continues by examining the researcher's motivation to undertake this research and the potential contribution to knowledge. The chapter concludes with an introduction to agriculture and the agricultural economy of Uruguay (Section 1.6). Chapter 2 reviews the literature on soy as a commodity, its expansion into South America and how its adoption drives land-use change. Chapter 3 describes the research design and methods used to undertake the project using a mixed methods approach. In Chapter 4, the first line of research (Section 1.2) is explored in the context of global markets. Temporal Causal Modelling (TCM), a form of time-series modelling, was used to analyse quantitatively the trends in soy production and the area planted to soy in Uruguay using a wide range of regional and global parameters. The chapter introduces TCM as a method and then follows this with a discussion of the modelling strategy adopted, the decisions made during modelling, and the significant models. The outputs from temporal causal modelling are discussed against the changes in soybean production in Chapter 5. Chapter 5 discusses the outputs from the TCM model and then discusses the production shift in soy and what initiated the soy boom including a discussion on the transition to a soybean-dominated cropping system, the decline in sunflower cropping and the flight of Argentina's capital into Uruguay. Chapter 6 follows on with a discussion on Uruguay's response as a result of the production shift in soy cultivation and the shift in soy cropping. It discusses the evolution of the soy supply-chain, who the actors are in the supply-chain, the elements of infrastructure and processes including a discussion on exports and the role of Uruguayan and Multinational companies in the supply-chain. The results from TCM are returned to in Chapter 7. However, in this chapter the focus is on the area under soy. The chapter concludes with a conceptual model of arable cultivation-pasture-cultivations dynamics. Chapter 8 concludes by highlighting the main results and analysing their contribution to land use science.

The thesis is written in a traditional format, as allowed under Flinders University regulations. The target number of publications for a thesis produced in the College of Science and Engineering is between one and three. However, these do not need to be published or in review before the thesis is submitted. There are plans for the chapters to be reviewed for publication once the thesis is submitted. The main journals which are being considered at the present time are Journal of Land Use

Science. Journal of Environmental Economics and Management, Land, and Land Use Policy. No articles had been written and submitted to academic journals from this thesis at the time it was submitted.

1.4 Personal motivation

Motivations for this research came through trying to understand environmental changes across the globe. There is interest in understanding the global impact which an increase in population is having on land-use and the implications which accompany these changes. Soy bean cultivation seemed to be a recurring theme which came up in the literature, but the majority of the research had been undertaken in Argentina and Brazil. After much exploration, Uruguay, being the seventh largest soy producer at the time globally (2013), was an interesting and unlikely story; the highest rate in soy production growth, small population and small land area in comparison to Brazil and Argentina. Through the literature little was found on Uruguay and its land use changes due to soy.

Being born in El Salvador, there was a deep interest in undertaking research in the Americas, particularly since little research is undertaken in Australia with respect to the region. Being fluent in Spanish was advantageous in undertaking the study and it made it easier to form networks in Uruguay early on and allowed the exploration of ideas in Spanish, which gave the research a different perspective.

1.5 Contributions to knowledge

This research hopes to address an important understanding about the connectivity of the world, its people and its the environment. It contributes to the knowledge around indirect and direct land-use change and how both interactions play an influential role in land-use changes. Understanding the causes of land-use patterns is critically important in linking expansion of agriculture to deforestation, clearance of grasslands and other transitions from natural to anthropogenically-modified environment; as well as between different types of agricultural systems. However, there is often a combination of both proximate and underlying causes, which makes the influence of global markets on distant places difficult to measure. This thesis uses a method, which may identify possible global markets that play significant roles in driving either change or expansion of agriculture in a specific area.

The research on Uruguay is hoped to bring about further knowledge and understanding into the way highly mechanised cropping systems bring about a chain of events, from internal supply-chains and infrastructural changes to shifts in production. The knowledge will hopefully be disseminated in Uruguay to assist in policy regarding land–use outcomes.

1.6 Uruguay: agricultural situation and agricultural economy

Uruguay, the second smallest country in South America with a land area of 176,215 km^2, is bordered by Argentina to the south and west and Brazil to the north. Historically, it is politically and economically more closely associated with Argentina than Brazil. During two centuries, as an independent nation, it has been dominated by an agricultural sector serving both domestic and international demand. It is also one of the most economically developed countries in South America with a population of approximately 3.5 million people. GDP per capita in 2013 was approximately $16,400, having increased by 41% from $11,500 in 2010. While for neighbouring Argentina, Brazil and Paraguay GDP per capita grew from $11,500 to $14,700, $11,000 to $11,200, and $3,100 to $4,300 respectively (World Bank 2014). By way of comparison, Australia's GDP per capita in 2013 was $67,500.

It is highly urbanised, with 92% of its inhabitants living in urban centres, a proportion that is remarkably similar to Australia at 89%. More than half live in the capital, Montevideo. There are approximately 15 million hectares of agricultural land of which 1.8 million ha are cropland, 1 million ha are cultivated pasture, and 11.2 million ha are natural grasslands and improved pasture. Approximately a further million are under production forestry (Bervejillo, 2011 p.5). This distribution reflects the historical dependency of Uruguay on cattle production and beef exports. But, as will be shown in this thesis, the natural grasslands and improved pastures also act as a land reserve that can be converted to arable agriculture.

Agriculture makes a very important contribution to the national economy. In 2009, social security records show that the economically-active population engaged in agriculture totalled 192,00 people (Bervejillo 2011). This included farmers and rural workers living on farms and small rural centres. In 1985, 182,500 people worked in this sector. However, agricultural GDP, as a share of total GDP, shrank from between 13-14% in the 1980's to 8.2% in 2009. Between 1970 and 1990 agricultural GDP grew at an annual rate of 0.4%. However, this pales into insignificance compared to the exceptionally strong annual growth in agricultural GDP (approximately 25% per annum) between 1990 and 2010. This growth in the country's agricultural sector has been attributed to a weak U.S dollar, a significant jump in the price of farmland, the expansion of forestry plantations, and the shift to soy-dominated cropping systems (Bervejillo 2011; Redo et al. 2012). Generally speaking, developments in Uruguay's agricultural economy in the last half century reflect changes to the regimes in power, national economic policies, as well as external developments in the global economy, technological innovations in agricultural production and exports (including pioneering beef processing and export methods by Leibig at Fray Bentos) and expanding markets for agricultural products.

Soy has been grown in the Southern Cone of South America for well over a century, with the earliest reference dating back to 1882 (Shurtleff & Akiko 2004). During the 1920's soy was introduced to Brazil, Colombia and Paraguay, as an experimental crop to test its suitability in national nutrition programs as a food additive (Shurtleff & Akiko 2004). However, prior to this, Javanese farmers who had emigrated to Surinam from the Dutch East Indies, and Japanese immigrants in Brazil were cultivating soy (Aoyagi 2015). Commercialisation of soy only came about in 1946 in Brazil, with other countries soon following. This shift coincides with the post-WWII development boom and economic modernisation and import substitution in Latin America (Shurtleff & Akiko 2004). Nonetheless, the growth in soy during the 1950's was most rapid in Brazil. By the 1960s, the foundations of soy were established in the Southern Cone and Argentina alone passed the 10,000 MT production mark. In the following decade soy developed into a valuable export commodity across Latin America, particularly in Argentina, Brazil, Mexico and Paraguay which at the time were some of the top soy producers.

Uruguay witnessed significant growth in soy production after the 1980's. During the 1970's and 1980's it produced an average of 45,000 MT annually. Production grew significantly during the 1990's, especially towards the end of the decade (Figure 1-1) and it has maintained high levels of production since then. Because of the exponential growth in soy production in the last decade, Uruguay has become a recent entrant into an important group of global animal feed exporters; and became one of the top ten soy producing countries in 2013 Figure 1-2.

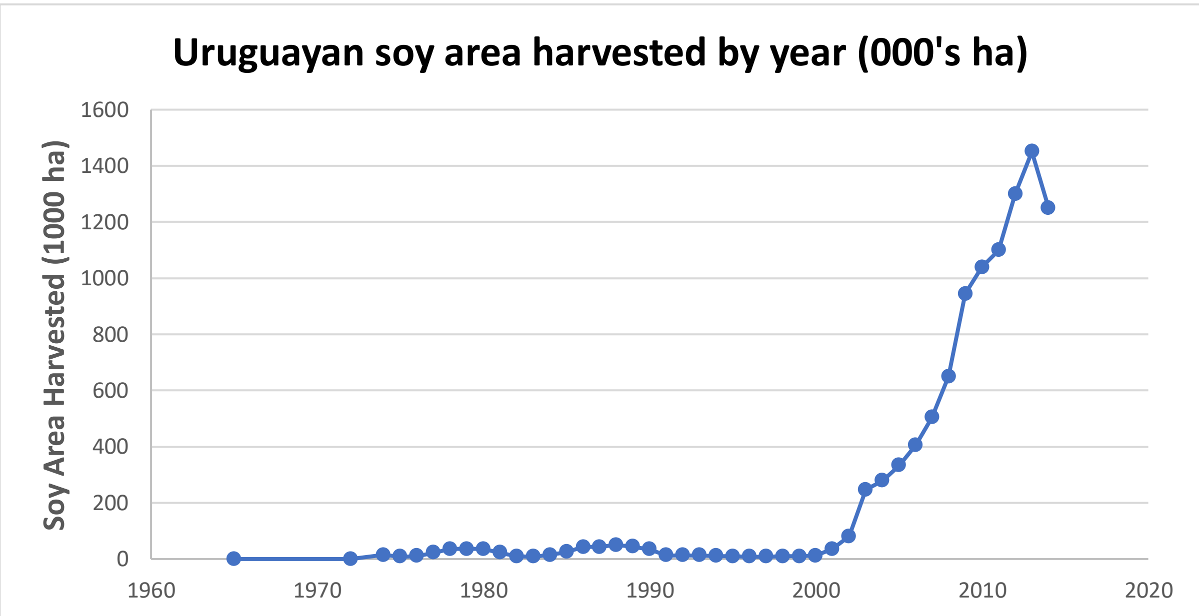

Figure 1-1 - Uruguay: soy area harvested 1965-2014. Source USDA.gov

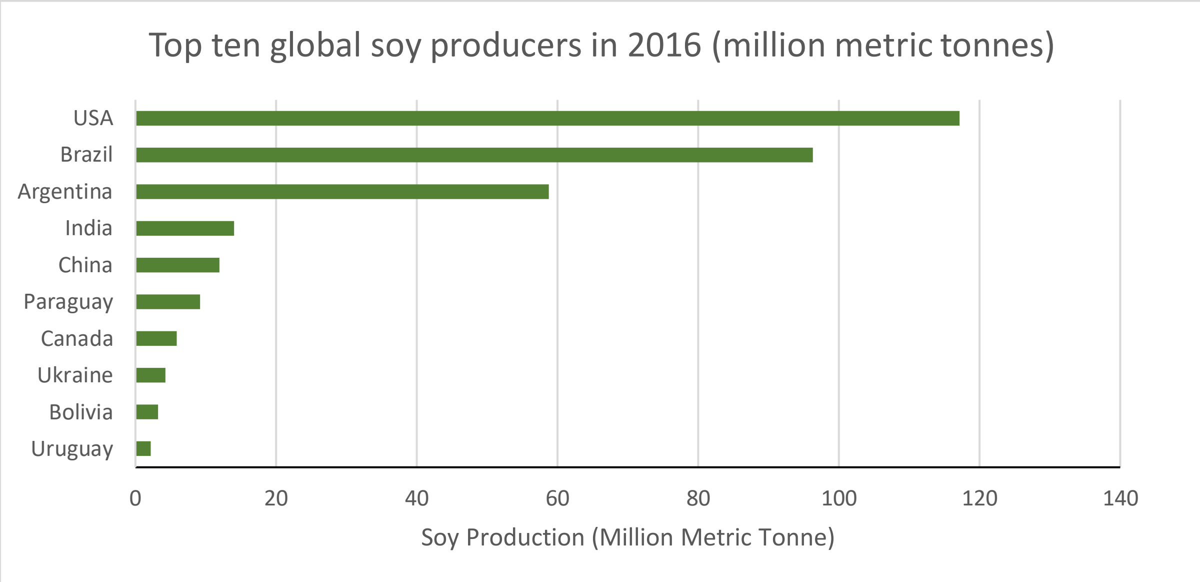

Figure 1-2 Top ten global soy producers in 2016 (million metric tonnes). Graph shows USA as top producer followed by Brazil and Argentina. Uruguay is the 10th largest producer

Uruguay's late appearance as a large soy producer and exporter compared to neighbouring countries is due to the historical legacy and importance of the country's major agricultural sector—livestock and related meat and animal products. There is a well-established history of cattle production dating back to the 1800s (Berretta Elbio 2015). Despite the boom in soy, the cattle sector remains important. Since the 1960s beef production has almost doubled to around 600,000 MT per year and it was the world's eighth largest beef exporter in 2016, exporting over 380,000 MT of beef globally and overtaking Argentina (USDA 2017). There are two further important products from this sector of the economy - dairy products and leather goods. Although dairying is important, it makes a much smaller contribution to agricultural GDP than beef. In addition, it is mainly focussed on the internal market. It is concentrated in the south of the country and importantly in the context of this research, land used to graze dairy cattle has been lost to soy as its production has grown since the 1990s. This is a result of the geography of dairying and cultivation in the region, dairying mainly takes place adjacent and to the east of the main zone of arable cultivation in Uruguay. This zone, known as the Litoral, comprises our departments in the south west of the country along the Rió Uruguay. From north to south these departments are Colonia, Soriano, Río Negro and Paysandú. As soy production grew from the 1990's it expanded onto pastures in the east of these departments and neighbouring departments that had been used for grazing dairy herds. Nonetheless, around 70-80% of the country's total land area is still under natural grasslands and improved pastures (FAOSTAT 2016).

Although soy production and exports in Uruguay is not as large as those of neighbouring Argentina or Brazil (Figure 1-2) production in the last decade has increased significantly. In 2013 its soy production made it the world's seventh largest producer. It exports approximately between 3-4 million MT whilst the area harvested was 1.25 million ha. In the early 2010's, the soy sector established a number of records in Uruguay. In 2012, exports exceeded one billion US dollars and displaced beef as the country's leading export, and 30% of the soy crop had yields higher than were expected; i.e., above 2 T/ha (MercoPress, 2012). In 2013, the soy crop was the largest in the country's history at 2.76 million MT. The area planted to soy climbed by 20% to 104,900 ha with yields of 2.6 T/ha (MercoPress, 2013). Bervejillo (2011) discusses the structure of agricultural exports from the early 1880's when wool and meat accounted for 82% of all agricultural exports, By the early 1990's wool prices had declined, and exports became much less important. Up to 2005, agricultural exports accounted for 60-63% of Uruguay's total exports (FAOSTAT 2013), but exports of timber, cereals and oilseeds have grown rapidly. By 2009 beef, cereal, oilseed (in particular soybeans), dairy products and timber accounted for 84% of agricultural products.

2 SOY: FROM A NORTH-EAST ASIAN CROP TO THE WORLD'S MOST TRADED AGRICULTURAL COMMODITY

2.1 Introduction

This chapter reviews many aspects of the evolution of soy from an important crop in North-East Asia to the world's most important agricultural commodity by traded volume in the early 21st Century. In particular, the following aspects are considered: historical background (Section 2.2), the crop's basic agro-ecology and genetic modifications to soybeans since the 1990s (Section 2.3), the uses of soy and its products in the modern world (Section 2.4), contemporary global trade in soy (Section 2.5), the crop's expansion into South America (Section 0), and aspects of land change science that are relevant to the expansion of soy in South America (Section 2.7).

The aim in taking this approach to soy cultivation and trade is to understand the contemporary situation with regard to soy production, trade and consumption. Of particular importance to this thesis is the discussion on soybeans in South America, and the effects this has had on the agricultural economies and land use in the major soy-exporting countries on the continent. Global soy trade and demand is discussed in the context of global tele-connections, as defined in the land change literature. The links to research carried out by global land community are important because many members of this research community have extensively researched soy agriculture and how its role, in a globalised market, has directly and indirectly impacted land uses in South America.

2.2 Historical aspects of soy cultivation and trade

Historically, soybeans have always been an important source of high quality, low cost protein. As early as 5,000 years BP, farmers in China grew soybeans and for centuries it was the world's foremost soybean producer (Campbell-Platt 1994). In the early 1900's it produced an estimated 71% of world's soybeans. At this time the other large producers were also from North-East Asia: Manchuria produced 16.5% of the world's soybeans, and Japan 5.9% (Shurtleff et al. 2014).

For centuries Manchuria and northern China shipped soybeans by boat to ports in southern China. By the late 1800's exports from Manchuria to Japan increased rapidly after China made special concessions at the end of the Sino-Japanese war in 1895 (Shurtleff et al. 2014). The expansion of soybean exports from Manchuria to the western hemisphere began between 1908-1930. This period marks the beginning of sustained rise in the volume of exports in Manchuria (Eckstein et al. 1974). The first shipment to the west was made in 1908, when Japanese businesses began to export soy from

Manchuria. Soybean, soybean cake and soybean oil accounted for 90% of Manchurian exports (Eckstein et al. 1974). Exports of soybean and soybean oil from Manchuria to Europe increased rapidly in the next two decades, with soybean production in Manchuria peaking at around 5.4 million tonnes in 1930 (Shurtleff et al. 2014). The European export trade was highly beneficial for the region in terms of its economic development. However, after the 1930's exports to Europe declined due to European concerns over the quality of the beans. During WWII the soybean trade was further disrupted when soybean imports to Europe fell to almost zero due to the disruption to trade routes and the Japanese invasion of Manchuria and China. Soy imports did not resume after the end of the war (Shurtleff et al. 2014).

In the USA soybeans were first planted in Georgia in 1765, and for many years were planted by only a handful of farmers in Georgia, Mississippi and Massachusetts, and in the vicinity of Philadelphia. In the early 1920s North Carolina began to cultivate soybean commercially. Three years later, Illinois had surpassed North Carolina's soybean acreage, and in 1924 it became the largest soy producer in the USA (NSRL 2017). Soybean production was stimulated in the early 1930's when, in parallel with the decline in Manchurian exports to Europe, the United States emerged as a major soy producer and exporter (NSRL 2017).

2.3 Soybean agroecology

Soybean (*Glycine max*.) is an annual herbaceous legume that is relatively easy crop to grow. It can grow up to two metres in height, although commercial varieties only grow between 0.3 to 0.9 metres (DPIR 2008). It is a daylight sensitive crop, that begins flowering as days become longer, though daylength also affects rates of vegetative growth before flowering begins (Martin 1998).

Traditional varieties of soybean grow best in cool temperate regions, e.g., North East Asia, and North America. Temperatures around 15^{o}C are required for seed germination and average temperatures of around 20-25°C are required in the vegetative growth phase (Martin 1998). Whereas moderate soil moisture levels are required for germination and seedling establishment, dry weather is necessary for the production of dry seed. Soybean yields suffer if the soil becomes waterlogged but they can withstand considerable drought (Saryoko et al. 2017). Though it is primarily adapted to a temperate climate, crop breeding and genetic modification have allowed its latitudinal growth range to expand into tropical and sub-tropical climates (Holshouser 2010).

The most important differences in soybean varieties are in day-length responses, resistance to disease, its ability to grow in humid climates, and yields. The International Soybean Centre (INTSOY) at the University of Illinois (now known as the National Soybean Research Laboratory, NSRL) categorises soybeans based on their adaptations to grow in tropical, subtropical or temperate tropical climates (NSRL 2017). One of the biggest pioneers on genetically modified (GM) soybeans is Monsanto, who began testing the crop's ability to withstand glyphosate herbicides. This allowed Monsanto to launch their first-generation Roundup Ready (RR) soybeans in 1996. This has been the most widely adopted biotechnological trait in soybeans planted by farmers (Monsanto 2017).

2.4 Genetically Modified soy

When Monsanto's Roundup Ready soy were introduced in 1996 only 2% of soybeans in the USA were grown from the company's patented seed. Twelve years later over 90% of soybeans grown in the USA contained Monsanto's patented gene. RR soy, which is more correctly known as glyphosate-resistant trait soy, is one of the most widely grown forms of GM soy worldwide as the herbicides sprayed to kill weeds in soy fields do not affect the crop.

The first herbicide tolerant varieties of soy were introduced in 1993. These were sulfonylurea-tolerant soybeans, which were developed to tolerate higher application rates of some of the herbicides that were being used in soybean cultivation at the time (Gianessi 1999). RR soy varieties allowed the use of the more-effective post-emergence herbicide, glyphosate, over the top of the growing soybeans (Gianessi 1999). There has been rapid uptake of RR soy varieties by farmers in many countries, not just in the USA. Trigo and Cap (2003) described the rate of adoption of transgenic soy in Argentina as "unprecedented" and even higher than in the United States. While it took 15 years for American farmers to exceed 90% adoption of total soybeans planted, in Argentina it only took seven seasons to reach that level.

Before herbicides were introduced, weed control in soy cultivation was achieved by mechanical means (Christoffoleti et al. 2008). The Roundup Ready technology simply relies on one herbicide to control a broad spectrum of weeds without damaging the soy crop or restricting crop rotation programs (Gianessi 1999). Planting GM RR soy is also a cost-saving strategy and has become commonplace as an agronomic practice to control weeds. Because its use eliminates expensive mechanical weed management strategies it is an economically favourable option.

RR soybeans have successfully been adopted across the soy-growing regions of South America. According to Gudynas (2008), Brazil has planted more than 22 million ha of GM soybeans since their introduction, and was producing around 60 million tonnes of RR soybeans per annum in the 1980s. In Argentina, 17 million ha were planted to RR soy in the mid-1980's and the annual harvest was approximately 48 million MT. Bolivia, Paraguay and Uruguay only grow GM soy. The introduction of GM soy in this region has been driven, to a large extent, by the increased global demand for soy created by an increasing number of new uses for soy products (*cf.* Sections 2.4 and 2.5). A number of countries in South America's Southern Cone—the world's major soy producing region at the present time (Section 0)–have generated high economic returns across the region as a result of soy cultivation and export (Furumo & Aide 2017; Richards et al. 2015; Innes 2006; Oliveira 2016). GM soy cultivation has proven to be an economically sound decision in South America. In Argentina Leguizamón (2014) has stated "*soy is the goose that lays the golden egg*s", and he has ascribed the revival of Argentina's more than moribund economy to the cultivation and export of transgenic soybeans. The country is now the third largest global grower and exporter of soybeans (Newell 2009). Uruguay, which is currently the tenth largest producer of soybeans (Figure 1-2), has displayed the fastest rate of increase in soy production over the last 10 years; with 3.5 million ha of natural grasslands cover having been converted to agriculture, mainly as a consequence of soybeans, in the early 21st Century (Redo *et al.*, 2012).

Nonetheless, GM soy and other GM crops are considered to bring about unwanted social and environmental outcomes (Rocha & Villalobos 2012; Qaim & Traxler 2005; Trigo & Cap 2003; Leguizamón 2014). Of particular importance in this research is the fact that monocropping with GM crops impacts land use by bringing more land into cultivation. This is testament to the effectiveness of GM modifications in expanding the range of crops to, for example, drier and more humid environments as noted above. This type of expansion can also displace crops that were previously grown as well as other agrarian activities such as stock grazing and dairying, and even exert pressure on natural grasslands and conservation areas (Oliveira 2016; Blum & Narbondo 2008).

2.5 Uses of soy

The main uses of soy until the late 20th Century have been twofold. First, as a food for humans; and secondly, as animal feed. New uses have emerged in the late 20th Century, e.g., as an edible and an industrial oil, and as biodiesel.

Soy has been widely used as a food in East Asia; in the form of processed bean curd (tofu and tempeh), as a vegetable, as fermented soy sauce, miso and soy milk (Campbell-Platt 1994). During the Sung Dynasty (960-1279), it is believed that dark soybeans were fermented to make soybean wine. These uses have diffused geographically in parallel with the Chinese diaspora, and as more people have adopted vegetarian diets in the western world. During the Russo-Japanese War (1904-1905), which was fought in Manchuria, locally-grown soybeans were important food sources for both armies. During this conflict, it was reported that the Russians were amazed at the stamina of the Japanese soldiers, who were eating dried frozen tofu and other preserved food as basic protein foods. This sparked interest among European scientists in the potential military use of soy products as food, an interest that was put to use in Europe during both world wars, though mainly by German troops (Eckstein et al. 1974). Manchuria found itself with a surplus of soybeans after the Russo-Japanese War and thus had to find new markets. During the WW I soy flour was used as an extender for both meat and wheat flour, which gave the image of soy as 'hardship food' (Hymowitz 1970).

In the early 20th Century Europe was experiencing high prices for traditional oilseeds such as cottonseed and linseed due to supply constraints. It was at this time that Manchuria made its first large shipment of soybeans to England (1907) where they were crushed and turned in oil mills in Liverpool to produce soy oil and soymeal (Hymowitz 1970). By the late 20th Century milled soy was used in a wider range of consumer goods such as cooking oil and in margarine (WWF 2014). It is processed into flour which is then used as a stabiliser that increases protein content in baked goods (APHIS 2014), and soy oil is used in the manufacture of margarines and shortenings. Industrially, soy oil is used as an additive in cosmetics and in products such as paints, soaps and disinfectants. Soy is increasingly used for the manufacture of biofuels; and soybean oil derivatives, such as the emulsifier lecithin, are used in the production of chocolate, ice cream, and baked goods.

The soymeal, which remained after oil extraction, was used for livestock feed and to make fibre. However, its use as an animal feed was known before this time. Soybeans had been used as livestock feed, especially for working animals, for centuries in east Asia. Horvath (1928) noted that black soybeans were used for animal feed in Manchuria, where whole or crushed beans were mixed with chopped millet straw and a little water. He also noted that black soybeans had long been preferred to yellow beans for livestock feed, since the black variety was known to contain much less fat than the yellow bean. In the USA, a few farmers began to grow soybeans as forage crop for cattle in the 1800s. Denmark experienced success nationally with soybeans between 1910-1930. The country was deprived by its poor wheat production and instead had to import wheat from America. It began rebuilding its livestock agriculture economy using soybeans as a substitute for wheat for livestock feed, and had become a major exporter of meat and dairy products during the 1940's (Horvath 1936). In summary, whole plants are used widely for animal fodder, dried to form a type of hay, or used as silage by compacting green as a fodder crop and fermenting it in airtight containers for winter feed. It is also grown as cover crop, that is sometimes grazed (EOL 2018).

It has been documented that soybeans were used in traditional Chinese medicines (TCM). An ancient pharmacopeia suggests black soybeans steeped in wine as a remedy for purifying blood, curing colds, and strengthening mothers after childbirth (Shurtleff et al. 2014). Another use during the American Civil War was a substitute for coffee berries.

In some ways the broad roles of soy as food for people and a foodstuff for animals has not changed over history. However, the number of ways soy is used in these two areas has expanded. In addition, new industrial uses have appeared. The increasing number of uses, plus increased demand from a growing population have, in part, led to a massive increase in demand for soy across the world and its rise as a globally-important commodity.

2.6 Soy as a traded commodity

Soy is the largest agricultural commodity in the world in terms of production and trade volumes. Global annual production stands at 335 million MT, consumption at 270 million MT and the traded volumes at 161 million MT (FAOSTAT 2016). The main producers globally for 2016 are shown in Figure 1-2.

During the first three decades of the 20th century, soybean production was largely confined to the Orient, and China, Indonesia, Japan and Korea were the largest soy exporters (Hymowitz, 1970). However, during the late 1940's and early 1950's the USA overtook China and then all of eastern Asia in terms of soybean production. By 1968, 28 million hectares of soybeans were sown in 25 countries around the world, including Europe and South America. Soybean cultivation then increased significantly, after the spread of BSE in the mid- to late-1980's in Europe (Shurtleff & Akiko 2004). By the late 1990's there was a global increase in soybean prices due to a shortage of high-protein, plant-derived animal feed. This shortage was mainly the result of the outbreak of bovine spongiform encephalopathy (BSE), more commonly known as 'mad cow disease', which spread through British herds in the mid-1980's, then quickly throughout Europe. Prior to the outbreak, meat and bone meal (MBM) was used as the basis of feed for ruminants; and this is thought to have been responsible for the spread of the disease through herds since cattle are natural herbivores (Coffey et al. 2011). MBM was banned in the UK in 1988 to prevent animal protein being fed to ruminants, with Europe quickly following suit. In the mid 1990's BSE outbreaks were reported again in France, and it is thought that this may have been the result of the import of cattle from the UK between 1985 and 1990 (Chachra et al. 1999). It is the case that MBM is no longer allowed in feed for ruminant animals in most countries, and soymeal has become the preferred substitute for MBM in animal feed.

At present three quarters of soy produced worldwide is used for animal feed. Soy beans have approximately 40% protein and 20% vegetable oil by weight. Thus, they produce more protein per hectare than any other major crop and have a higher percentage of protein than many animal products (RMIV, 2011 in WWF, 2014). This makes it not only a versatile crop, but also a nutritious one. The economic value of soy bean oil is significantly greater than soybean meal. After crushing soybeans on average yield 79% soybean meal and 19% oil by volume; while the proportions by value are 57% meal and 36% (Van Gelder and Kuepper, 2012 cited WWF 2014 p.15). Increased demand for soybean in the EU and in Asia is mainly a consequence of the intensification of meat production. Globally, increased meat consumption has led to an increase in the demand for soybean products to manufacture animal feed, and has led to its emergence as a strategically important agricultural commodity globally (Hoffman 2014; Le Polain de Waroux et al. 2017; Reenberg & Fenger 2011).

Soybeans are used to produce ethanol as an alternative energy source to petroleum-based fuels. Although, this remains a very small proportion just 2% of total soy production soy is predicted to supply about 10% of EU biofuel production by 2020 (Laborde, 2011). Soy accounted for 11% of the feedstock used in biodiesel production in the EU the early 2000's (Hard, 2004). However, according to one economic analysis (KPMG, 2013), the use of soy to produce biodiesel has been the second-most important driver of the growth in soy production. The growth in biodiesel production has been driven by biofuel targets set by the EU, as noted above, and the USA, which had a target to consume 36 billion gallons of renewable fuel (biofuel) annually by 2022 (KPMG 2013 p.6).

Global production and consumption of vegetable oils has increased markedly in the past decade. Almost two-thirds of this demand has been met by the growth in palm oil and soybean oil production. In 2007 palm oil represented more than 30% of all vegetable oil production in 2007, closely followed by soybean oil at 28%. Rapeseed and sunflower oil accounted for 15% and 9% respectively. Annual growth in the production of the major edible oils is shown in Figure 2-1. Various drivers have influenced the market for vegetable oils. These mainly include a rise in human consumption of vegetable oils, oil used in animal feed production, industrial oils and, as noted above, in biofuel production (particularly in the EU, USA, Argentina and Brazil) (Thiyagarajan & Sahu 2014; Elbehri et al. 2013).

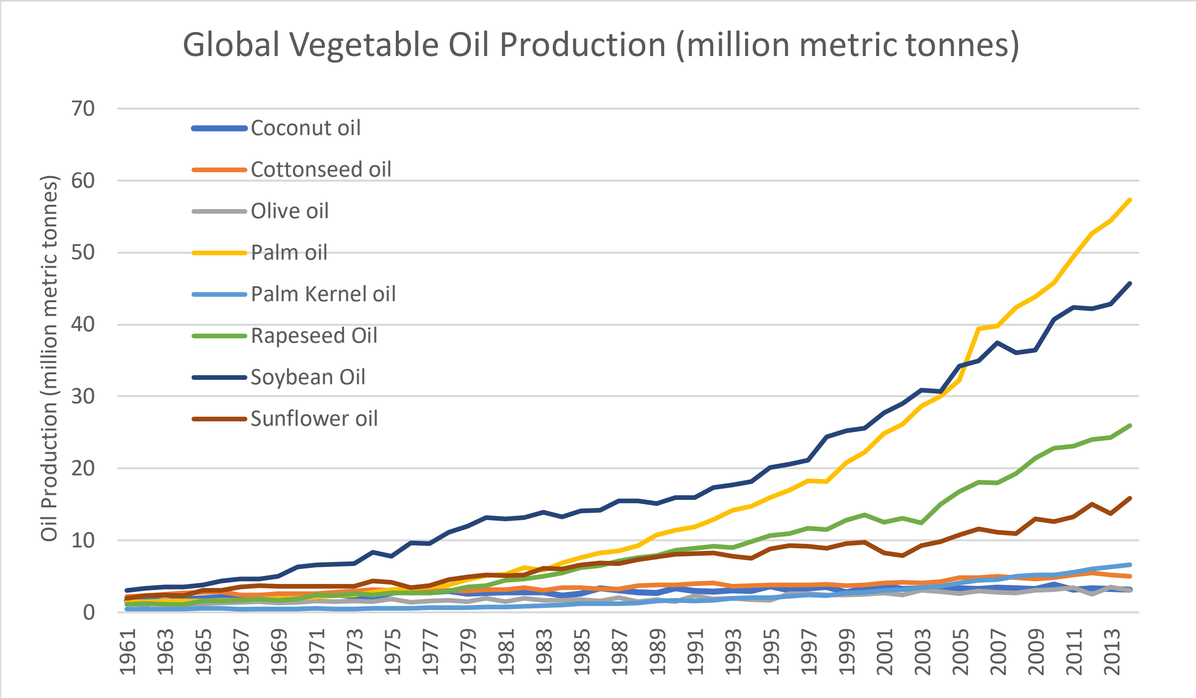

Figure 2-1 - Global vegetable oil production, 1961-2014. Source FAOSTATS 2016

Palm, soybean, and rapeseed are the three major edible oils globally. Together, they represent around 75% of the total production of vegetable oil used in food preparation. Production of palm oil—another of the world's most traded commodities–is dominated by Malaysia and Indonesia. These two countries account for 80-85% of the world's production (FONAP 2018). Palm oil is also produced in other South-East Asian countries, Sub-Saharan Africa and northern South America. Rosillo-Calle (2009) predicts that South America could become a leading producer and exporter of vegetable oils. While most of this would be soybean oil, palm oil production is increasing across the continent with Brazil, Colombia and Peru expanding oil palm and their high potential to grow oil palm in parts of Bolivia and Paraguay (Pacheco 2012).

The UN predicts that the world's population will increase from 7 billion to 9.3 billion over the next 40 years (United Nations 2015). A major global challenge emanating from this will be to produce enough food to meet the demand created by the growing global population. The main ways that this is likely to be achieved will be to (i) increase the amount of farmland globally, and (ii) as the amount of cultivable land is finite, further intensification of crop and animal production will need to take place (Lambin et al. 2006). Other challenges include improved food security, reduction in food waste, and improved sustainability in food production to minimise natural resource use (Ghaley et al. 2014; Sandhu & Sandhu 2014; Carreño et al. 2012). The changing food demand of many developing countries, especially those in south and south-east Asia, are not only increasing because of population growth generally and in cities in particular, but are also changing because of the adoption of more protein-rich diets as a result of urbanisation and increased incomes (Liu, Hull, Batistella, DeFries, et al. 2013; Kharas & Gertz 2010; Hoffman 2014; da Silva et al. 2017).

As a result of these shifts in demand and increased demand related to population growth, global soy production has grown from 27 to 330 million MT globally in the last 50 years (Figure 2-2); and the total area of soy cultivated globally exceeded one million km^2 in 2014, the combined area of France, Germany, Belgium and The Netherlands (WWF 2014). As a consequence, it plays a key role in addressing some of the challenges posed by concerns over global food security.

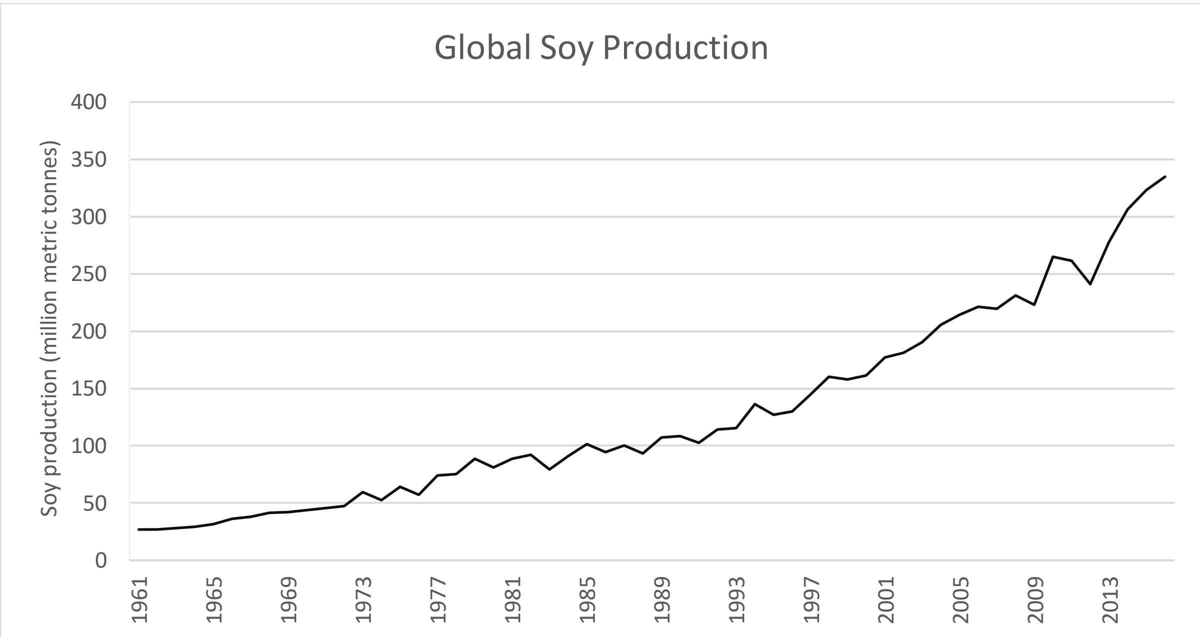

Figure 2-2- Global Soy Production 1961-2016 Source: FAOSTATS 2018

2.7 The expansion of soy into South America

The development of soy-dominated agricultural systems globally has grown from strength to strength since the 1990s. Nowhere has this been more evident than in the MERCOSUR[2] region of South America. In the last three decades agricultural land-use changes in South America's Southern Cone have been strongly influenced by the progressive expansion of soy agriculture, which has also grown in parallel with the increase in global meat production (Le Polain de Waroux et al. 2017; Barona et al. 2010; Baumann et al. 2016a; Franzluebbers et al. 2014). From 1990 and 2010, soy production increased from 33.1 million to 132.3 MT , and the harvested area expanded from 17.7 million to 46.2 million ha (Pacheco 2012). By 2016, the harvested area had grown to 58.5 million ha and production increased to 169.8 million MT (FAOSTAT 2016).

Its growth has positively impacted on the economies of these countries, e.g., in terms of increased export revenues and significant changes in and upgrading of the respective agro-industrial sectors. However, this growth has been accompanied by ecological and social costs. Many family farms have been consolidated, and intensive livestock production has been displaced. This in turn has raised concerns about the long-term impact on natural resources in forest and woodland areas and in terms of sustainability (FAO 2007; Leguizamón 2014; Spehar 1995).

Brazil is currently the second largest soy producer in the world after the USA, with more than 33 million ha devoted to producing around 96 million tonnes of soybean (Figure 2.1). Argentina is the third largest producer globally, with 19 million ha devoted to soybeans and a production of 58 million MT. Soybean cultivation is concentrated on some of the richest soil in these countries, including Mato Grosso in Brazil, the pampas in Argentina and across the Gran Chaco. Concentration of soy in these areas has pushed the cultivation of other crops and cattle rearing to more peripheral regions

[2] *Mercado Comun del Sur* or the Common Market of the South is an economic and political agreement between Argentina, Bolivia, Brazil, Paraguay, Uruguay and Venezuela promoting free movement of goods, services and people among member states.

(Caballero et al. 2011; Gudynas 2008). Paraguay has the largest percentage of its agricultural land devoted to soybean of any country in the world; an estimated 10% of its cultivable land. Soybeans have displaced cotton as Paraguay's main export and now account more than 50% of the country's exports (Turzi 2011). Uruguay had the fastest rate of increase in soy production in the early 21st century, with 3.5 million ha of herbaceous cover having been converted to soybean cultivation in 2009 (Redo et al. 2012).

2.7.1 Non-GM soy in Brazil

Since the introduction of new agricultural technologies around soy production, GM soy cropping has become widespread. Garrett et al. (2013) explain that the production of non-GM soy has declined in the face of the onslaught of GM soy. From 1995 to 2010 the non-GM-soy production in North and South America has declined by 80%, with the exception of Brazil where approximately 25% of soy beans produced in Brazil are free from genetic modification (Cert-id 2014).

Currently, Brazil remains the largest producer of non-GM soybeans globally, producing 15 million tonnes annually (Garrett et al. 2013). The continued production of non-GM soy in Brazil has led to a strong trade link between Brazil and the EU. According to Garrett (2013), these strong trade links have been established by upgrading the non-GM supply-chain to enhance opportunities for Brazilian producers whilst at the same time promoting Brazil's sustainable production credentials in soy farming for non-GM. Certification programs are used to incentivise producers to improve product quality by offering premium prices (Garrett et al. 2013). For example, from the consumer perspective, certification programs provide uniform standards to any producer which can then be verified by third party organisations, this is particularly true for the food industry. Such programs have been created for non-GM soy in Brazil to foster environmentally sound production practices. There are two major certification standards for environmentally responsible production in the soy chains: ProTerra and the Roundtable on Responsible Soybeans (RTRS). ProTerra certification standards were created within CERT-ID to support food chain sustainability performance by putting the onus on producers to grow high-quality non-GM soy. It also ensures farms use sustainable practices in terms of soil, pesticide and water use and do not convert native forests or other high conservation value areas (HCVAs) to cropland. Specifically, in Brazil, certified soybeans cannot be grown on HCVA land that was cleared after 2004 (Garrett et al. 2013).

CERT-ID is one of the largest certifying programs for non-GM soybeans. It is a Brazilian multi-stakeholder company that provides a sustainable approach to food production, not simply soy, through third-party certification programs that are concerned with detecting the presence of GM foods in supply-chains (Cert-id 2014). It has been certifying Brazil's non-GM agricultural production for over 10 years (Pelaez et al. 2010). RTRS certification was created at the same time as Proterra in 2006. Its certification standards are similar in that they both receive certification through an accredited third-party auditor. Compliance with environmental laws is the same, except soy many not be grown on HCVA land that was cleared after 2009. Under the RTRS certification programme producers can grow both GM and non-GM, or organic soybeans (Garrett et al. 2013).

The strong trade links with the EU have facilitated the creation of the parallel non-GM supply-chain model. In fact, in complying with CERT-ID standards, means non-GM and GM soybeans have separate supply-chains to avoid contamination. This has enhanced opportunities for soy producers in Brazil and brought rewards and incentives for environmentally sustainable production through eco-certification programs (Garrett et al. 2013). None of the other Latin American countries have been able follow Brazil and compete with non-GM soy in Brazil, and they only produce and export GM soy.

According to Garrett et al. (2013), Mato Grosso was the earliest, and is now the largest, region of certified non-GM soybeans in South America. Their research illustrates how longstanding production of non-GM soybeans in this region has led to the development of the infrastructure necessary to segregate, trace and test the physical quality of local soybeans.

2.8 Drivers of soy Cultivation in South America

There are three key demand drivers of the growth in soy in South America can be identified from the literature. These are:

- increased demand for soy in food processing, especially due to changing diets, in East Asia;
- Increased demand for soy for animal feed; and
- Increased biodiesel production.

In China diets are changing, middle-class consumers in China are not only consuming more protein (and therefore creating demand for protein from meat, especially pork and chicken) but also demanding higher quality food underpinned by more stringent food safety standards (Gale & Huang 2007; Shi et al. 2011; Wen 2016). The increased demand for protein in East Asian countries, not only China, has increased global demand for soy for human consumption and also to manufacture animal feed for intensive pig and chicken farming. Intriguingly, research has found that Chinese consumers are willing to pay premiums for foods with trusted safety-related certification (Wang, 2003, 2006 cited in Gale & Huang 2007 p.2), and this has prompted some commentators to suggest that China may be on the verge of importing more non-GM soy, though at the present time most imports are GM soy. Increasing affluence of some Chinese consumers has led to greater expenditure on meals in restaurants and processed food products, especially those that are certified free of harmful chemicals (Gale & Huang 2007). Increasing demand for high-quality food with safety certification and verifiable provenances means that the Chinese markets will not only continue to be a large driver in terms of food production globally, but it will lead to new production and marketing opportunities. For example, it may see a fundamental change in the balance of non-GM soy trade flows from South America and may stimulate other countries to follow Brazil's lead and establish a non-GM supply-chain.

The growing demand for meat from animals fed non-GMO feed has directly lead to increased demand for non-GMO soybean meal in the European Union (Garrett et al. 2013) (*cf.* Section 2.7.1). Consumer demand has meant that major food retailers in the UK like Asda, Iceland, Safeway, Sainsburys, Tesco and Waitrose only source meat from suppliers who could guarantee that animals had only been fed non-GMO products or were free-range. Other European retailers, e.g., France's Carrefour, Superquinn in Ireland, Danish Crown, Coop Italia, and Spar in Austria have also committed to selling non-GMO meat products (Schoneker 2007). The majority of the EU's non-GM soymeal comes from Brazil, the world's leading producer, smaller amounts come from Canada and the USA (isaaa.org 2017). Leading the promotion of non-GM-food products is the Brazilian Association of Non-Genetically Modified Grain Producers (ABRANGE). Established in 2008 they have around 40 members, this includes non-GMO soybean producers and processors, cooperative and certification organisations. Founding member companies include Andrew Maggi, Imcopa, Contrimao, Braswey, Brejeiro and Caramuru. Up to 2005, Brazilian farmers only grew non-GM soy. GM soy varieties became legal in 2005, after this time their use was quickly adopted (Pelaez 2009). Though non-GM soy production in Brazil decreased as a consequence of the introduction of GM soybeans (Garrett et al. 2013), it remains the largest GMO-free soy producer in the world and incorporates all aspects of the non-GM supply-chain. This ensures that foreign buyers, in particular those from Europe who are paying significant premiums, are guaranteed certified non-GM soybeans.

Though the research in Brazil has been in the development of a non-GM soy supply-chain, it does indicate that research into soy supply-chains may be able assist in understanding agricultural trends in Southern Cone countries.

Increased biodiesel production from soy plant extracts is relatively small in comparison to the demand from food and animal feed proportion. However, it has been noted by some researcher that it has the potential to drive soy expansion further in South America (Elbehri et al. 2013; Leguizamón 2014; Furumo & Aide 2017).

2.9 Theoretical Frameworks

2.9.1 Land use systems

Land-use systems systemically represent the intricate web of relationships, factors, process and structured that impinge on land-use. Land is continually changing and transforming because of various natural and manmade processes. Human populations and their use of land have transformed most of the terrestrial biosphere into anthropogenic biomes. (Verburg et al. 2015). Such process have caused a variety of patterns and processes to emerge and have been significant over the last 8000 years (Ellis 2011).

More recently issues related to land-use have gained attention from land-use change researchers ranging from those who favour modelling spatial temporal patterns of land conversion to those who try to understand the causes, impacts and consequences (Verburg et al. 1999; Theobald 2001). There is a more comprehensive understanding that many of these human induced impacts are often driven by socio-economic factors despite the restrictions on the physical conditions (Long et al. 2007)

More generally and over time, land-use changes often include land transformation from one type to another and land cover modification though the management of how the land is used and this inevitability has altered a large proportion of the earth's land surface- aiming to satisfy the immediate demands for natural resources as human population continues to grow (Meyer & Turner 1992). These drivers have occurred worldwide, forests, farmlands, waterways are being driven by the need to provide food, fibre and water to more than 6 billion people meaning that global croplands pastures, plantations and urban areas have expanded rapidly in recent decades. This expansion is accompanied by large increases in energy, water and fertilizers consumption, along with considerable loss of biodiversity (Foley et al. 2005; Friis & Nielsen 2019)

Over time these land process have been identified and has further identified the growing importance of understanding what drives these land-use system to change so quickly. In past instances local processes were thought to be responsible for those land-use changes. But more recently streams of research have converged to understand the way distant drivers are also having significant impacts on LULCC (Müller & Munroe 2014; Rudel et al. 2009; Meyfroidt et al. 2013b; Boillat et al. 2017; Gollnow & Lakes 2014).

2.9.2 Proximate and underlying drivers of land-use

In the past, much research conceptualised Land-use in a linear fashion. The primary land-use trajectory was thought of as the conversion of forests to agricultural use with driving forces attributed to something immediate to a specific area such a population growth (Lambin et al. 2003). This over-simplification of drivers has been recognised by recent research; there is now an understanding of the complicated interrelationship that exist between indirect and direct drivers of land-use. Lambin and Meyfroid (2011) discuss that economic globalisation has muddied the waters for those investigating the drivers of land-use changes and political actors trying to influence these trends. Because of this, a number of frameworks are proposed to try to account for direct and indirect influences on land-use change.

Proximate and underlying drivers of change are presented to understand both the direct causes of land-use change, as well as the more distant and indirect drivers of change (Geist & Lambin 2002). Proximate causes refers to the direct human actions that affect LULC, while underlying causes refers to a complexity of variables such as, economic, political, demographic, technological ,cultural and biophysical. These underlying drivers are systemic in nature (Geist & Lambin 2002; Contreras-Hermosilla 2000).

In 2002 Geist and Lambin (2002) identified the major proximate and underlying causes of tropical deforestation in a meta study of 152 cases studies. The proximate cause, which were most evident, included infrastructure expansion, agricultural expansion, and wood extraction. Whilst the main underlying causes included demographic factors- migration; economic factors- market growth; technological factors - changes in agro technology; policy and institutional factors- formal policies and cultural factors ; public attitudes- values and beliefs (Geist & Lambin 2002). In all these cases, there is an array of proximate and underlying drivers to LULCC.

There are studies which have identified both proximate and underlying drivers. For example, a study of land-use change in Pakistan identified wood extraction and accessibility as major proximate causes of deforestation and agricultural expansion; underlying causes were related to weak government and conflicts over property rights (Qasim et al. 2013). Miyamoto et al.'s (2014) case study cite Palm oil expansion as an proximate driver and poverty alleviation efforts as underlying drivers of forest cover change in Malaysia. In another study Cropper et al. (2006) assess the impact of a number of variables on land clearings in Thailand. The study stresses that the most important factors affecting the probability of an area being cleared was the relative distance to an all-season road.

Proximate and underlying drivers of land-use are areas of research that persists in the LCS literature and continue to influence land system science. However, the distinction between these two types of drivers has come under scrutiny. It is argued that this framework portrays land-use as a linear process and does not take into account non- linear developments including feedback, loops and thresholds into account (Turner et al. 2007; Seto et al. 2012). Friis & Nielsen (2014) argue that the complexity involved in shaping current land changes challenge the distinction between proximate and underlying drivers, as they interact in a multifaceted manner across spatial, institutional and temporal scales.

2.9.3 Teleconnections and Tele-coupling

Teleconnections was first used in atmospheric sciences and refers to connections between climate variations in non-contiguous geographic areas (Nigam & Baxter 2015). The teleconnections framework, more recently has been used in various ways to link local and land-use changes to geographically distant places. Seto (2012) defines urban and rural land teleconnections as " the distal flows and connections of people, economic goods and services, and land use change processes that drive and respond to urbanization" (Seto et al. 2012 p. 7687). This means that the teleconnections framework focuses on the processes that link distant and otherwise independent places together. These teleconnections can range from very short to very distant linkages and can include multiple linkages between urban and non-urban areas (Güneralp et al. 2013).

The teleconnections framework is not only an important and powerful tool for linking urbanisation to rural land-use changes but for identifying and understanding the consequences of that connectivity. One example of a teleconnection is the correlation between rising incomes of urban workers and the willingness of urban residents to pay for the protection or conservation of certain ecosystem services. In this example the agglomeration of capital in urban areas and the willingness of urban residents to pay can be linked to several near and distant environmental conservation efforts (Güneralp et al. 2013). On the other hand teleconnections can result in unfortunate unintended LULC. For example, when demand for building materials in urban areas like Monterrey and Mexico City influenced land-use in the Perote Valley of Mexico, farmers converted their agricultural land to mines in order to meet the demands for pumice in those urban areas. However once the market saw a decline in demand, the land was depleted and no longer suitable for agriculture (Güneralp et al. 2013). In a classic example of teleconnections, Nepstad et al (2006) analysed economic teleconnections and the environmental impacts – mainly deforestation- of beef and soy production in the Brazilian Amazon. The market for beef and soy produced in Brazil is primarily located in Europe and China, thus creating teleconnection between the demand for meat in large urban territories and land-use transitions in the Amazon from forests to agriculture. In identifying the connections between urban drivers and rural land-use change, it is possible to investigate the social, political, and economic factor that directly facilitate changes in rural land-use at a local scale.

The telecoupling framework is another relatively new framework within the LCS literature that is proposed to analyse distant drivers of land-use change. While it is similar to teleconnections, the concept of telecoupling puts an added emphasis on the feedbacks between the land use change and the distant driver of that change. Liu at al (2014) argue for a highly structural approach while Eakin et al. (2014) take a much more agent-based approach.

Eakin et al. (2014) present a framework that hones in on the process of establishing a telecoupling by identifying five key aspects: the trigger, direct impact, indirect impact, feedback process, and institutional change. This approach focuses heavily on the actors involved telecouplings and their role to land change and feedbacks between distant systems. An example provided in this paper is that of a smallholder farmers in Vietnam and Mexico and the respective impact of a fluctuating global coffee market on land-use and livelihoods within those countries (Eakin et al. 2009; Eakin et al. 2014).

In contrast to the above Liu et al (2014) apply a structural approach that also involves five key components: systems, agents, flows, causes, and effects. The examples provided in the paper apply these components, as well as characteristics about the types of systems, to cases of invasive species and transnational land deals (Jianguo Liu et al. 2014). Once each case is systematically sorted into the individual components of a telecoupling, their implications are the described more broadly, most often in economic terms. Friis and Nielsen (2014) point out that one primary way in which these approaches differ is that Liu et al's (2014)framework offers a rather stringent list that must be applied to each telecoupling, while Eakin et al (2014) offer a more heuristic option that is more flexible and is more appropriate for small –scale , local applications.

2.10 Soy Cultivation and land-use change in South America

Over the last two decades, significant progress has been made in understanding land-use and land-cover change through work carried out under the auspices of the LUCC project (1995-2005) and its the successor, the Global Land Project (GLP 2018; igbp 2018; Millington et al. 2017). In the context of this thesis, the incorporation of concepts and theories about 20th Century globalisation (e.g. Dicken 2015) into land-change research has been very important.

Many researchers now consider land-use changes as part of complex systems of interconnected drivers and feedbacks that operate simultaneously over a range of geographical scales following the pioneering research of Ramankutty, Foley and Olejniczak (2002), Lambin et al. (2006), Lambin and Meyfroidt, (2011) and Foley et al.(2005). This has had a profound effect on thinking about land-use amongst land-use researchers. This shift in thinking has created a framework for researching and understanding land-use and land-cover change in a wide range of environments across the world. For example the LULC in the Páramo of South Central Ecuador (Ross et al. 2017); agricultural land-use in

Europe (van Vliet et al. 2015), rural USA (Plantinga and Stavins 2008), and tropical forests around the world (e.g, Wyman and Stein, 2010; Redo *et al.*, 2012; Verburg *et al.*, 2015; Furumo and Aide, 2017). Lambin et al. (2006) conceptualised the idea of interconnected proximate causes and underlying drivers from a metanalysis of published research on tropical deforestation. Proximate causes are land-use change decisions that have their origins in the locale of land-use change. These are usually landowner decisions, e.g., clearing forests or woodlands to create cropland or suburban housing, draining wetlands, or decisions by local or regional government to build roads or other infrastructure. Underlying drivers are causes of land-use changes with origins that are geographically distant from the actual site of the change in land use, e.g., national government policies that encourage migration to underdeveloped rural areas, e.g., the Indonesian transmigration program and Brazil's policies to resettle people in the Amazon Basin; or agribusiness decisions, e.g., decisions made by Singapore-based agribusinesses to convert forest to oil palm plantations in Sumatra. Underlying drivers usually operate through nested linkages with decisions cascading from the distant, original source through intermediate locations to the ultimate site of land-use change (Lambin et al. 2006).

Building on the driver's approach to land-use and land-cover change, international trade in commodities has been integrated into this general model and become a key underlying driver of agricultural land-use changes in countries that are major exporters of agricultural commodities. Put succinctly, spatial and temporal patterns of direct and indirect land-use change (Barona et al. 2010; Furumo & Aide 2017; Verburg et al. 2015; Meyfroidt et al. 2013a) in an exporting country can be driven by demand for agricultural commodities from distant countries (Meyfroidt et al. 2013a; Gasparri et al. 2016; Yu et al. 2013; Liu et al. 2015). However, trade flows such as these are rarely simple, with complexity being introduced by (i) the roles of vertically-integrated actors such as multinational agribusinesses in commodity supply-chains; (ii) the interactions between production areas for the same crops in different parts of the world due to the differential effects of climate fluctuations (Sternberg 2012) or economic performance of different exporting countries; and (iii) the imperfect nature of commodity trading markets, in particular feedback loops where global commodity prices are essentially driven by production volumes, which In turn can be linked to human activities and policies such as energy prices and market protectionism (Zilberman et al. 2013; Le Polain de Waroux et al. 2018). These processes are incorporated in modern conceptualisations of globalisation, especially globalisation of agricultural land use.

The increasing importance of soy as a global commodity (Dros 2004) has spawned many avenues of economic, political, environmental and land change research in the past two decades. In the South American context, focus has been on the roles of soy in direct (dLUC) and indirect land use changes (iLUC) (Andrade de Sá et al. 2013; Arima et al. 2011; Baldi & Paruelo 2008; Barona et al. 2011; Brannstrom 2009a; Brown et al. 2005; De Sy et al. 2015; Fearnside 2001; Gasparri & de Waroux 2015; Grau et al. 2008; M. Hansen et al. 2013; Hecht et al. 2008; Henders et al. 2015; Jasinski et al. 2005; Lapola et al. 2010; Macedo et al. 2012; Morton et al. 2006; Müller & Munroe 2014; Nepstad et al. 2006; Paruelo & Oesterheld 2004; Richards 2018; Silva et al. 2006; Steininger et al. 2001; Walker et al. 2009; Zak et al. 2008; Zak et al. 2004); soy supply-chains (Garrett et al. 2013a; Garrett et al. 2013b); the interactions between soy and beef production (Le Polain de Waroux et al. 2016; Le Polain de Waroux et al. 2017; Gasparri & de Waroux 2015) and socioeconomic development as a result of soy cultivation (Leguizamón 2014).

Increased demand for soy from China and the EU28 (He et al. 2014; Schleifer 2017; Qiang et al. 2013; McAlpine et al. 2009) has led to significant land-use change across the Americas. More specifically in South America, where it has led to direct conversion of Amazonian forests (Fearnside, 2001; Steininger *et al.*, 2001; Brown *et al.*, 2005; Hecht, 2005; Morton *et al.*, 2006; Walker *et al.*, 2009; Hansen *et al.*, 2013; De Sy *et al.*, 2015; Henders *et al.*, 2015); iLUC, where forests are cleared for new pastures to replace pastures elsewhere that have been converted to soy (Andrade de Sá et al. 2013; Arima et al. 2011; Barona et al. 2010; Gollnow & Lakes 2014; Lapola et al. 2010; Macedo et al. 2012; Müller &

Munroe 2014; Nepstad et al. 2006; Richards et al. 2012); the *caatinga* of Brazil (Brannstrom 2009b; Jasinski et al. 2005; Jepson et al. 2010); dry forests in Argentina, Bolivia and Paraguay (Boletta et al. 2006; Grau et al. 2005; Killeen et al. 2008; Silva et al. 2006; Zak et al. 2008; Zak et al. 2004); grasslands (Baldi & Paruelo 2008; Paruelo & Oesterheld 2004; Piquer-Rodríguez et al. 2018); and grazing lands which are a mosaic of grasslands and dry forests in Bolivia (Redo & Millington 2011) and Brazil (Rudel & Meyfroidt 2014; Le Polain de Waroux et al. 2016).

The focus of most of the research on soy and land use change in South America has been limited to large areas where soy production has increased significantly at a rapid rate (Barona et al. 2010; de Waroux et al. 2016). In addition, this line of research has been dominated by the expansion of soy frontiers at the expense of natural vegetation and in some cases soy replacing cattle ranching (Andrade de Sá et al. 2013; Barona et al. 2011; Arima et al. 2011; Nepstad et al. 2006) less attention has been paid to the role of soy in agricultural intensification, which is the dominant land-use dynamic in Uruguay. The reasons for this are related to the lack of research on soy in Uruguay, because it is a relatively new soy producer in South America, and it has a relatively small research community. Therefore, the expansion of soy in Uruguay, which has mainly been at the expense of other arable land, rather than forest has been neglected. This research suggests that a further reason why research might not have been undertaken in Uruguay is the very patchy nature of continuous departmental-level statistics on cultivation. National-level data are available (either through AFO or MGAP) and have been used in research on policy drivers of land use change (Redo et al. 2012); foreign land ownership (Piñeiro 2012); the intensification of beef production and ecosystem services (Ran et al. 2013); the integration of no-till into crop-pasture rotations (García-Préchac et al. 2004); and as part of a regional analysis of changes in cultivation since 2000 (Volante et al. 2016) (Volante et al. 2015). Even then, the impacts of the expansion of soy in Uruguay have not been explored in detail in a country-based analysis.

2.10.1 Globalisation and land-use change

Reductions in trade barriers and improvements in transportation and logistics have accelerated commodity flows across the world and facilitated links between agricultural source regions and distant markets (Lambin & Meyfroidt 2011; J. Liu, et al. 2013). This has been termed land-use tele-coupling and is a contemporary and important research topic in land system science. The importance of these human-driven changes are well documented, e.g., the effects of land-use change on biodiversity loss, water quality, deforestation, displacement of communities and land-use displacement (Reidsma et al. 2006; Weinzettel et al. 2013). Grau et al. (2013) assessed the trade-offs between food production and biodiversity at landscape and ecoregion scales. More recent research has analysed the way in which new forms of market-based governance such as sustainable corporate sourcing, eco-labelling, and market exclusion of commodities, that do not meet sustainability criteria, can influence land use through global value chains of specific forest and agricultural products (Meyfroidt et al. 2013 p. 441). Rueda and Lambin (2013) explain how understanding price premiums for goods that are certified or meet a specific sustainability criteria are distributed along supply-chains and may help progress towards more sustainable land use in the context of coffee value chains in Colombia.

Garrett et al. (2013) show how globalisation may help kerb deforestation in some cases. Brazil's strong trade relations with European consumers with respect to non-GM has facilitated the upgrade of the soybean supply-chain in the country as noted earlier. They explain that the upgrading of the soy supply-chain to meet eco-certification programs has created new conservation opportunities for Brazilian farmers who can differentiate their products based on the environmental quality. These new mechanisms use certification programs which are an attractive way to tap into niche markets. This is the case in the food sector where individual producers undergo the use of certification mechanism that span throughout the entire supply-chain. These certification mechanisms, from the consumer perspective, provide theoretical uniform standards which can be applied to any producer and can be independently verified by a third party (Garrett et al. 2013 a).

Soybeans are an excellent example of a commodity where the spatial attributes of agricultural land-use in exporting countries can be linked to importing countries, and intermediary countries through which the commodity may be re-exported or be processed; it plays a role in establishing a complex international network in soybean trading. Reversing the situation in the early 20th Century, China has become the largest importer of soy globally, due to a growing population, with a flight of rural labour to cities and an increasing number of urban dwellers; a change in diet which requires more animal feed production to meet protein demands; with a loss of agricultural land. In order for China to begin to import soy at low prices they became members of the World Trade Organisation (WTO) in 1995, and reduced its tariffs on imported soybeans from 130% to 3% in 1995 (Yang 1999). Since then soy has literally poured into China on ships from around the world. One important consequence of this, in terms of land use, has been a substantial decline in the amount of land planted to soy in China (NBSC 2015). In 2014, China imported 61% of the total exported soybeans; most came from the USA and Brazil. The USA is both the largest producer of soy and the largest exporter to China. One quarter of its production was exported to China in 2014. Although, US soybean exports to China are still increasing, the pace at which it has been increasing has slowed down due to competition from Brazil (Casey 2012). The proportion of soybeans imported by China from the United States decreased from 82% in 1995 to 45% in 2014, while the proportion from Brazil increased from 3% to 40% over the same period (ASA 2015). As a consequence of the challenges posed by deforestation caused by soy cultivation directed to the Chinese markets, Brazil conservation strategies have been put in place. The most significant if these is the Soy Moratorium which forbids soy traders from purchasing soybeans grown on land cleared after 2006; which has curbed illegal clearance of forest land for soy farming (Gibbs et al. 2015). Nevertheless, the production of soy in Brazil continues to increase as a result of agricultural intensification (Lambin & Meyfroidt 2011).

The impacts of economic globalisation of agriculture on land-use change and other aspects of the environment are not straightforward to predict and can be contradictory. On the one hand, Liu et al. (2013) identify how globalisation of agriculture can lead to unexpected environmental impacts, with consequent unintended implications for sustainability. While on the other hand they note that interactions such as export flows can also be advantageous environmentally.

2.11 Summary

This chapter provides a broad context for the remainder of the thesis by providing both global and regional (South American) perspectives on the expansion of soybeans from North-East Asia to a crop that is grown in other bioclimatic zones; its historical and contemporary uses; and its growth as a traded commodity of global importance. The latter part of the chapter focusses on the impact the expansion of soy into South America has had on land-use change processes, and how these can be related to economic globalisation through land-use change tele-coupling.

Its growth as a traded commodity of global importance and the fact that economic globalisation underpins land-use change tele-connections form the theoretical foundations of the time-series modelling of soy production and area under soy in Uruguay between 1961 and 2016 that are presented in Chapter 4 and Sections 5.2and 7.2a. The impact the expansion of soy in Uruguay, which forms the basis of Chapter 7, will be discussed in the context of soy's influences on land-use change processes to South America précised in this chapter.

3 RESEARCH DESIGN AND METHODS

3.1 Introduction

The purpose of this chapter is to present the design of the research project, and the methods that were used in pursuit of the research. In doing so, it provides an overview of the research design (Section 3.1), justification of the research area selected (Section 3.2); a discussion and justification of the methods used for data collection (Section 3.3); and a similar discussion of the techniques used in analysing and presenting data and results (Section 3.4).

This research mainly focusses on the expansion of soy in Uruguay in the last 20 years; specifically, it investigates the drivers behind the expansion of soy in Uruguay and its consequences in terms of arable production systems, the soy supply-chain and land use. Although the focus of thesis on the period from 1990 to 2016, time different time periods. Therefore, there are several layers of agricultural data that are discussed which date as far back as the 1960's. These archival data are mainly used to build an historical agricultural context in the Southern Cone, for time series modelling of soy area and production in Uruguay, and in examining interactions between cattle and soy production in Uruguay. The research adopted a mixed-methods approach by collecting and analysing qualitative and quantitative data.

3.2 Research Design

Social and cultural geographer Gill Valentine stated:

> *Research design is a result of a series of decisions we make that emerge from our knowledge of the academic literature, the research questions we want to ask, our conceptual framework and our knowledge of the advantages and disadvantages of different technique* (Valentine 2001, p41 Cited in Limb & Dwyer 2001).

The framework below outlines the process which was undertaken to reach the aims of the project. The themes mentioned in Chapter 1 are illustrated in Figure 3.1. In order to address the research objective. The research contains a mix of methods (quantitative and qualitative) to collect the data.

During the collection of data, the researcher used the following methods including desktop study, semi-structured interviews and observation of field and land sampling surveys. Some of these data were analysed using statistical techniques, transcribing interviews, land observation and analysing secondary materials (Valentine & Clifford 2003).

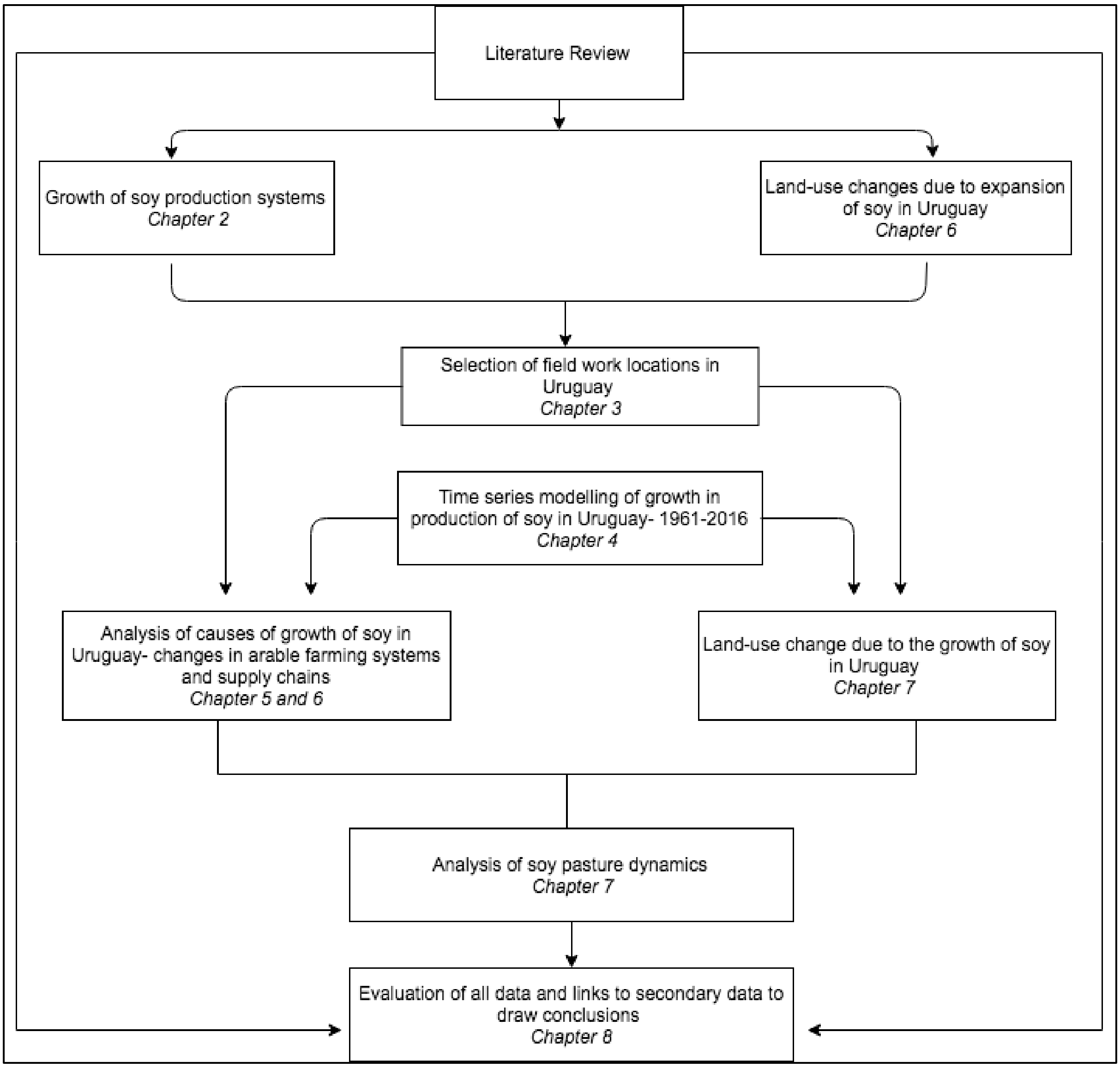

Figure 3-1 Conceptual Framework for the research in relation to Research Themes and main methodological approaches

3.3 Justification of the area selected for study

Soy cultivation has grown to become the most widely cultivated and profitable (legal) crop in South America in the last two to three decades. As the area under soy cropping systems has expanded and cultivation of soy intensified, it has led to significant documented direct and indirect land-use and land-cover changes (Section 2.8). Large amounts of research have been conducted in Argentina and Brazil on land-use and land-cover changes consequent upon the adoption of soy, and there have been research studies from the other three countries growing soy in the southern cone regions: Bolivia, Paraguay and Uruguay.

Of these three under-researched countries, Uruguay was selected because:

1. It is under-researched compared to Argentina and Brazil;
2. It is the most recent of the five South American countries to adopt soy as a major crop, and is the most recent of the five to become one of the world's top ten exporters;
3. While the expansion of soy in Paraguay has been mainly at the expense of sub-tropical woodland, and in Bolivia at the expense of sub-tropical woodland and extensive grazing systems; in Uruguay soy has mainly replaced other arable crops;
4. Uruguay is closely linked culturally and economically with Argentina, and by studying soy adoption in Uruguay the role of Argentina in that process could be investigated.

Within Uruguay, the conversion to soy cropping systems has mainly occurred in the four departments of the Litoral- Paysandú, Rio Negro, Soriano, and Colonia. This was confirmed by crop production data (MGAP, 2014) and therefore these four departments were the main focus of interest for the research. The remainder of the country focuses on cattle ranching, with some dairying. Because there is great interest in understanding how the exponential growth in soybeans could impact land-use in cattle rearing and dairying areas because of displacement or spill-over effects, crop and cattle production in other departments were researched to set the research conducted in the four main soy-growing departments in a wider context.

3.4 Methods and Data Sources

Figure 3.1 (research design) suggests that different methods were required to obtain the data required to answer the different research questions. Research on global drivers of the changes on soy production and area in Uruguay since 1961 relied on a form of time-series analysis which incorporates

Granger causality. Statistical data inputs for time-series modelling were acquired from FAO, The World Bank and USDA. The modelling approach and the data inputs for this aspect of the research are discussed in detail in Chapter 4.

The remaining research questions, which are evaluated in Chapters 5, 6, and 7 focus on Uruguay, and therefore required different research methods and data sources. The following methods were used to obtain data on Uruguay: secondary sources (government reports and databases), semi-structured interviews, field visits with agronomists, and surveys of agricultural land parcels (Yin 2003).

In the early stages of the research, reports obtained from MGAP databases on crop areas and production indicated that key variables such as data for soy cultivation (both area and amount harvested) for each department were not available on an annual basis. The data only existed for the years 1990, 2003, 2004, 2005,2006. This was not anticipated because the MGAP database is the national database that includes annual data on agriculture. It includes, for example, total exports of agricultural commodities, land area used for cropping, the amounts of products and by-products exported, and cost of farm inputs and total cattle for each department. However, most of these data were found to be national estimates, and only patchy departmental-level data were available. This situation was confirmed by the researcher's major contact at the Universidad de la República, Pedro Arbeletche.

As statistical data in soy and related aspects of agriculture in Uruguay were patchy, especially for the four departments the research focussed on; other methods were adopted to obtain primary data on the growth in soy cultivation. The primary data was used because of its focus, the wide range of collection methods, and the way it can be adjusted to specific research tasks (Montello & Sutton 2006). The main primary data from Uruguay used in this research were semi-structed interviews with individual farmers and farmer groups, agribusinesses, government officials and university researchers; and field surveys. Primary data were collected during fieldwork undertaken between 8th February and

31st March 2016. Secondary data that is only available in Uruguay was also consulted during this time, such as agricultural statistics from MGAP, export data from economists in universities and government departments in Uruguay, and newspaper articles.

3.4.1 Primary data collection

Interviews

Interviews were a key primary data source and were used to elicit information from agribusinesses involved with soy plantation and who had knowledge of the soy supply-chain in Uruguay. Flinders University Social and Behavioural Ethics Committee (Approval Number 7113, 8th January 2016, v Appendix A) approved the interview process used for research in Uruguay. In parallel a permission letter was obtained from the Government of Uruguay, through MGAP, to conduct this research. In addition, consent was obtained from all of the people interviewed in Uruguay through signed consent forms as a condition of the ethics approval process.

The basis for recruitment of people interviewed was as follows (Table 3-1). Agribusiness owners were contacted through a search of a current Uruguay trade directory. One hundred agribusinesses located in the four Litoral provinces were selected at random from the trade directory, and a 15% sample was chosen at random from these hundred (Table 3-2).

Many of the government officials interviewed were from different sections of MGAP (Ministerio de Ganadería Agricultura y Pesca) and from people responsible for publishing the Anuario Estadístico Agropecuario (Uruguay's Official Agricultural Report and Agricultural Census).

Table 3-1- Participants and basis for recruitment, extracted from Flinders University Social and Behavioural Ethics Application, Approval Number 7113.

Participant Type	Basis for Recruitment	Component of Research Involved In (e.g., survey, interview, focus group, observations)
Agribusiness	Random selection of agribusinesses selected from the Trade Directory of Uruguay (this outlines all agribusinesses in the country). Selected based on their main crop production. Emails will be sent out as part of recruiting	Interviews based on a set of questions
Government official/ policy makers	List of relevant government officials (who are mainly located in Uruguay's capital city, Montevideo.	Interviews based on a set of questions

Table 3-2 - Sampling procedure for interviewees

Participant Type / Group	Population Pool	Numbers approached
Agribusiness	100 selected from the Trade Directory in Uruguay.	15% = 15
Officials from government departments	Email will be sent out and they will be selected from 60 government officials from the department of agriculture and fisheries	20 approached

Emails were sent to selected potential interviewees explaining the nature of the research project and requesting an interview. If they agreed to be interviewed, a time and location for the interview was made by follow-up email or phone call. The interviewees chose the time and location of the interview, which hopefully gave them a comfortable environment and the confidence to express issues without reservations. For example, interviews with central government bureaucrats took place while the researcher was in Montevideo. Interviews with these officials were held during business hours.

When a meeting time had been scheduled another email was sent out prior to the meeting with a letter of introduction attached and an information sheet (Appendix A). This information provided the interviewee with the details of the study; and contact details for the interviewer, the researcher's supervisor, and the Flinders University Social and Behavioural Research Ethics Committee, as per standard Australian research guidelines.

Issues arose around timing when organising interviews. Some potential interviewees were either on holidays or were not available during the day because of work. All interviews were held at times and location suggested by the interviewees' schedules; often in the morning before the afternoon siesta or in the evening. The second issue was distance and logistics. Some areas were not easily accessible unless the researcher had access to a vehicle. This was not always possible. Public transport was another logistical option which was not always reliable especially given the location where many interviews took place; in rural towns and farming areas. A third issue was the lack of participation by multinational companies. It was anticipated that multinationals active in the soy sector in Uruguay would be interviewed. However, they were very reluctant to be interviewed, and used a number of tactics to thwart being interviews. Most common was simply not responding to e-mail requests or follow up phone calls. On the rare occasions that they responded positively, they put obstacles in the way of arranging times and locations. Therefore, the agribusinesses that were interviewed were national and regional (Argentine) companies, locally based ones.

Interview questions were used to guide the interview, both closed- and open-ended questions were used. Different questions were developed for agribusinesses, farmers and farmer groups, and government officials (Appendix A). The questions were designed with enough flexibility during interviews that the order of questions could be changed, questions could be combined or omitted, or that interviews could introduce discussion points that had not been included in the initial list of questions. As the interviews progressed, new questions were added as the researcher developed a more thorough understanding of the history of soy cultivation in Uruguay.

The interviews varied in duration, but as they were detailed, involving mainly open-ended questions, they usually took between one and two hours. Many of the participants were eager to contribute and were very detailed in their responses. The majority of local and regional businesses interviewed were very willing to be interviewed and often provided a great deal of information.

The interviews were conducted in Spanish. They were recorded on a voice recorder (after permission was obtained from the interviewee) and notes were taken in Spanish. The transcripts and notes were later translated into English. All participants agreed to the use of a voice recorder while the interview took place.

Observation of agricultural farms

There was an opportunity to observe soy cultivation in the department of Soriano when soy producers from Argentina company, Garmet, took the opportunity to invite the researchers out to a large soy farm east of Mercedes. They went through what soy cultivation entails, harvesting season, what occurs during rotations and soil conditions. This was an opportunity, which provided great depth and understanding regarding soy rotations. Discussion around cattle farming versus soy was also discussed providing firsthand experience regarding land changes which have occurred in Uruguay, and how some Uruguayan farmers have benefited from the mechanisation of soy cultivation. Garmet provided documentation about the agricultural systems on the farms visited, notes were made and photographs taken. These were used in analysing data later, e.g., the rotation systems analysed in Section 6.3.3. Unfortunately, no other opportunities to make farm visits arose during the field research.

Agricultural parcel survey

A survey of summer crops growing during February and March 2016 was undertaken to obtain data on geographical variations in the variety of crops being grown and their relative proportions across the four Litoral provinces.

The survey was conducted by driving along almost all sections of main and secondary roads in the area and recording the crops growing in the adjacent fields on either side of the road. As the land parcels are very large, due to consolidation, this was feasible. Another factor that made this feasible was that the surveys were conducted when the researcher's supervisor was visiting Uruguay, so that one person could drive while the other recorded agricultural land-uses. The transects extended from approximately 40 km north of Paysandú in the north to Colonia in the south of the study area (*cf.* Figure 7-3). The survey was designed to cover the soy growing areas of the four littoral provinces, details of which were obtained from staff at the Agronomy Faculty of Universidad de la República and the first round of interviews in Montevideo. Only one small, isolated soy-growing area around the town of Guichón in Paysandú was omitted from this survey due to logistical constraints, However, when all of the data were analysed at Flinders University it was clear that it might have been informative to extend the agricultural parcel survey into the western sections of Durazno, Flores and San José.

In total, the length of transects was 490 km. As the crops growing in fields either side of the transects were recorded, it was possible the estimate the area of agricultural land covered by these fields by multiplying the total length of transect by the mean field length of 0.908 ± 0.468 km. The latter parameter was calculated by measuring the length of 120 fields that were randomly selected along the transect lines in Google Earth imagery using the ruler tool. The area surveyed was 442.5 ± 229.3 km^2.

A list of agricultural land-use classes was developed in consultation with people interviewed and staff from the Agronomy Faculty of Universidad de la República. The agricultural land-use categories were

- Soy
- Sorghum
- Maize
- Natural Pasture
- Artificial Pasture
- Orchard
- Vineyard
- Eucalyptus Production Forestry

Others were categorised as fallow:

- Cereal fallow
- Maize fallow
- Forage
- Rotation Sorghum

The land-use in each field was then recorded against one of these categories in a notebook while driving along the roads. Because the landscape is open and rolling, and fields are fenced with wire, there were generally unobstructed views into fields. However, on the few occasions there were avenues of roadside trees or views were obstructed, the researcher got out of the car and walked to the field to identify the crop.

The transects were planned on a road map of Uruguay. To avoid bias and maximise the number of transects that could be surveyed in the time available UTM coordinates were obtained with a hand-held GPS in non-differential mode every 10 km along transects.

Conducting this type of survey allowed the researcher to use their personal judgment, which can sometimes impact the quality of the survey as the researcher is relying on their own personal judgment, knowledge and interpretation. However, as the researcher and supervisor worked together bias was reduced due to factors such as:

- The supervisor was on hand to advise on the selection of the extent of the area the researcher planned to survey, which itself was based on guidance from staff in MGAP and the university.
- Before leaving for fieldwork each day, the selection of transects were discussed and chosen.
- Any difficulties in identifying land-uses could be addressed through discussions in the field. Example of a type of difficult fallow for example, identifying between wheat fallow or oat fallow.

3.5 Data management and analysis

Analysis of interviews conducted in Uruguay were translated to English. The translated interview records were stored in the Flinders University server and on the researcher's personal laptop, as were the data from the land-use surveys. Both quantitative and qualitative techniques were used to analyse primary and secondary data gathered as part of this research. The use of both types of analysis simultaneously can provide a deeper level of understanding than reliance on one.

3.5.1 Quantitative methods

The land-use survey methods were recorded during the field work. Information was entered from the field survey into Microsoft Excel worksheets to manage it. Counts of each land parcel was entered for each agricultural land category and for each individual transect. In Excel the results were summed together for each transect and proportions of crops were calculated respectively to produce pie charts and assess land-use distributions. The transect points were explored and located on Google maps and ArcGIS was used to enter the data. The outputs from the pie charts produced, display the geographical variations of crops and pastures in the area where the sampling took place. Table 3-3 presents the overall structure of the data collection.

Secondary data, which was sourced from various statistical organisations (Section 3.4) were downloaded into Microsoft Excel Worksheets to produce time-series line charts to see area of land-use over time as well as production over time. Time-series line graphs were used to compare between production and change in cropping land area between countries and between other competing crops. For the economic data, data was extracted into Excel and then ordered accordingly and transferred into SPSS. In SPSS a temporal causal model was used using time-series analysis to assess global trade flows (Section 4.5).

Table 3-3 – Survey and study construction

Section	Objective	Data Collection
Part A: Interviews; agribusiness, cooperatives, farmers, researchers and government officials Part B: Land-use Sampling	• What land-use changes had taken place as a result of expansion • What logistical and infrastructural changes occurred as a result of soy expansion • To understand the role of companies in the expansion of soy	11 questions Used different locations across el Litoral
Part C: Statistical secondary data	• To examine and understand the drivers which initiated the expansion of soy in Uruguay	World Bank MGAP FAO USDA

3.5.2 Qualitative methods

According to Anderson (2010) qualitative research is the collection, analysis, and interpretation of data which relates to the social world and concepts and behaviour of people in it. The qualitative data used in this research were a mixture of structured and opened-ended interviews. The interviews undertaken with agribusiness, cooperative, government officials and researchers were recorded digitally, and field notes were taken. The researcher presented the qualitative data based on Anderson (2010) and discussed them through a series of quotes from interviews, with the speakers specified at the end of the quotation (Questions in Appendix A).

Thematic analysis, informed by Braun and Clarke's (2006) framework for analysing qualitative data, was used to analyse the interview responses in this research. There are six steps to this method of thematic analysis, which are (i) familiarisation with the data to generate initial coding, (ii) search for themes, (iii) review the themes, (iv) define the themes, (v) name the themes, and (vi) reporting on the findings. Nvivo10.0 software was used during analysis of interviews to support data management. Thematic analysis was used because it enables the researcher to identify and develop patterns or themes within a dataset and to describe the details of these themes (Boyatzis 1998). Moreover, Braun and Clarke (2006) suggest that thematic analysis is both a foundational and an appropriate method for analysing qualitative data due to its flexibility and potential in providing rich and detailed information. It also allows the researcher to integrate all aspects identified directly from the raw data (Boyatzis 1998).

Synthesis of thesis was obtained through the integration of the temporal causal modelling and the interviews. The results from the TCM has allowed to inform me of the production of changes. In addition the results from the TCM and other statistics has resulted in discovery of further area changes and dynamics which were not know before. The TCM, in particular is what helps ground the thesis and helped bring those other statistics together. The synthesis can be found in Chapter 5 and 6 where the results from the TCM are used to bring the thesis together. The results have assisted in further identifying soy and pasture dynamics in Uruguay's litoral which are synthesis in their own right.

3.6 Summary

After illustrating the research design and justifying the choice of study area for the research, this chapter provides a description of the methods used in order to collect and analyse the data. The two primary data collection methods used to gather data in Uruguay were interviews with key government officials, agribusiness and farmers. The other primary data collection method was a survey of agricultural land-use in the summer cropping season (2015/16) along transects in the Uruguay Litoral. Research ethics approval and research permissions that were undertaken during this research are described, and relevant documentation is provided in the appendices.

4 MODELLING SOY PRODUCTION AND LAND USE IN URUGUAY IN A GLOBAL MARKET CONTEXT: METHODOLOGY AND RESULTS

4.1 Introduction

This chapter examines interactions in the global soybean market with the aim of attempting to understand the causes behind the growth in soy production, and the area planted to soy, in Uruguay. This is achieved through an application of time-series modelling to macroeconomic and import and export data in major producing and importing nations; and soy production and areas under soy in major producing nations. The time-series model used is temporal causal modelling, and a background to temporal causal modelling is provided in Section 4.2, 4.3, and 4.4. The modelling strategy and details about the data inputs are provided in Sections 4.5 and 4.6 respectively. The results of the TCM models run are presented at the end of the chapter in Section 4.6 and 4.7. In the following chapter the modelled predictions of soy production in Uruguay are analysed and discussed; and in Chapter 6 the predictions of the land area under soy production in Uruguay are treated in similar manner.

Temporal causal modelling—a form of time-series modelling based on Granger Causality–recently became available in SPSS Version 23. It was used to model both soy production and soy area in using data on soy imports into the two largest markets—China and the European Union (EU); production, areas planted to soy and export quantities for the ten-major soybean producing countries; and macroeconomic data for all of these countries between 1961 and 2016.

The contribution of this chapter is that it provides the first comprehensive analysis of soy production and land under soy in Uruguay. Moreover, to the author's knowledge, it is the first application of temporal causal modelling to (i) understand interactions for a global agricultural commodity, and (ii) in determining the relative importance of potential economic drivers of land-use change. The model applied in this chapter is theoretically driven and grounded in causal economic theory. It shows how diverse types of evidence are combined with causal hypotheses to generate empirically-based causal theories; a process which occurs over long time scales.

4.2 A context for time-series modelling: the evolution of soy as a commercial crop in South America

Soybeans were originally a cool temperate crop originating from north east China (Chapter 2). The first written record of them dates to back to the 11th Century BC and for centuries they were eaten in the form of beans, tofu and fermented soy sauce throughout eastern Asia and the oriental diaspora (Shurtleff and Aoyagi, 2004). Production in cool temperate regions of Canada and the USA began in the late 1800's (NSRL 2017). Approximately four to five decades later varieties suited to cultivation in warm temperate and sub-tropical climates in North America had been developed, and this led to their introduction (and subsequent diffusion) as an arable crop in Argentina, Bolivia, Brazil and Paraguay. By the late 1980s these four countries formed a contiguous block of major exporters into the global market (Dros 2004). The increase in the area planted to soy in South America has generally been attributed to the increase in global demand, particular from China and, in the case of Brazil, the European Union as well (Nepstad et al. 2006; R. Garrett et al. 2013; Le Polain de Waroux et al. 2017). Globally soybean production increased by 220 million tonnes between 1990 and 2016 (MT) (FAOSTAT 2016) and currently over 70% of all soy exported from producing nations is imported by either China or the EU. In contrast to the historical uses of soy, the major contemporary uses are for vegetable oil, animal feed and, increasingly, for biodiesel. Much of this global demand is met by South American producers.

Soon after the emergence of the Green Revolution soybean production began taking off. Soy cultivation started in Latin America, first in Mexico due to the country's success with wheat production as part of the Green Revolution, and then to South America (Bulmer-Thomas 2003). The 1970s and 1980s saw rapid increases in the area of soy grown and harvested due to agricultural expansion and intensification. New agricultural areas were cleared, and soy was planted; and types of (i) seeds were bred for particular soils and climate, (ii) fertilisers, and (iii) farm mechanisation were adopted by farmers. However, during the 1990's, soy cultivation in Latin America appeared to stagnate until the start of the 21st Century. Although the expansion of soy agriculture in South America has come at the expense of other crops, it has also resulted in deforestation and a reduction in the area of many natural ecosystems. Large scale land-use changes, consequent upon changes in global demand, have been well documented throughout the Brazilian Amazon, the Chaco in Argentina and the lowlands in Bolivia (e.g., Garrett, Lambin, et al. 2013; Brown et al. 2005). More detailed discussion of these land-use changes and more complete sets of references are provided in Chapters 2 and 7.

Uruguay was the last of the Southern Cone countries to adopt soybean as a major crop. The country's production has increased dramatically since 2003 with total soybean production having increased by over 1500% in the last 10 years alone. Highest soy production was in 2013 when it reached 3.2 million tonnes (FAOSTAT 2016). This growth is particularly significant given Uruguay's small area relative to the other four South American producers, and even more so when one considers that the vast majority of soybean production is restricted to the south-west of the country known as the Uruguayan Litoral. While much research has been published on soy in Argentina and Brazil, there has been much less published on Bolivia, Paraguay and Uruguay. Moreover, if these last three countries are compared, the least published research has been on Uruguay's rapid soy expansion from either an agricultural economic or a land-use viewpoint.

The scant literature that exists attempts to explain soybean expansion in Uruguay and the land-use changes it has experienced in the last two decades after there was an acceleration in soy cultivation. Vancutsem et al. (2013) mapped winter and summer crops using MODIS, while Barrios et al. (2010) and Redo et al. (2012) attempted to assess changes in land-use policies as drivers of land-use. Much of the research in the region has focused on the expansion of soybean agriculture in Brazil and, to a lesser extent, Argentina. Studies have either focused on the drivers of accelerated land changes (e,g, Polain de Waroux et al. 2016; Ramankutty et al. 2004; Zak et al. 2008; Gasparri & Grau 2009), or the impacts of soybean growth on environmental sustainability and forest cover at both large and small scales (Boillat et al. 2017; Grau et al. 2005; Aldrich et al. 2009; Brown et al. 2005; R. Garrett et al. 2013; Le Polain de Waroux et al. 2016). Many of these studies have quantified the rapid land-use and land cover changes using time-series of remotely sensed imagery and in doing so have identified the rapid rate at which agricultural expansion has affected natural ecosystems and rural populations (Furumo & Aide 2017; Veldkamp & Lambin 2001; Defries et al. 2013).

If the research that has examined Argentina and Brazil is considered, one can posit that globalisation is the overarching reason why there has been a massive shift to soy production in South America. Under the umbrella of globalisation, the relaxation of trade barriers, improved logistics, transnational investments, improvements in technology and communications, and the emergence of vertically-integrated soy supply-chains have been highly influential drivers of the conversion of soy-dominated land uses worldwide (Baldi and Paruelo 2008; Ericksen 2008; Foley et al. 2005; Gasparri et al. 2016; Garrett, Rueda, and Lambin 2013). However, there are other drivers of change which these papers have not addressed directly. Changes in many eastern Asian diets has increased demand for animal protein (Pingali 2007; Yan et al. 2009; ADB 2010) which in turn has led to intensification of cattle, pig and chicken production and increased demand for soy-based animal feed. The growth of the population in eastern Asia has also led an increase in demand for traditional soy-based foodstuffs, and adoption of vegetarian and vegan diets in the western world has increased demand for tofu globally. The development of genetically modified varieties of soy has extended its climatic range and increased its resistance to disease are also implicit in the expansion of soy. Attempts to link land-use change to external and distant drivers such as globalisation are relatively recent (Persson et al. 2014; Friis et al. 2015; Meyfroidt et al. 2013a), though Geist and Lambin (2002) introduced the concept of proximate causes and underlying, distant drivers of land-use change from their meta-analysis of research on tropical deforestation a decade earlier. The drivers concept is still valid in land-use change that attributes change to globalisation, as globalisation drivers are in fact underlying distant drivers as defined by Geist and Lambin (2002). Other research has attempted to quantify land-use through modelling techniques focusing on supply-chain systems, deforestation and exports between food production and supply and demand (Defries et al. 2013; Villoria & Hertel 2011; Meyfroidt et al. 2013a).

However, finding definite causes of land-use change in particular locations or regions is often complicated because multiple, interacting causal influences are in play at any one time. This creates complexity, which has to be resolved if the relative influences of different drivers are to be determined, let alone quantified. In many instances, these interactions are part of a supply network that share a multidimensional relationship where all the actors play a role within the network.

The time-series modelling aspect of this thesis specifically addresses the following questions: (1) can past global market interactions be used to make inferences about causes of land-use change? and (2) which causal parameters can help in explaining Uruguay's soy expansion?

4.3 Time-series analyses

Time-series analysis is used across many disciplines including economics and finance, sociology, biology, human and physical geography, demography and medicine to analyse sequences of data over a specified time period. It is used to analyse trends in data, and associations between sequences in different data sets. It can be used to analyse sequences of historical data, as well as predicting and forecasting future trends.

It is widely used in social sciences; as one of a number of statistical tools used to analyse phenomena that vary over time, e.g., public opinion, government policy and socioeconomic parameters. For example, Sun and Zhang (Sun & Zhang 2016) used time-series analysis to analyse social and economic factors that contribute to suicide, and found that unemployment, inflation and divorce rates significantly influenced fluctuations in suicide rates across the UK from 1981-2011. It has been used in population analysis to identify hot spots for migrant settlement (Zhang & Song 2003; Stats NZ 2018; ABS 2018) and determine the contributions of immigrants to a national economy (Cushing & Poot 2003), amongst other aspects of demography (Sun & Zhang 2016; Wah et al. 2014; Liu et al. 2010). Understanding the origin and spread of disease can be assisted by probabilistic simulations (Saboia 1974), as was the case with tuberculosis in Singapore where modelling and forecasting populations using data collected from 1995-2011 helped identify significant demographic differences between resident and non-resident tuberculosis cases (Wah et al. 2014). Population assessment using multivariate time-series analysis has also been used in biology to identify species endangered because of ecosystem degradation (Damos 2016; Williams et al. 2003; Tolimieri et al. 2017; Lozano et al. 2009).

Time-series analysis has been used in land science to find relationships between LULC change and external drivers (Keeney & Hertel 2009; Barona et al. 2010; Ramankutty & Coomes 2016). Applications have included the expansion of commercial crops (Persson et al. 2014; Sánchez-Cuervo et al. 2012; Furumo & Aide 2017; Lambin et al. 2006) and the way institutions and organisations affect land-use change Jepson et al. (2010) and Richards et al. (2012) have combined economic market variables with crop production data in time-series modelling to identify indirect land-use changes. In summary, time-series modelling in land-change science has been used to provide simple representations of reality by using epistemological assumptions about each study area that facilitate these less complex simple perspectives of the world that can potentially enhance understanding and knowledge of land change phenomena.

4.3.1 Granger Causality

Granger Causality (G-causality) was developed in the field of econometrics, but since then has found applications in the broad areas of climate science (Leggett & Ball 2015; Papagiannopoulou et al. 2017), finance (Papana et al. 2017; Yao & Lin 2017); microbiology (Brovelli et al. 2004); and neuroscience (Guo et al. 2010; Seth et al. 2015; Wen et al. 2013) in particular. It has been used extensively in neuroscience and neuroimaging to assess brain network interactions (e.g., Wen et al. 2013; Seth et al. 2015). In biology, G-causality has been used to reveal regulatory networks in gene expression; whilst in climate science it has been applied to find relationships between levels of CO_2 and atmospheric temperatures, and to investigate human influences on climate (Leggett & Ball 2015; Triacca 2001; Smirnov & Mokhov 2009; Mosedale et al. 2006).

In the context of this research, G-causality has been used by others to model time-series of economic and financial data. Lean and Smith (2010) found a unidirectional, non-reciprocal G-causality relationship between economic growth and electricity generation in Malaysia, and it was also applied to find relationships between real exports and real GDP in 24 OECD countries (Kónya 2006). Relationships between imports, exports and labour productivity in Malaysia were examined by Thangavelu & Rajaguru (2004), and co-integration and causality were used to explain export-led growth in Mexico (Thornton 1993). Narayan and Smyth (2004) used G-causality to examine the relationship between male youth unemployment and real income in Australia between 1964 and 2001, while Hoffmann et al. (2005) reported on G-causality in trying to determine the relationship between foreign direct investment (FDI) and pollution across 112 countries. Zaman et al. (2012) investigated bi-directional causal relationships between agricultural technology and energy demand in Pakistan. Finally, in finance, Papana et al. (2017) have performed connectivity analysis on long-term financial records of 21 international stock indices.

Using G-causality in the field of land systems science may have advantages because of its ability to identify relationships between drivers of land-use change using time-series modelling, that may not be revealed using the commonly used approach of mapping land-use and land-cover change from time-series of remotely-sensed imagery and then attempting to explain these changes by examining changes in selected drivers, which may be available at a finer temporal scale than the imagery.

In simple terms G-causality is a way of investigating causality between two or more variables in a time-series. The method is a probabilistic account of causality. Given two sets of time-series data, x and y, G-causality attempts to determine whether one series is likely to influence change in the other. This is accomplished by taking different lags of one series and using that to model the change in the second series. Two models are created, one (Ω) which predicts *x* with only past values of *y*, and the other (π) which predicts *x* with past values of *x* and *y* (Thurman & Fisher 1988). A key advantage of a G-causality operational system is that it is able to process large volumes of longitudinal data. Such data sets can be difficult to analyse because parameters are collected at different spatial scales, and by different collection methods which may not be standardized. For example, meteorological data are collected at regular but different temporal frequencies across the globe using different instruments and measurement protocols. Another example is gene expression microarray data, which are collected for different species under different conditions.

4.4 Temporal Causal Modelling and Granger Causality

In 2010 Temporal Causal Modelling (TCM) was added to the suite of programs in version 23 of SPSS. TCM is a program developed by scientists at IBM (Kambadur et al. 2016; Liu et al. 2010) that operationalises G-causality in this widely-used software package. Prior to its release users had to program G-causality in environments like R. TCM allows users to input their data, select fields of interests, run the model and obtain outputs. However, in using it for this research, and in comparing the results obtained from applications such as those referenced in the section above, a number of limitations became apparent. These are discussed in Section 4.5.

In SPSS, Temporal Causal Modelling generalises the concept of G-causality in a multivariate time-series model, where the term *causal* refers to Granger causality, *not* actual causes. G-causality is an operational definition of a type of causality that is well known to econometricians, i.e., the relatively straightforward idea that causes can precede or proceed events and therefore that G-causality can be used to predict their effects[3]. Although the concept can be originally attributed to the US-based Swiss mathematician Norbert Wiener, the econometrician Clive Granger first operationalised it in terms of linear vector autoregressive (VAR) models of stochastic time-series data (Granger 1969).

In TCM the interest is in knowing whether an entire time-series *xt-1, xt -2,…, xt -i* provides additional information that can be used to help predict another time-series, *yt*. It differs from multivariate regression analysis, where the known causes (*x, y, …*) and effect (*z*) are found by regressing *z* against *x, y, …*, because the objective of TCM is to find if *x,* causes *z* or *z* causes *x*; *y* causes *z* or *z* causes *y*; and *x* causes *y* or *y* causes *z*. It also differs from regression analysis where a statistically significant fit to a regression line, i.e., between variables, does not imply directionality. Generally speaking, in G-causality when a condition is satisfied it can be said that there is an information flow from *x, y, …* to *z* or *z* to *x, y, …*. The justification behind using G-causality to investigate relationships is the approximation to transfer entropy, a directed version of Shannon's mutual information theory, which in turn is a very general way of characterising statistical dependencies or shared information between two or more variables (Barnett et al. 2009).

In practice, G-causality analysis rests on estimating and comparing two Vector Auto-Regressive (VAR)[4]. For example, assuming we have three variables*: x, y* and *z* and the objective is to measure the information flow from *x* to *y*, the first step is to estimate the time-series of each variable *x, y* and *z*

[3] Granger Causality is not equivalent to true causation but rather intended to provide useful information regarding causation.
[4] VAR models are simple mathematical models in which a variable at a particular time is modelled as a (linear) weighted sum of its own past (this is usually done over a number of discrete time steps) and of the past of a set of other variables.

with a VAR model. This leads to a particular prediction or estimation error within a set. Then, a second VAR model is generated, which omits the potential cause (*x* in the example above), which produces a second set of prediction errors for each remaining variable. If the prediction error for *y* is significantly smaller for the VAR model that includes *x* than it is for the VAR model that excludes *x*, it can be said that *x* G-causes *y*, conditioned on *z*. The magnitude of the G-causality is given by the ratio of the variance of prediction-error terms for the two VAR models.

4.5 MATERIALS AND METHODS

4.5.1 Modelling strategy and data inputs

Given the research questions being addressed in this part of the thesis (Section 4.1), the drivers used to model soy-related land-use changes in Uruguay are facets of the global soy trade; and the models were run for Uruguayan soy production and for the area planted to soy in Uruguay between 1961 and 2016. This approach was adopted for the following reasons:

- because Uruguay exports approximately 98% of its soybean production (FAOSTAT 2016) it is highly likely to exhibit a high dependency on, and sensitivity to, international demand for soy;
- this dependency will be strongly influenced by its competitiveness vis-à-vis other major producers; and;
- its competitiveness in turn will be exacerbated, in part, because of the relatively small size of its national economy compared to other producers. Its GDP(Purchasing Power Parity) is 77.8 billion Int$ (IMF 2018). This makes it one, of only three, of the top ten soy producing countries by volume with a GDP(PPP) of <100 billion Int$; the others being Bolivia and Paraguay. In addition, its GDP(PPP) is only 0.34% the size of the largest economy of the ten largest soy producing countries—China (IMF 2018).

Another important element of this research design was that modelling soy area and production for Uruguay was based on a continuous set of data from 1961-2016[5]. The use of a continuous historical dataset should allow potential drivers of change to be identified from inter-annual changes in soy area and production. This is in contrast to the commonly used approach in land-change science where archival remotely sensed data are the primary source of land-use change information, and potential drivers *emerge* from spatially-explicit changes in land use between images that are then ascribed to any drivers that might have been in play during the inter-image periods. This is, in fact, the approach adopted by Redo et al. (2012) in Uruguay.

The TCM modelling strategy adopted in this research is illustrated in Figure 4.1. The model focuses in global trade flows between the top ten producing countries, and China and the European Union (EU) as the importers; the basis for which is that 98% of Uruguay's soy production is currently exported, and 78% of soy exports globally are destined for either China or the EU. The time frame for the model was limited to the first year of comprehensive data holdings at FAO and the World Bank, 1961, and the last year for which complete records existed when modelling was started, 2016[6].

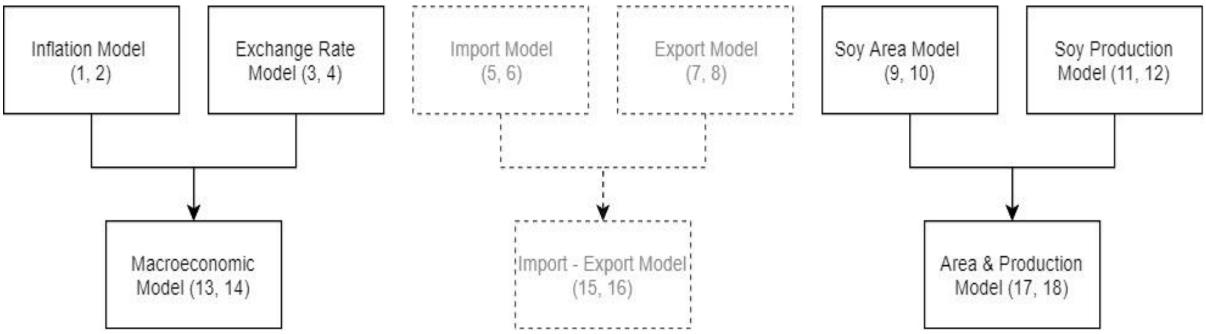

Figure 4-1 . Temporal causal modelling strategy for the 1961-1989 or pre-soy boom. The model numbers (in brackets) refer to Table 4-9, Table 4-10 and Table 4-11. The target variables for odd-numbered models are for Soy Area in Uruguay, and for even-numbered models they are for Soy Production in Uruguay. Note models 5-8 and 15-16 (shaded) were not run due to unviability of data.

[5] 1961 was the started year for most data. Although some data was only available from 1970 (Bolivian exchange rates and Argentinian exchange rates (the models were still run from 1961 as the majority of data was available from 1961.
[6] Data for national inflation rates and exchange rates were available from 1961-2016 from the World Bank. Data for soy production and areas under soy were available from FAO for 1961-2016. However, soy import and export data had not been updated beyond 2013 when this thesis was finally submitted. In addition, import and export data were not available prior to 1990 therefore were not included in the pre-soy boom models.

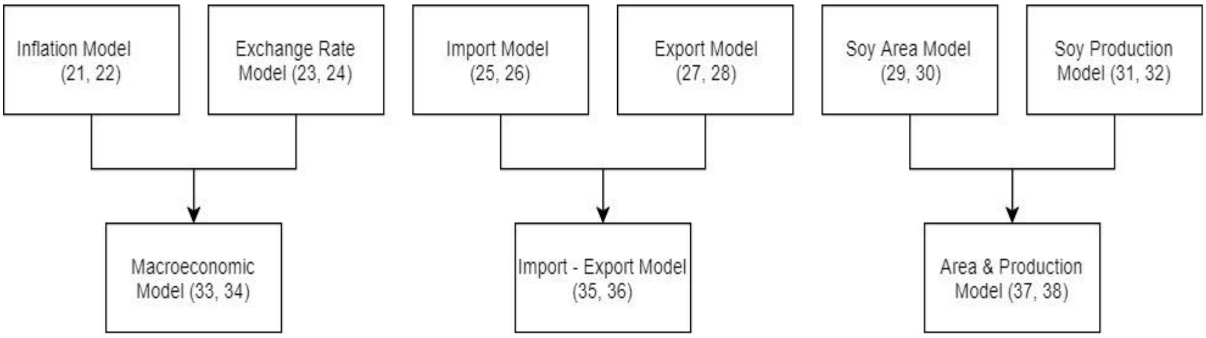

Figure 4-2 Temporal causal modelling strategy for the 1990-2013-2016, the soy boom period. The model numbers refer to Table 4-9, Table 4-10 and Table 4-11. The target variables for odd-numbered models are for Soy Area in Uruguay, and for even-numbered models they are for Soy Production in Uruguay.

Time-series of potential input data were accessed from either FAOSTAT, the World Bank or USDA. FAOSTAT provides comprehensive sets of annual agricultural commodities by country of interest. The data acquired were soy production in tonnes, area in hectares, and export and import flows in million metric tonnes for the top ten producing countries (which includes China, which is also one of the two main importers) and the EU. The World Bank and USDA provided annual data on inflation and exchange rates respectively for all countries dating back to 1961. FAOSTAT data was chosen due to the wide range of data available, the World Bank data is a reliable source for exchange and inflation rates by country and year.

Data were acquired for (i) Argentina, Bolivia, Brazil, Canada, China, India, Paraguay, Ukraine, Uruguay and USA—nine of the ten largest soy producing nations by volume; (ii) the European Union, one of the two largest soy importing economies globally; and (iii) China, which is both one of the ten main producing nations and the other major economy importing soy. The reasons for this are as follows:

- as mentioned above, because Uruguay is one of the ten largest producers of soy, and exports soy to China and the EU, it was posited that trade relationships between Uruguay and these two countries would be significant. For example, Uruguay exported just over 24% of its total soy exports to China in 2015. Therefore, the amounts imported into China and the EU each year were included in the data sets;

- annual soy exports from the top ten producing nations were included because each country's export performance in the soy sector should be critical to understanding the changing dynamic of trade globally in this commodity, and because exports are key determinants of a country's relative economic wealth (World Bank 2014a); and
- annual exchange rates and inflation rates were included because of their important roles in national trade balances (World Bank 2014a). Exchange rates are also an important mediating mechanism in trading on global markets. As soy is traded in US dollars, its price depends on both the international price and the exchange rate of the exporting currency (Richards et al. 2012). For Uruguay, the international price for soy and the UYP: USD[7] exchange rate help determine agricultural export demand, influence agriculturally-based incomes, and factor into decisions about growing soy.
- Inflation is included because of the strong association between inflation and exchange rates within a country. Relatively high inflation rates reduce the value of a country's currency while exchange rate depreciation can increase inflation. Depreciation in exchange rates means a currency buys less foreign currency, and imports become more expensive while exports become cheaper (World Bank 2014a).

These data have limitations in terms of its continuity, history and accuracy. For example, data are missing for some variables because information was not collected or reported to the FAO or the World Bank. Prior to 1990, Ukraine was part of the USSR, and the data that existed for the Ukraine SSR were not available. In addition, India was also not included as it is not a major exporter of soybeans Descriptions of the variables used in TCM modelling are provided in Table 4-1.

[7] ISO4217 currency codes are used throughout the thesis. ARS Argentine peso, BOB Bolivian boliviano, BRL Brazilian real, CAD Canadian dollar, CNY Chinese Yuan Renminbi, EUR Euro, PYG Paraguayan guarani, UYP Uruguayan peso, USD US dollar.

Table 4-1 Variables used in TCM modelling of soy production and land under soy in Uruguay, 1961-2016.

Variable	**Variable Code in TCM**	**Description of variable (units)**
Land planted to soy[Ø]	A	Area under soy in a country (ha)
Soy production	P	Total soybean production from all sources in a country (‘000 metric tonnes)
Export Quantity	ExQ	Total soy exports from a country from all sources. (‘000 metric tonnes).
Import Quantity	Imports	Total soy imports into a country from all sources (‘000 metric tonnes).
Average Annual Exchange Rate	ExR	The average rate at which a national currency was exchanged with USD for a particular year. ExR = average of the 12 monthly real change rates (local currency: USD).
Average Annual Inflation Rate	Inf	The average inflation rate for a country for a particular year. Inf = the average of the 12 monthly real change rates. A general measure of the increase in the price of goods within an economy (%). Negative values denote deflation.

[Ø]Soy refers to soybean in all cases, and excludes soy meal, soy oil, or any other soy derivatives

Table 4-2 Countries included in TCM modelling

Country	Variable Code used in TCM	Justification for inclusion
Uruguay	URY	Object of the research. 9th largest soy producing country, 4th largest economy in the Southern Cone. 9th largest South American Economy. A founding member of MERCOSUR (1991). Between 2003 and 2013 it had the greatest percentage increase in soy production of any of the major soy-producing countries.
Argentina	ARG	3rd largest soy producing country, 2nd largest economy in the Southern Cone and 2nd largest South American economy. A founding member of MERCOSUR (1991). Soy production was 18% of the world total in 2016. It is generally accepted that there are strong economic links between Argentina and Uruguay.
Bolivia	BOL	9th Largest soy producing country globally, 2016, 8th largest South American economy. Soy production was 1 % of the world total in 2016. Not considered part of the Southern Cone, but member of MERCOSUR since 2015. National economy generally considered not well linked to Uruguay.
Brazil	BRA	Largest soy producing country, largest economy in the Southern Cone. A founding member of MERCOSUR (1991). Soy production was 29% of the world total in 2016. Despite being a neighbouring country, it is generally accepted that economic links between Brazil and Uruguay are less important than those for Argentina.
Paraguay	PRY	6th largest soy producing country, smallest Southern Cone Economy A founding member of MERCOSUR

		(1991). Soy production was 3% of the world total in 2016.
Canada	CAN	7th largest soy producing country, 10th largest economy globally. Soy production was 2% of the world total in 2016.
China	CHN	2nd largest world economy (excluding the European Union as an economic zone). Responsible for 2% of worldwide soy production. Largest importer of soy (% world soy imports). Primary use of soy is livestock feed.
		4th largest soy producing country, 2nd largest economy globally. Soy production was 4% of the world total in 2016. Largest importer of soy globally (63 % world soy imports). Primary use of soy is for livestock feed.
India[Ø]	IND	7th largest economy globally. Responsible for 4% of soy worldwide. Soy mainly used domestically (FAOSTAT 2016)
United States of America	USA	Largest national economy globally. Responsible for 35% of worldwide soy production. Largest global soy producer.
European Union	EU	2nd largest economic bloc globally, behind the USA. 2nd largest importer of soy after China. Primary use of soy is imported and used for livestock feed.
Ukraine[Ø]	UKR	8th largest global soy producer.

Table includes only top 10 global soy producers. Information for all countries are for the year 2016. Size of economy is GDP (PPP). Source (Worldbank 2016; FAOSTAT 2016; IMF 2018)

[Ø]India and Ukraine were not used in modelling, see below.

Initially the entire data set consisted of 64 variables. However, they were split into sub-groups (*cf.* Table 4-3, Table 4-4, Table 4-5, Table 4-6, Table 4-7, Table 4-8) based on their role in TCM modelling. Data for India and Ukraine were not used in modelling. Although India harvests very large quantities of soy, most is traded and used domestically and only small quantities are exported (FAOSTAT 2016). Data for Ukraine were not used for reasons outlined above. Data structures within SPSS comprise column-based and multidimensional data. A column-based structure was used, where each field contains a time-series of a trade, macroeconomic or soy area or production variable for each year. This is a normal data structure of time-series modelling. TCM in SPSS is limited to 30 column-based data inputs. This means that a maximum of 30 input target and predictor variables could be modelled simultaneously. The two target variables—soy production and the area planted to soy in Uruguay–occupied two of the columns in each model, therefore the number of predictor variables was always limited to a maximum of 28. This meant that all possible predictor variables could not be used simultaneously to model either soy production and area. Therefore, a modelling strategy was adopted in which the dataset, minus data for India and Ukraine, was subdivided subsets. These were used to run six first-order models each for URY soy production and URY soy area Figure 4-1and Figure 4-2. The variables in the six first-order models are listed in Table 4-3 -Table 4-8.

All variables had complete annual time-series between 1990 to 2016, with the exception of soy import and export data which is currently only available up to 2013 from FAOSTAT. However, before that there were runs of years where some variables were missing. These are Argentine export quantities prior to 1964, Bolivian export quantities prior to 1978, and Uruguayan export quantities prior to 1966; imports data for the EU prior to 1986 and for China before 1990; average annual inflation rates for Brazil prior to 1981 and China prior to 1987; and Bolivian average annual exchange rates prior to 1985. In an attempt to fill the gaps caused by missing data linear interpolation was employed. However, a visual inspection of the time-series after linear interpolation showed little change compared with recent years. A rule was established in SPSS, which was that if >25% of a dataset was missing the parameter was rejected. Therefore, the parameters used in the modelling were chosen on the basis of their completeness.

The following model settings were used for every model. The target variables were either URY Soy Production or URY Soy Area, and the confidence interval and the threshold for outliers were both set to 95%. The number of lags analysed was determined automatically by the TCM program based on the input data interval. Outputs for the target variables were displayed for the ten best fitting targets for the model measured, with r^2 being employed as a measure of goodness-of-fit. Only relationships that exceeded a significance level of 0.05 were displayed as outputs.

Table 4-3 Inflation Model codes

Variable code in TCM	Variable	Year range
URY_SoyP	URY soy production	1961-2016
URY_SoyA	URY soy area	1961-2016
ARG_Inf	Argentina, average annual inflation rate	1961-2016
BOL_Inf	Bolivia, average annual inflation rate	1986-2016
BRA_Inf	Brazil, average annual inflation rate	1982-2016
CAN_Inf	Canada, average annual inflation rate	1961-2016
CHN_Inf	China, average annual inflation rate	1986-2016
EU_Inf	EU, average annual inflation rate	1961-2016
PRY_Inf	Paraguay, average annual inflation rate	1961-2016
URY_Inf	Uruguay, average annual inflation rate	1961-2016
USA_Inf	USA, average annual inflation rate	1961-2016

Table 4-4 Exchange Rate Model codes

Variable code in TCM	Variable	Year range
URY_SoyP	URY soy production	1961-2016
URY_SoyA	URY soy area	1961-2016
ARG_ExR	Argentina, average annual exchange rate	1979-2016
BOL_ExR	Bolivia, average annual exchange rate	1970-2016
BRA_ExR	Brazil, average annual exchange rate	1970-2016
CAN_ExR	Canada, average annual exchange rate	1970-2016
CHN_ExR	China average annual exchange rate	1970-2016
EU_ExR	EU average annual exchange rate	1970-2016
PRY_Inf	Paraguay average annual exchange rate	1970-2016
URY_ExR	Uruguay average annual exchange rate	1970-2016
USA_Inf	USA average annual exchange rate	1970-2016

Table 4-5 Import Model codes

Variable code in TCM	Variable	Year range
URY_SoyP	URY Soy Production	1961-2016
URY_SoyA	URY Soy Area	1961-2016
EU_Imports_ARG	EU soy imports from Argentina	1986-2013
EU_Imports_BRA	EU soy imports from Brazil	1986-2013
EU_Imports_BOL	EU soy imports from Bolivia	1986-2013
EU_Imports_CAN	EU soy imports from Canada	1986-2013
EU_Imports_PRY	EU soy imports from Paraguay	1986-2013
EU_Imports_USA	EU soy imports from USA	1986-2013
EU_Imports_URY	EU soy imports from Uruguay	1986-2013
CHN_Imports_ARG	China soy imports from Argentina	1990-2013
CHN_Imports_BRA	China soy imports from Brazil	1990-2013
CHN_Imports_CAN	China soy imports from Canada	1990-2013
CHN_Imports_USA	China soy imports from USA	1990-2013
CHN_Imports_URY	China soy imports from Uruguay	2004-2013

Table 4-6 Export model codes

Variable code in TCM	Variable	Year range
URY_SoyP	URY soy production	1961-2016
URY_SoyA	URY soy area	1961-2016
ARG_ExQ	Argentina, soy exports	1964-2013
BOL_ExQ	Bolivia, soy exports	1978-2013
BRA_ExQ	Brazil, soy exports	1961-2013
CAN_ExQ	Canada, soy exports	1961-2013
CHN_ExQ	China, soy exports	1961-2013
PRY_ExQ	Paraguay, soy exports	1961-2013
URY_ExQ	Uruguay, soy exports	1966-2013
USA_ExQ	USA, soy exports	1961-2013

Table 4-7 Soy Production Model codes

Variable code in TCM	Variable	Year range
URY_SoyP	URY soy production	1961-2016
URY_SoyA	URY soy area	1961-2016
ARG_SoyP	Argentina, soy production	1961-2016
BOL_SoyP	Bolivia, soy production	1961-2016
BRA_SoyP	Brazil, soy production	1961-2016
CAN_SoyP	Canada, soy production	1961-2016
CHN_SoyP	China, soy production	1961-2016
PRY_SoyP	Paraguay, soy production	1961-2016
USA_SoyP	USA, soy production	1961-2016

Table 4-8 Soy Area Model

Variable code in TCM	Variable	Year range
URY_SoyP	URY soy production	1961-2016
URY_SoyA	URY soy area	1961-2016
ARG_SoyA	Argentina, soy area	1961-2016
BOL_SoyA	Bolivia, soy area	1961-2016
BRA_SoyA	Brazil, soy area	1961-2016
CAN_SoyA	Canada, soy area	1961-2016
CHN_SoyA	China, soy area	1961-2016
PRY_SoyA	Paraguay, soy area	1961-2016
USA_SoyA	USA, soy area	1961-2016

The first-order models introduced above were paired to create second-order models (Figure 4-1, Figure 4-2) as follows: average annual exchange rates and inflation rates were paired and labelled 'macroeconomic' models; export and import data were paired and labelled 'export-import' models; and soy area and production data were paired and labelled 'soy area and production' models.

First- and second-order models were run for two different time frames due to the constraints imposed by missing data. Fortuitously, there is a break in the data in the time-series around 1990, with full datasets existing after 1989. The break point more-or-less coincides with the start of the soy boom in Uruguay. The time frames used were:

- 1961-1989, 'pre-soy boom' model; and
- 1990-2013, 'soy boom' models.

Though, as noted above and in Table 4-3to Table 4-8, not every parameter was available for the full range of years in each model.

4.6 Model outputs Summary of outputs from an example of a TCM model

The outputs from SPSS 23 from the TCM outputs are provided in Appendix B .The output is only for the first order Import Model.

- The overall model System is a geographical representation of the causal relations between series in the inputs data.
- The model fit statistics table contains the same information in the overall model system.
- The impact diagram is also a geographical representation of the causal relations between the series of interest and other series that it effects or that affect it. In the case of the figure in Appendix B the interaction is that a, b and c have affected d.
- Parameter estimates outline the coefficients, standard error, T value, Sig value and a lower bound and Upper bound confidence interval.

4.7 Results

The key results from G-causality modelling of these parameters are summarised in the following tables:

- Table 4-9 first-order soy area modelling;
- Table 4-10 first-order soy production modelling;
- Table 4-11 second-order soy area and production modelling;
- Table 4-12 Information on lags from first-order soy area modelling.
- Table 4-13 Information on lags from first-order soy production modelling.
- Table 4-14 Information on lags from second-order soy area and production modelling.

Table 4-9 to Table 4-11 provide results for the first- and second-order TCM models introduced in Section 4.5.1. Only significant models are included in these tables, according to the F values of the target and predictor variables. The model fit is presented for each model based on three parameters, the root means square error (RMSE), the root mean percentage square error (RMPSE), and the

Bayesian information criteria (BIC). The latter was preferred to the Akaike information criteria because it reflects better parsimonious solutions, i.e. those that use fewer predictor variables in arriving at a model solution. r^2 values were also calculated, they were all very high and showed very little variation between models, as the graphs of predicted and observed target variables in Chapters 5, 6 and 7 will make clear.

Table 4-12 to Table 4-14 provide information on the significant lags, from zero to five years, for the models included in Table 4-9 to Table 4-11. TCM in SPSS calculates significant values for the target and the predictor variables using the Student's t test.

These tables are introduced and described below. They are discussed and analysed in Chapter 5 in the context of soy production in Uruguay, and in Chapter 7 in the context of areas planted to soy in Uruguay.

Table 4-9 Summary of the results from first-order TCM model outputs for predicted soy area in Uruguay. Only models in which at least one of the target or predictor variables had an F value with a significance value >90% are included in the table.

Model (see Table 4.1a)		**Date range**	**Target variable: URY soy area**					**Predictor variables**					
			F	**F sig**	**RMSE**	**RMPSE**	**BIC**	**F**	**F sig**	**F**	**F sig**	**F**	**F sig**
								BOL inflation rate		CAN inflation rate		EU inflation rate	
1	**Inflation rates**	1961-89	*23.03	0.013	2412.07	0.55	1390.67	*18.59	0.018	*5.98	0.086	2.85	0.209
								BOL exchange rate		ARG exchange rate		CHN exchange rate	
3	**Exchange rates**	1961-89	**5.05*10^{21}	0.000	2.00*10^{7}	1.26*10^{11}	-719.89	0.00	**0.000	0.00	**0.000	0.00	**0.000
								CAN soy area		BRA soy area		PRY soy area	
9	**Soy area**	1961-89	**43.15	0.005	629.63	0.21	326.30	*19.49	0.017	**96.05	0.002	**43.51	0.005
								BRA production		CAN production		CHN production	
11	**Soy production**	1961-89	*13.21	0.030	4502.05	1.21	420.62	4.72	0.116	2.17	0.278	0.58	0.725
								EU inflation rate		ARG inflation rate		BRA inflation rate	
21	**Inflation rates**	1990-2016	*99.80	0.076	53917.41	0.78	476.30	9.38	0.243	1.62	0.533	1.24	0.590
								ARG export quantity		CAN export quantity			
25	**Export quantity**	1990-2013	1.66	0.357	32319.21	1.02	406.61	8.83	0.051	**33.75	0.008		
								CAN imports to CHN		BRA imports to CHN			
27	**Import quantity**	1990-2013	7.58	0.63	10461.45	0.46	363.75	*22.19	0.014	3**3.75	0.008		

Significance levels: 90% *, 95% **

Table 4-10 Summary of the results from first-order TCM model outputs for predicted soy production in Uruguay. Only models in which at least one of the target or predictor variables had an F value with a significance value >90% are included in the table

Model (see Table 4.1b)		**Date range**	**Target variable: URY soy production**					**Predictor variables**					
			F	**F sig**	**RMSE**	**RMPSE**	**BIC**	**F**	**F sig**	**F**	**F sig**	**F**	**F sig**
								PRY inflation rate		BOL inflation rate		URY inflation rate	
2	**Inflation rates**	1961-89	**62.45	0.003	1652.32	0.56	372.51	**34.65	0.007	**38.98	0.006	1.90	0.317
								BOL exchange rate		ARG exchange rate		CAN exchange rate	
4	**Exchange rates**	1961-89	$**1.32*10^{19}$	0.000	$2.00*10^{7}$	$1.26*10^{11}$	-719.89	$**2.8*10^{19}$	0.000	$**1.6*10^{19}$	0.000	**1.5*119	0.000
								USA soy area		PRY soy area		CHN soy area	
10	**Soy area**	1961-89	*9.33	0.048	2577.96	0.66	369.12	*23.04	0.013	*13.29	0.029	3.52	0.165
								ARG export quantity		BRA export quantity			
28	**Export quantity**	1990-2013	**72.21	0.003	57098.99	1.1	413.13	*6.12	0.084	3.92	0.145		
								CAN imports to CHN		BRA imports to CHN			
26	**Import quantity**	1990-2013	**69.06	0.003	8265.56	0.23	354.79	**46.19	0.005	**185.44	0.005		

Significance levels: 90% *, 95% **

Table 4-11. Summary of the results from second-order TCM model outputs for predicted soy area and soy production in Uruguay. Only models in which at least one of the target or predictor variables had an F value with a significance value >90% are included

Model (see Table 4.1a and 4.1b)		Date range	Target variable: URY soy area					Predictor variables					
			F	**F sig**	**RMSE**	**RMPSE**	**BIC**	**F**	**F sig**	**F**	**F sig**	**F**	**F sig**
								BOL inflation rate		URY exchange rate		USA inflation rate	
13	**Macroeconomic**	1961-89	*23.91	0.013	2130.59	0.62	384.71	*12.90	0.031	3.67	0.157	4.56	0.121
								CHN soy production		CAN soy area		BRA soy area	
17	**Global area and production**	1961-89	*17.25	0.020	3004.88	0.88	410.22	1.34	0.422	*11.15	0.037	3.02	0.196
								CAN imports > CHN		BRA imports > CHN			
35	**Export-Import**	1990-2016	*7.58	0.063	10461.45	0.45	363.75	*22.19	0.014	**33.75	0.008		
			Target variable: URY soy production					**Predictor variables**					
			F	**F sig**	**RMSE**	**RMPSE**	**BIC**	**F**	**F sig**	**F**	**F sig**	**F**	**F sig**
								BOL exchange rate		URY inflation rate		PRY inflation rate	
14	**Macroeconomic**	1961-1989	**50.92	0.004	1569.89	0.52	370.05	*43.24	0.005	1.77	0.033	*23.41	0.013
								USA inflation rate		URY inflation rate		PRY exchange rate	
34	**Macroeconomic**	1990-2016	*967.67	0.024	17062.57	0.06	425.67	*366.56	0.040	*115.81	0.070	*181.15	0.056
								CAN imports > CHN		BRA imports > CHN			
36	**Export-Import**	1990-2013	**69.06	0.003	8265.56	0.23	354.79	**46.19	0.009	**185.44	0.001		

Significance levels: 90% *, 95% **

4.7.1 Lags Summary

Tables 4-12, 4-13 and 4-14 present the construction of the various TCM models that predict Soy Area, and Soy Production for the various date ranges. In TCM lags can be thought of as the delay between an event and a response to that event which may exist where a causal relationship may be present (See Section 4.3.1). Only lags that were significant are reported for the various models and when no significant lags are presented this is specified in each table.

Table 4-12 shows that inflation rates in the EU, CAN and BOL were predictors of Uruguayan soy area between the years 1961 – 1989. However, from these models no significant lags were produced. Exchange rate proved to be the best predictor of soy area in this time period, where the best indicators were BOL, ARG and CHN exchange rates with all lags having 95% significance levels. CAN to CHN and BRA to CHN imports were also predictors of Uruguayan soy area, though the significance levels of these lags were 90%. CAN, BRA and PRY soy show similar results having 90%, and 95% significance level lags respectively. From a supply and demand perspective this is quite plausible; exchange rate affects the immediate purchasing power of a currency and will influence immediate demand. This could be expected to produce relatively fast reactions from farmers who may be able to make shifts in production and changes in land-use (i.e. Increasing or decreasing the proportion of their land that producers devote to soy). The price on soy could be expected to be a large motivator for changes in cropping area. Each of the three exchange rates that were found to be the best predictors of soy area come from competing producers (BOL and ARG) or the major consumer (CHN), and this could reflect the attractiveness of the alternative markets' currency (URY, ARG and BOL) and the purchasing power of the importer (CHN).

Each of BOL, ARG and CHN exchange rate models has five lags. This may correspond with several concepts. Short lags are responsible for more immediate responses that result from purchasing power and attractiveness of currency, whereas longer lags (greater than 3) may correspond to behavioural shifts a market makes in response to demand (i.e. clearing more land-use area, rather than prioritisation of land-use area). Soy area models of CAN, BRA and PRY support this. These models, with the exception of PRY, only have the 4th lag as being significant. This could mean, there is significant inertia between when soy cultivation changes occur in competing markets in relation to when changes occur in Uruguay. This could be explained; where there were numerous lags associated with exchange rate, representing the volatility of currencies, there are few and long lags with changes in soy area.

Apart from reprioritisation of land for small scale changes in area, large scale land area changes take time as they require land clearing, policy and other behavioural changes. Land clearing is expected to have the most inertia, changes in competing market land areas will have impacts on supply, though the reactionary change in land-use cannot be immediate for large areas, a possible explanation for the lag between changes in soy area in competing markets and changes in Uruguayan soy area. This may not always point to an increase, though this is the case with Uruguay. Interestingly the same trend with soy area in competing markets exists for soy area in URY itself; in this model the 4th lag is significant, and this agrees with the existence of inertia in large scale land-use changes.

A similar trend seen for predictors of Soy Area (Table 4-12), exists for the predictors of Soy Production. Exchange rate (Model 4) has the same predictive effect as for Table 4-12. Where inflation rate (Model 2) did not have significant lags when predicting soy area in Table 4-12, it did in Table 4-13 when predicting production. Possible explanations for this are similar to those for exchange rate; a currency's inflation can determine the purchasing and power of other countries and the selling power of that country. The only other model which has significant lags that could predict soy production was itself, where all five lags had significance levels of 90% or higher (Model 10). Logically, as soy production changes it can influence itself as there is competition and reactionary market forces within Uruguay itself, as there are outside. This could manifest through factors such as plantation density and efficiency without land area changes. Models for export and import quantity between the years 1990-2016 had no significant lags.

The final table (4-14 Soy area for production models) presents macroeconomic (Model 13 and 14), export import (Models 35 and 36), global area, and production modelling (Models 17 and 14) for pre-soy boom and soy boom periods. Global soy area and production models were found to have no significant lags but were predicted by CAN, BRA and CHN soy areas' pre-soy boom (Model 17). BOL and USA Inflation and URY exchange for Model 13 had significant lags for predicting area; lags were not immediate, only the 2nd lags for USA inflation and URY exchange were significant and 4th and 5th BOL Inflation had significance above 90% (Model 34).

Soy production was well modelled both pre-and post-soy boom by macroeconomic models (Second-order models, Models 34). Pre-boom, BOL exchange, PRY and URY inflation were found to predict soy production, though URY inflation lags did not have significance above 90%. During the soy boom period, URY and PRY inflation had significant lags, though instead of BOL exchange rate, USA inflation became the best predictor of production. Except for PRY inflation, the lags were smaller for both USA Inflation (1-4) and URY inflation (1-2). During the soy boom, CAN to CHN and BRA to CHN both had significant lags beyond the first. Changes in exports between two competitors BRA and CAN to CHN influences URY production, though there is some delay in the response to this. URY production has a swift response in influencing itself with both the first and second lags being significant.

Table 4-12. Lags associated with first-order models predicting soy area in Uruguay that are significant at 90% or greater.

Model [model number]	Date range	Target variable (Soy Area in Uruguay)			Predictor variables								
		Lag	Coefficient	t	Lag	Coefficient	t	Lag	Coefficient	t	Lag	Coefficient	t
					EU Inflation rate			**CAN Inflation rate**			**BOL Inflation rate**		
Inflation rate [1]	**1961-1989**	*No significant lags*			*No significant lags*			*No significant lags*			*No significant lags*		
Exchange rate [3]	**1961-1989**				**BOL Exchange rate**			**ARG Exchange rate**			**CHN Exchange rate**		
		1	0.23	3.8E-9**	1	-3.19E+04	-1.27E+10**	1	1.88E+04	1.36E+10	1	-9.30E+03	-1.38E+10**
		2	-0.08	-1.5E-9**	2	5.21E+04	3.60E+09**	2	3.09E+03	1.33E+09	2	-3.84E+02	-3.58E+08**
		3	0.22	5.1E-9**	3	-3.91E+05	-9.68E+09**	3	1.14E+04	5.96E+09	3	-3.84E+03	-5.01E+09**
		4	-0.28	6.7E-9**	4	-3.83E+06	-2.61E+09**	4	3.21E+04	2.56E+10	4	-1.30E+04	-4.36E+10**
		5	-0.09	-3.5E-9**	5	7.92E+08	3.29E+09**	5	2.77E+03	1.17E+09			
Import [7]	**1961-1989**	*No significant lags*			**CAN to CHN**			**BRA to CHN**					
					2	-0.84	-4.50*	1	0.03	*2.47			
					4	1.48	2.77*	3	-0.03	*-2.42			
Soy area [9]	**1961-1989**				**CAN soy area**			**BRA soy area**			**PRY soy area**		
		4	-0.45	-3.42*	4	-0.09	-2.48*	4	-0.01	-4.90**	2	-0.03	-3.00*
											4	0.13	4.33*
Imports [25]	**1990-2013**	*No significant lags*			**CAN to CHN**			**BRA to CHN**					
					2	-0.84	-4.50**	1	0.03	2.42*			
					4	1.48	2.77	3	-.03	-2.47*			

Significance levels: 90% *, 95% **

Table 4-13. Lags associated with first-order models to predict soy production in Uruguay that are significant at 90% or greater.

Model [model number]	Date range	Target variable (Soy Production in Uruguay)			Predictor variables								
		Lag	**Coefficient**	**t**	**Lag**	**Coefficient**	**t**	**Lag**	**Coefficient**	**t**	**Lag**	**Coefficient**	**t**
Inflation rate [2]	**1961-1989**				**PRY Inflation rate**			**BOL Inflation rate**			**URY Inflation rate**		
		1	1.43	*5.93	1	653.29	8.37**	1	1.14	2.89*	*No significant lags*		
		2	-0.61	-1.84	3	-956.03	-6.72**	2	1.71	3.01*			
		3	-0.19	-1.03	4	1029.94	4.64*						
Exchange rate [4]	**1961-1989**				**BOL Exchange rate**			**ARG Exchange rate**			**CHN Exchange rate**		
		1	0.23	3.8E-9**	1	-3.19E+04	-1.27E+10**	1	1.88E+04	1.36E+10	1	-9.30E+03	-1.38E+10**
		2	-0.08	-1.5E-9**	2	5.21E+04	3.60E+09**	2	3.09E+03	1.33E+09	2	-3.84E+02	-3.58E+08**
		3	0.22	5.1E-9**	3	-3.91E+05	-9.68E+09**	3	1.14E+04	5.96E+09	3	-3.84E+03	-5.01E+09**
		4	-0.28	6.7E-9**	4	-3.83E+06	-2.61E+09**	4	3.21E+04	2.56E+10	4	-1.30E+04	-4.36E+10**
		5	-0.09	-3.5E-9**	5	7.92E+08	3.29E+09**	5	2.77E+03	1.17E+09			
Soy area [10]	**1961-1989**				**USA soy area**			**PRY soy area**			**CHN soy area**		
		1	1.40	4.04*	4	-0.01	-7.73**	3	0.16	5.51*	1	-0.01	-2.84*
		2	-0.84	-4.57*									
		3	1.07	5.70**									
		4	-0.84	-2.84**									
		5	1.20	3,77**									
Export quantity [28]	**1990-2013**	*No significant lags*			**ARG Exports**			**BRA Exports**					
					No significant lags			*No significant lags*					
Import quantity [26]	**1990-2013**	*No significant lags*			**CAN to CHN**			**BRA to CHN**					
					No significant lags			*No significant lags*					

Significance levels: 90% *, 95% **

Table 4-14. Lags associated with second-order models to predict soy area and production in Uruguay that are significant at 90% or greater.

Model [model number]	**Date range**	**Target variable (soy area or production in Uruguay)**			**Predictor variables**								
		Lag	**Coefficient**	**t**	**La g**	**Coefficient**	**t**	**Lag**	**Coefficient**	**t**	**Lag**	**Coefficient**	**t**
SOY AREA													
Macroeconomic [13] ok	**1961-1989**				**BOL Inflation rate**			**URY Exchange rate**			**USA Inflation rate**		
		1	0.78	3.13*	4	-46.88	-2.65*	2	-285.85	-2.60*	2	3185.62	4.64
					5	443.32	2.86*						
Global area and production [17]	**1961-1989**	*No significant lags*			**CAN Soy area**			**BRA soy area**			**CHN Soy area**		
					No significant lags			*No significant lags*			*No significant lags*		
Export-Import [35]	**1961-1989**	*N/A*											
SOY PRODUCTION													
Macroeconomic [14] OK	**1961-1989**				**BOL Exchange rate**			**PRY Inflation rate**			**URY Inflation rate**		
		1	1.25	4.48*	1	26722.76	2.60*	1	570.15	4.26*	*No significant lags*		
					2	-97566.19	-2.71*	3	-910.70	-6.46**			
								4	793.22	-6.46*			
Macroeconomic [34] OK	**1990-2016**				**USA Inflation rate**			**URY Inflation rate**			**PRY Inflation rate**		
		1	1.69	12.60*	1	-13137.32	-7.67*	1	30342.55	6.37*	4	40.66	0.036*
		3	-0.45	-0.12*	2	21480.42	17.27*	2	-30100.05	-6.35*			
		4	-0.72	-0.34*	3	-192555.27	-11.46*						
					4	426679.32	9.85*						
Export Import [36]	**1990-2013**				**CAN to CHN**			**BRA to CHN**					
		1	1.32	5.74*	2	-2.03	-4.75**	2	-0.06	-5.82*			
		2	-0.88	3.27*	3	3.72	7.49**	3	0.06	5.51*			
					5	4.19	0.017*						

Significance levels: 90% *, 95% **

Four of the six pre-soy boom models for soy area in Uruguay have either significant target or predictor variables. These are the Inflation rates, exchange rates, soy area and soy production models (Table 4.9). In the Inflation rates model soy area in Uruguay is predicted in terms of Bolivian, Canadian and EU inflation rates. The first two of these are significant at 90%, as is the target variable. In the exchange rates model soy area in Uruguay is predicted in terms of Argentinian, Bolivian and Chinese exchange rates. The target variable and all of the predictor variables are significant at 95%. Three predictor variables, the areas under soy in Brazil, Canada and Paraguay, are significant at 95% in the soy area model, as is the target variable. Finally, in the soy production model only the target variable, i.e. soy area in Uruguay is significant; the predictor variables are soy production in Brazil, Canada and China. All the relationships between variables in these four models are positive.

The models predicting soy area in Uruguay in the soy boom period are in stark contrast to the pre-soy boom models (Table 4-9). In the inflation rates model run on 1990-2016 data soy area in Uruguay was significant at 90%; but all three predictor variables, EU, Argentine and Brazilian inflations rates were significant at <90% significance. The export quantity model run on 1990-2013 data had two significant predictor variables, Argentine export quantity at 90% and Canada export quantity at 95%. However, the target variable was not significant at >90%.

Three of the six pre-soy boom models for soy production in Uruguay have either significant target or predictor variables. These are the Inflation rates, exchange rates, and soy area models (Table 4-10). In the exchange rates model Uruguay soy production is predicted in terms of exchange rates in Bolivia, Argentina and Canada. In the inflation rates model, the target variable and two of the three predictor variables are significant at 95%. Three predictor variables are the inflation rates in Paraguay, Bolivia and Uruguay. The first two are significant at 95%, as is the target variable. Finally, in the soy area model the target variable, i.e. soy production in Uruguay is significant; as are two predictor variables—

soy areas in the USA and Paraguay. The relationships between the variables in these models are positive.

Two models from the soy boom period predict soy production in Uruguay at high levels of significance. These are the export and import quantities models (Table 4-10). The import quantities model for soy production in Uruguay uses Canadian and Brazilian exports to China as predictor variables. The target and predictor variables are significant at 95%. In the export quantity model soy production in Uruguay is predicted from the quantities of soy exported from Argentine and Brazil. The target variable is significant at 95%, and exports from Argentina are significant at 90%.

Both the macroeconomic, and area and production second-order models are good predictors of soy area in Uruguay before 1990 (Table 4-11) In the macroeconomic model soy area in Uruguay is explained by Bolivian and USA inflation rates, and Uruguay exchange rate. The Bolivian exchange rate and the target variable are significant at 90%. In the area and production model soy area in Uruguay is explained by Brazilian and Canadian soy area and Chinese production. The target variable and Canadian soy area are significant at 90%. Only one soy boom model for soy area in Uruguay is significant. This is the export-import model of soy area in Uruguay (Table 4-11) which can be predicted by both Canadian and Brazilian exports to China. The target variable is significant at 90% and the predictor variables are significant at 95%.

The macroeconomic second-order model predicts soy production in Uruguay before 1990, but unlike for the second-order models predicting soy area at this time, the area and production model does not. The macroeconomic model uses Bolivian exchange rate, and Paraguay and Uruguay inflation rates to predict soy production in Uruguay up to 1989. The target variable is significant at 95%, and two of the predictor variables—Bolivian exchange rates and Paraguayan inflation rates– are significant at 90%. Two second-order models in the soy boom period predict soy production in Uruguay, the macroeconomic and export-import models. The first predicts soy production in Uruguay on the basis of the USA and Uruguayan inflation rates and Paraguayan exchange rate. All variables are significant at 90% except exchange rates in Uruguay. In the export-import model, Canadian and Brazilian exports to China dominate once again. The target and predictor variables are significant at 95%.

It is possible to identify a distinction between the variables that predict soy area and production in Uruguay in the pre-1989 and post-1990 models. The variables are summarised in Table 4-15.

Table 4-15. Summary of predictor variables from the first- and second-order soy area and productions described in Table 4-9 to Table 4-11.

	1961-1989 models MERCOSUR countries	**Other countries**	**1990-2016 models MERCOSUR countries**	**Other countries**
URY soy area prediction models	ARG exchange rate BOL exchange rate BOL inflation rate BRA soy area BRA soy production PRY soy area PRY inflation rate URY exchange rate URY inflation rate	CAN exchange rate CAN inflation rate CAN soy area CAN soy production CHN soy production EU inflation rate USA inflation rate	ARG exchange rate ARG inflation rate BRA inflation rate BRA-to-CHN soy export quantity PRY exchange rate URY inflation rate	CAN export quantity CAN-to-CHN soy export quantity EU inflation rate USA inflation rate
URY soy production prediction models	ARG exchange rate BOL exchange rate BOL inflation rate PRY soy area PRY inflation rate URY inflation rate	CAN exchange rate CHN soy area USA soy area	ARG export quantity BRA export quantity BRA to CHN soy export quantity	CAN-to-CHN soy export quantity

Before the soy boom which started in the 1990s, both the soy area and soy production in Uruguay are predicted using many variables (Table 4-15), though slightly more in the case of area prediction models (16) compared to the number used in predicting production (10). There are more variables associated with soy producers in MERCOSUR, than that from the other four countries included in the models—Canada, China, the EU and the USA. The variables are also drawn widely from inflation and exchange rates, and from soy area and production.

After 1990 fewer variables predict Uruguay's soy area or production: 9 compared to 16 in terms of soy area models, and 5 compared to 10 for production models. Again, more variables are drawn from MERCOSUR producers than the other soy-producing and importing countries. It is noticeable that variables related to Bolivia do not appear after 1990 in terms of MERCOSUR countries, and that variables related to Canada were important in predicting soy area and production in both time frames in which modelling was undertaken.

4.8 Summary

This chapter introduced and applied a type of time-series modelling based on the concept of G-causality that has not been used previously in land change science, and which has recently been operationalised in SPSS as temporal causal modelling. It was used to predict soy area and soy production independently in Uruguay for two-time periods. These were approximately 1961-1989, and 1990 to 2016: the latter time period covers the soy boom in Uruguay. Exchange rate, inflation rate, import, export, and soy area and production data from the main soy producing and exporting nations, and the major soy importing economies— China and the EU –were used as model inputs.

Eighteen models predicted either soy area or soy production in Uruguay in one of the two-time periods and were deemed significant because the F value of at least one of the target or predictor variables was significant at >90%. In the majority models both the target and at least two predictor variables were significant. Four first-order and two second-order models predicted soy area between 1961 and 1989; while three first- and one second-order models predicted soy production over the same time. Three first- and one-second order models predicted soy area after 1990; while two first- and two second-order models predicted soy production in this later time period. Before 1990 many variables were used to predict area and production, and more of them were associated with MERCOSUR countries. After 1990 fewer variables predict Uruguay's soy area or production, though again more are drawn from MERCOSUR soy production.

5 THE CHANGING NATURE OF SOY PRODUCTION IN URUGUAY

5.1 Introduction

In the previous chapter, statistically significant models that predicted trends in soy production and the soy cultivated in Uruguay were identified (Section 4.7). This chapter discusses the significant models in the context of global drivers of soy production in Uruguay in Section 5.2. In Chapter 4 a threshold around 1989/1990 was identified; with the models based on data between 1961 and 1989 being termed pre-soy boom models, and those after 1990 being termed soy boom models. This threshold relates to the shift to soy-dominated cropping systems in eastern Uruguay. The reasons behind this shift is analysed in Section 5.3.

5.2 Discussion of production models

In this section, the soy models of soy production are discussed. Greater emphasis is placed on the models for the soy boom era, i.e. 1990 onwards, as this is the main focus in the thesis. Figure 5-1 and Figure 5-2 show the observed and predictive series for both export model 26 and import model 28.

5.2.1 Soy boom era production modelling

The models discussed in this section are the first-order export and import quantities models (Table 4-10) and the second-order Macroeconomic and Import-Export models (Table 4-11). The significant variables were: Argentine and Brazil export quantities, Brazilian and Canadian imports to China, the USA and Uruguay inflation rates, and PYG: USD exchange rate. These models draw attention to the importance of the global trade in soy. Soy boom models are discussed in Section 5.2.2 and pre-soy boom models in Section 5.2.3.

5.2.2 Soy boom models

The two predictor variables in the export quantities model (Model 26) are export quantities from Argentina and Brazil (Table 4-10), and the model itself shows a very strong relationship between predicted and observed soy production in Uruguay (Figure 5-1).

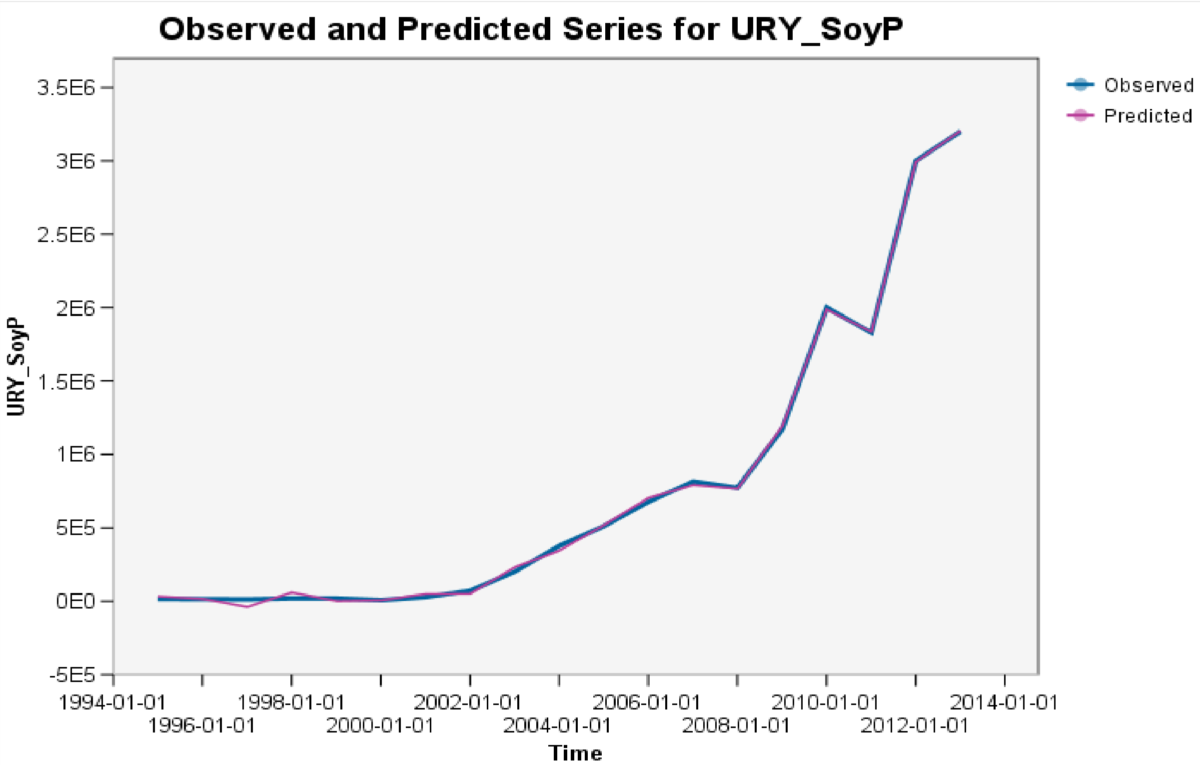

Figure 5-1 Export quantity model, Model 26, for the soy boom era

The economic reforms of the 1990's successfully put the Argentine economy on a sustained growth path and notwithstanding two minor recessions, GDP growth averaged 4.7 percent per annum between 1991 and 1999. Argentina's exports increased 8.2% over this period (Pou 2000), and soy as a major export commodity was a major component of the overall growth in exports. Brazil's soy exports growth also increased in the last decade contributing to deforestation in the region (Nepstad et al. 2006; Richards 2018; Jepson et al. 2010; Richards et al. 2012; Kaimowitz & Smith 2001). The growth of Uruguay's soy exports mirrors Argentine and Brazil's soy exports between 1991 and 1999, even though they are much smaller in volume. Uruguay's membership of the Mercosur means political and economic relations between Argentina and Uruguay is strong. Given their geographical location, they share access to the same ports, have access to the same shipping line and export means via the

Rio de la Plata basin. The statistical relationships between soy exports from these two countries are based on the influences of these economic connections and can be considered causal in the true sense of the term. Although agricultural economies of Brazil and Uruguay are not as strong as an Argentina-Uruguay one, both countries still share a mutual dependence. The relationship for this model is likely to be a statistical correlation based simply on the fact that soy production grew in a similar manner in almost all of the top ten producing countries after 1990 in response to the growth in global demand from China and the EU, rather than that particular economic linkages between the Uruguayan economy and that of another country. The importance of growing Chinese demand is returned to in the next section.

During the late 1980's the Argentine economy fared badly during the global debt crisis. Growth in real output stagnated, financial markets collapsed, prices rose as the Argentine peso steadily depreciated, and capital fled to safer havens (World Bank 2014b). Most public enterprises were running large deficits at this time, and the country's external debt kept mounting. Moreover, the central government, which was hampered by low rates of tax collections and desperate for larger, stable revenue streams, turned to the Banco Central de la República Argentina to increase the money supply and introduced a tax on deposits (IMF 2000). Inflation, which had been steadily rising over previous decades, soared during the late 1980's and reaching an average annual rate of 2,600% between 1989 and 1990 (Pou 2000). Although the government tried to bring inflation under control, the central bank was unable to do so because of the reliance on inflationary financing. The hyperinflation of 1989-1990 was the impetus for reform, which was achieved through the *Convertibility Plan* (Palermo 1998). The main components of this plan were to peg the exchange rate of the peso with the US dollar, and to introduce far reaching structural reforms that included cuts in public expenditure, the privatisation of almost all government enterprises, tax reforms, and financial and trade liberalisation. At first, the results were impressive. Output grew at an average annual rate of approximately 8% between 1991 and 1994, and this was mirrored by high rates of growth in consumption and investment.

However, this economic boom was short-lived and came to an end after the collapse of the Mexican peso in December 1994 in what is known as the *Tequila Effect*. This led to a run on the Argentine banking system, which in turn led to and a credit crunch in March 1995 that out many financial institutions out of business (Laufer 2013; Roett & Crandall 1999). At the same time period, Brazilian inflation rates were also high as the country had adopted inflation targeting after a brief period of exchange-rate targeting in a major currency crisis. Specifically, from 1994 to 1998 high domestic interest rates and privatisation were used to reduce inflation: the main objective of Brazilian economic policy at this time (Barbosa-Filho 2008). A side effect of this was exchange-rate appreciation and a substantial increase in the current account deficit and net public debt. This had parallels with what was happening in Argentina and Mexico during the 1990's (Krinstinek & Anderson 2002), though in Brazil macroeconomic stabilisation was heavily dependent on the continuous flow of foreign capital which, due to its international financial position, became quite fragile after contagion effects from the 1997 East Asian currency crisis and the Russian crisis of 1999 (Barbosa-Filho 2008).

The outputs from the model (i) Argentina export quantity, (ii) Brazil export quantity and (iii) China's imports of soy from Brazil (Table 4-10) are all variables that can be explained by these events. While the first two variables are accounted for above (Model 26), Model 28 (Figure 5-2) covers, in part, Brazil's exports, and China's imports of soy from Brazil.

The two predictor variables in Model 28 are Chinese soy imports from Canada and Brazil (Table 4-10), and model itself shows a very strong relationship between predicted and observed soy production in Uruguay (Figure 5-2). The trade in soy from Brazil to China is of particular importance and is part of a much bigger global picture involving the two countries. The development of the Chinese economic (and political partnerships) with some Latin American countries began as early as the 1980's (Domínguez et al. 2006; Cheng 2011; Torres 2018; Wise 2016). Today China is the third largest trading partner on the continent, and its strategy is based on a south–south cooperation scheme that includes areas such as economy, trade, and energy security (Wilkinson & Wesz Jr 2013). In the post-Mao China, the government has turned its attention to developing its economy through the development of external trade in response to the need to grow its infrastructure. Resource demands have been enormous because of a series of influences such as the size of the economy, increasingly large urban populations, and infrastructure development. This has forced China to look outward to resource-rich developing countries in Latin America, Africa and the Middle East. For example, China's increasing external trade with developing countries provides them with raw materials such as petroleum, copper, nickel, iron, wood, leather and chemicals, and agricultural commodities like soy (Sutter 2012). In the context of this research, what is important is that China has been increasing agricultural imports to accommodate the needs of growing domestic markets, particularly increasing demand for pork, wheat, corn , rice milk and sugar (FAOSTAT 2016).

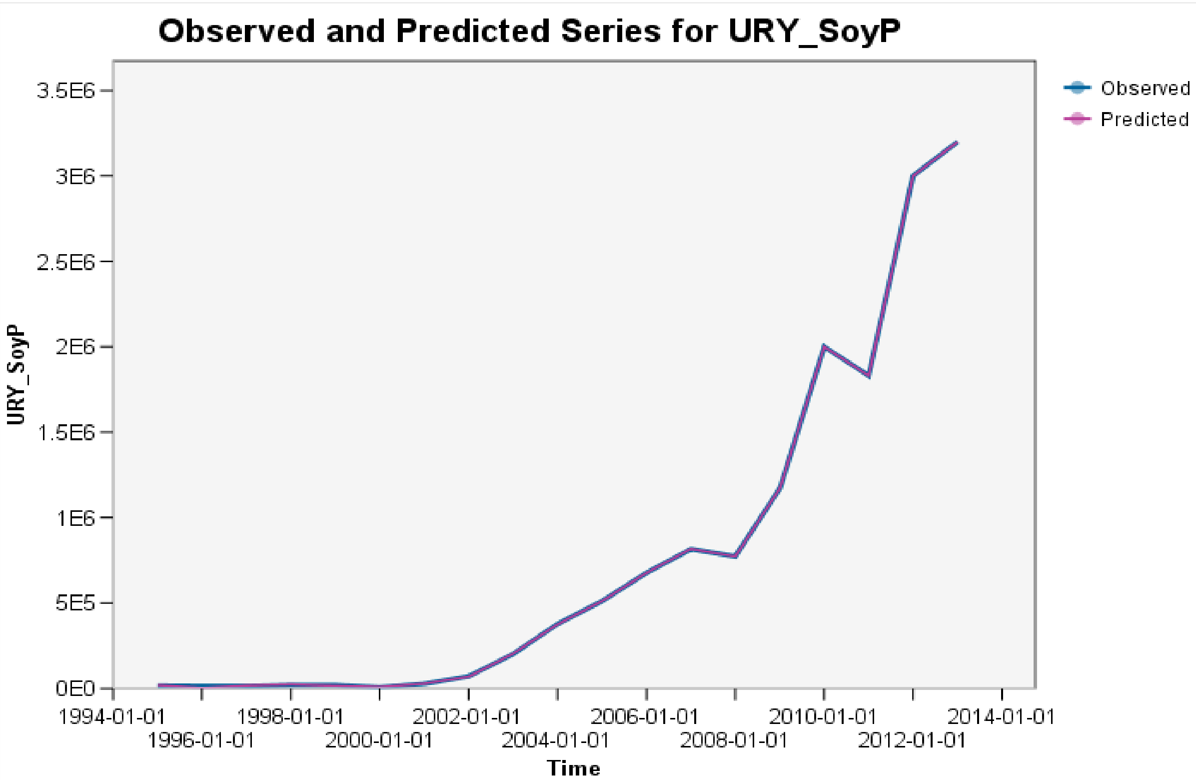

Figure 5-2. Import quantity model, Model 28, for the soy boom era

Trade relations between individual Latin American countries and China have strengthened as both regions sought to move away from inward-looking economic models and integrate more fully into the world economy (Wise 2016; Torres 2018). However, out of all the partnerships between each Latin

American country and China, Brazil is the only one of the five emerging national economies or BRICS in Latin America. A point made by President Hu Jingtao during his Latin American tour in 2004 when he made it clear that China sees Brazil is the most important partner in the region (Domínguez et al. 2006). The economic strength of this partnership is built on the importation of natural resources from Brazil into China, in particular, the agro-industrial, agricultural commodity and food sectors. While China is transforming itself into one of the largest food markets globally, Brazil is consolidating itself by being a leader in the export of agricultural products to China (Wilkinson & Wesz Jr 2013; Gunderson 2014). Soy is one of the most important commodities traded in this partnership. To achieve this position, the vigorous introduction of technological innovations has increased agricultural productivity in Brazil (Mackey 2011; Lambin & Meyfroidt 2011; Nica 2013). Simultaneously, strong demand from European markets, Russia, and Middle Eastern nations has also allowed Brazil to challenge the United States as the leading exporter of major agricultural food commodities globally, these include soy, orange juice, coffee, tobacco, cotton, and pulp (Wilkinson & Wesz Jr 2013).

Introduction of new technologies and the investment of foreign capital in developing countries has increased. This has led to political economic power structures, China and Brazil are an example where transnational agribusinesses quite often create a landscape where vertical integration exists along the supply-chain, for example dominance by specific players within the agribusiness sector; for example ADM, Bunge, Cargill, and Louis Dreyfus Commodities (ABCD) (Gunderson 2014).

The trade relations between China and the Latin American region seems to suggest an interdependence between the two regions. China has become an export destination for Latin America in particular Brazil where strong bilateral trade relations between the two countries exist.

5.2.3 Pre-soy boom era production modelling

The three first-order models that predicted soy production in Uruguay (Table 4-10) revealed the following statistically significant variables: (i) inflation rates for Bolivia and Paraguay; (ii) the Argentine, Bolivian and Canadian exchange rates; and (iii) the areas under soy in Paraguay and the USA. The structure of these first-order models is apparent in the second-order models (Table 4-11), where both the macroeconomic, and the global soy area and production, data had significant F values for soy production in Uruguay. There were only two significant predictor variables in these models. The Bolivian inflation rate (in the macroeconomic model) and the area under soy in Canada (in the global area and production model).

However, soy was a very small part of the arable crop mix in Uruguay at this time (Section 1.6, Figure 1-1) and therefore a decision has been made to focus on explaining the growth and subsequent fluctuations in soy production in Uruguay's soy boom era after 1990.

The last few decades has seen vast integration of world markets. Prior to this (prior to 1990), the global environment was under post-war reconstruction and development. From the end of the Second World War (1945) to the early 1970's (when the Bretton Woods monetary system collapsed) there was a period known as the "Golden Age of Capitalism", a period of economic prosperity; high and sustained levels of economic growth and high levels of productivity and low levels of unemployment. This was particularly the case for Western Europe and East Asia (United Nations DPAD 2017; Feenstra 1998). This period was also associated with the emergence of new international institutions such as the international Monetary Fund and the World Bank as part of the Bretton Woods Monetary System and the United Nations Industrial Development Organisation (UNIDO) (United Nations DPAD 2017; Birdsall & Fukuyama 2011).

In summary, the importance of the economic situation in the neighbouring MERCOSUR countries for predicting soy production in Uruguay is clear when modelling in the 1961-1989-time frame, though Brazil is an exception to this general statement.

5.3 The transition to a soybean-dominated cropping system

The models of soy production in Uruguay, and area, clearly show that arable production systems dominated by soy began in earnest during the late-1990's after which, between 2000 and 2009, soybean production grew exponentially. Five crops had dominated the arable sector until the late-1990s, especially in the four Litoral departments where most cultivation took place. These comprised two winter crops—wheat and barley–and three summer crops—maize, sorghum and sunflower. The introduction of soy saw massive shifts in production. Maize and sunflower witnessed significant drops in production as soy, another summer crop, quickly became the preferred crop for many farmers. Wheat, a winter crop, rather than being the key crop in the winter-summer cropping patterns became a secondary crop in soy-dominated summer-winter rotation systems as will be shown in Section 7.5. The areas under these different crops (Figure 5-3) reflect these shifts in production

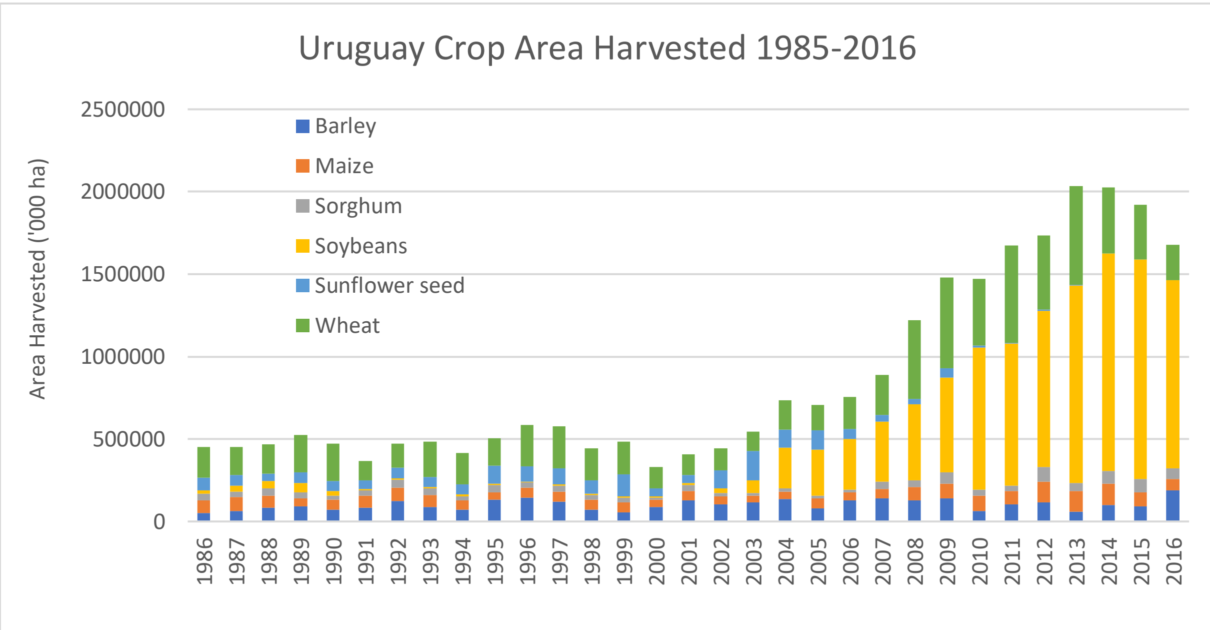

Figure 5-3 Areas harvested of main crops in Uruguay, 1985-2016. Source: FAO (FAOSTAT 2016)

Interviews with government officials and agribusinesses (Section 3.4.1) indicated that five factors influenced this shift in crop production around the turn of the millennium. The comments made in interviews were cross-referenced with secondary sources. The key drivers include both proximate regional causes (drivers i and iii below), and underlying global factors (driver iv)[8]:

i. a decline in sunflower cultivation (discussed in Section 5.3.1);
ii. the economic downturn in Argentina, and the flight of capital and agricultural know-how from that country. The latter aspect includes the diffusion of genetically-modified soy (Section 5.3.2);
iii. the role of MERCOSUR (5.3.3); and
iv. increased global commodity prices for soy, which in part were due to increased global demand of soy due to foot and mouth disease.

All of these drivers played pivotal roles in combination with each other in resetting Uruguay's arable agricultural sector so that it was able to enter the global soy trade as a major exporter. Each of these factors is discussed individually below, before their relative contributions are analysed. The events occurred simultaneously, and their timing appears somewhat simultaneous, making it is difficult to identify whether, when or where one driver was more important than another.

For example, a government committee measure exports, how much tourism a project will generate, including how much employment it will create over time and on a long-term basis. The projects are given a score and are measured to see how much taxes it will cost. Among many of these, agricultural projects are presented. Overall, the way government assess a new project and investment is through a score system. They include agricultural and industrial projects, which all compete for approval. Each

[8] This last driver is not discussed in this section because the focus is on regional drivers. However, it is discussed in Chapter 2.

of them have their own advantages. Ultimately decisions are often guided by how much revenue a project will create.

Uruguay's association with laissez-faire economic liberalism has in part enabled the rapid expansion of this new crop. Interviews with government officials from the MGAP indicated this was the prevailing state of affairs, and it is supported by the models of soy production and area.

> *Uruguay tiene una economía abierta y el liberalismo les ha dado mano a los productores de plantar la soja con mucha facilidad….*
>
> (Uruguay's open economy and its adoption of neoliberalism has facilitated the growth of soy) [MGAP Government official, 8 February, Montevideo]

The interviews indicated that the Uruguayan government welcomes and promotes investment that is associated with fiscal policy.

> *…debido a esto, le dio paso a las grandes inversiones que se ingresaron al país... sin los grandes inversores, la cantidad de soja que se está cultivando en el país sería improbable….*
>
> [Because of this (neoliberalism and open economy), large investors were able to enter the country… without their (investors) input the amount of soy being cultivated would probably be unlikely] (MGAP, government official, 8 February, Montevideo).
>
> *El gobierno ha abierto sus puertas a grandes inversiones… esta nos has ayudado mucho… especialmente a la economía*
>
> [The government has been very open to large investments… this has helped us a great deal… the economy of Uruguay, especially] (MGAP, 9 February, Montevideo)

These investments range from national, through regional (other southern cone partners) or international. Interviews in Montevideo affirmed that when an opportunity presents itself in Uruguay there is a government commission that assesses and defines how much monetary capital a project will bring into the country.

> *El gobierno tiene un sistema que evalúa una lista de actividades económicas, inversión extranjera, turismo, por ejemplo, y cuáles van a aportar más valor monetario. Sucede que cuando llegaban las grandes compañías agrícolas, iban a traer un montón de plata…*

[The government has a system which evaluates a list of economic activities from foreign investment and tourism to name a few. They assess which of these will bring in more monetary value. It was this process that allowed the large agricultural producers to settle here… they were going to bring in lots of money…] (MGPA, government official and agronomist 10 February, Montevideo).

5.3.1 The decline in sunflower cultivation

During the 1980's, *Phomopsis* fungal infection reduced sunflower yields in Yugoslavia (Huguet, 2005 Cited in Viranyi 2008). By the late 1990's and early 2000's it was recorded in Entre Ríos Province in eastern Argentina and Soriano Department in the Uruguayan Litoral (Viranyi 2008). These two adjacent regions are only separated by the Río Uruguay and transmission of fungal spores, between the two administrative divisions, would have been relatively straightforward by either natural or anthropogenic processes. The impact of *Phomopsis* was particularly severe in Uruguay, and sunflower yields declined markedly after 2002 (Figure 5-4).

In 2005, before the overall decline of yield due to disease, sunflower was one of Uruguay's most successful summer export crops. The decline in yield inevitably led to a decline in production, which resulted in lower export tonnages. The overall responses was substitution, the replacement of one export crop (sunflower) with another that was suited the environmental conditions (soy) (Figure 5-4). Farmers replaced sunflower with soy across the region. But as Figure 5-4 shows they did more than plant soy to compensate for the previous area that was under sunflower. The statistics show that the area under soy far exceeded the greatest area under sunflower at any time between 1961 and 2002. This is prima face evidence that the introduction of soy to replace sunflower also led to a massive change in the entire cultivation system in the area and an expansion of land under cultivation. Support for the argument that the occurrence of *Phomopsis* led directly to the demise of sunflower and that this in turn encouraged many farmers to look to soy to lead crop development was obtained from many interviews.

> *…el hongo en la planta no pudo ser salvada, era la razón para cultivar soja…. simplemente, también porque la soja empezaba a dominar…era fácil para cultivar…*

> [the fungus in the plant (sunflower) could not be saved, it was the reason many switched to soy… quite simply also because soy was starting to dominate… It was easy switching (to soy)]. (Interview with a group of farmers in Mercedes, Feb 14th, 2016).

> *Para muchos productores la soja era más fácil para cultivar porque los recursos ya tenían disponibles por las grandes empresas por el paquete…*

> [For many producers it was easier making the switch to soy because the resources necessary were already at their disposal from the multinationals] (Interview with an agronomist at a cooperative, Young, Feb 1st, 2016]

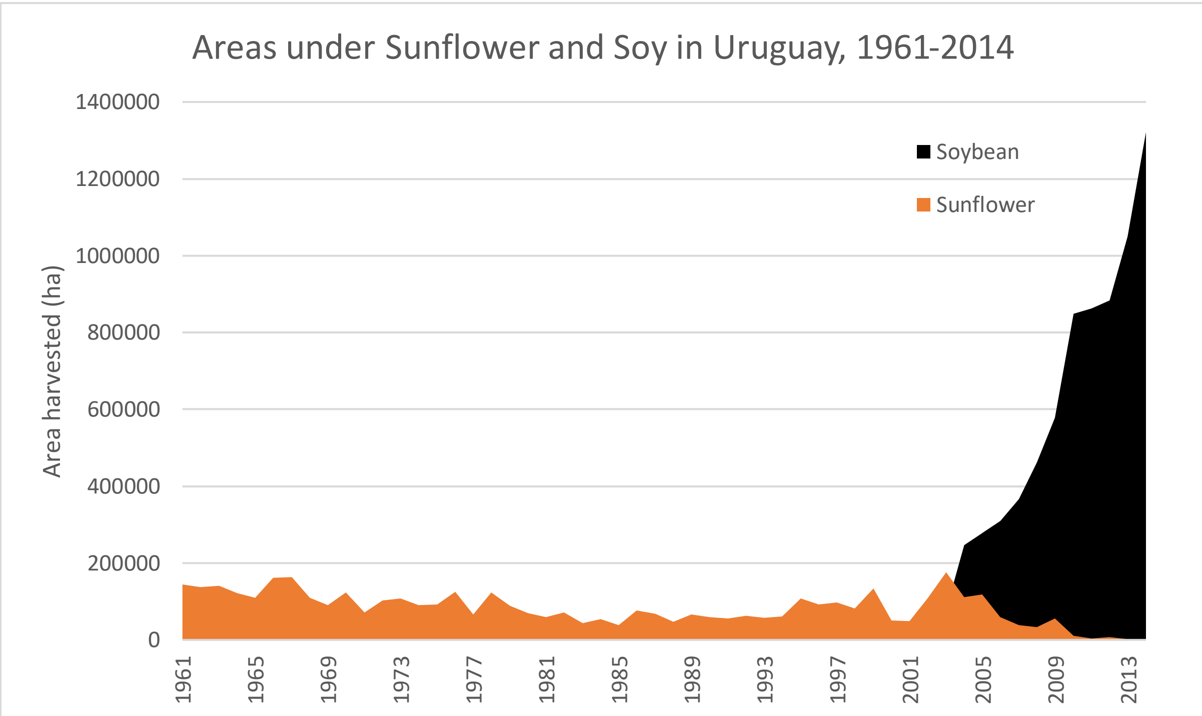

Figure 5-4 Areas harvested under sunflower and soy in Uruguay, 1961-2014. Source: (FAOSTAT, 2016)

Most interviewees also indicated that the fungus was difficult to treat. While all of them cited that it was their primary reason to shift to soy, they also considered soy to be a more profitable alternative than sunflower. It is a moot point as to whether the shift from sunflower to soy as the dominant summer crop would have occurred as quickly as it did within the occurrence of *Phomopsis*, but the responses suggest soy would have expanded into Uruguay anyway.

5.3.2 The flight of Argentine capital

Uruguay is generally considered to be a stable economy in relation to its neighbours, particularly Argentina. This has been the result of the policies of successive governments since the mid-1980's and has led to a favourable investment environment for individuals and businesses in neighbouring countries. This was the case for investors from Argentina when sovereign risk drove many to flee the country and invest their money elsewhere (1998-2002). These Argentinians were considered economic migrants (Uruguayan interviewees viewed them as economic migrants) in many ways because they were looking for opportunities that were no longer available in their own country. There was a constant rhetoric which reverberated during discussions with producers and cooperative members around the mutual interdependence that Argentina and Uruguay exhibit.

> *Uruguay y los argentinos siempre hemos sido conectados. Somos como el hermano chiquito… Nos llevamos muy bien, la única vez cuando estamos uno contra el otro es en el futbol*
>
> [Uruguay and the Argentines have always been connected. We are like the little brother. We get along quite well... the only time when we are against each other is in football] (Interview with cooperative members in Mercedes and Rodo, February 25th, 2016)

However, this mutual interdependence is not just applicable to Argentina and Uruguay:

> *muchos de los agricultores [uruguayos] se han ido a Paraguay, donde han comprado tierras baratas para la ganadería… …ósea que han vendido las tierras acá para comprar allá*
>
> [Many of the Uruguayan farmers have left to invest in land in Paraguay, where land is cheap for their cattle grazing…selling their land here to buy land over there (Paraguay)] (Interviews conducted with cooperative in Paysandú and Young, February 27th, 2016)

In fact, Latin America as whole and particularly South America have shared subregional interdependence in the post-colonial era in which financial investments have been provided by neighbouring countries, particularly after they begun to industrialise (Sánchez 2011).

However, the international relations between countries in the region has not been straightforward. There are lingering boundary conflicts with neighbours that often have their origins is the early post-colonial period. For example, the Paraguayan War, or the War of the Triple Alliance[9] (1864-1870). This developed after Brazil struggled to gain hegemony in the region, especially towards Paraguay. Since this war Brazil has more-or-less maintained economic and political influence where necessary in the region (Duarte Recalde 2013).

Many Brazilians have established themselves in Paraguay, particularly as farmers. For example, one of the richest Brasiguayos[10] farmers, Tranquilo Favero, cultivates 168,000 ha of soybeans (Duarte Recalde 2013). Many Brazilian farmers currently living in Paraguay are a product of Alfredo Stroessner's military dictatorship from 1954 to 1989. During his time in office he claimed and redistributed over 8 million ha of land to the military, politicians, parliamentarians and other associates outside the country, from Brazil to Nicaragua (Duarte Recalde 2013). This land is commonly referred to as *Tierra Malhabidas*[11] in Paraguay. This is but one example of the ongoing interdependencies within the region, which lead to more-or-less continuous power struggles and contested natural resources (Sánchez, 2011).

Although, Argentinian farmers in the pampas began growing soy in 1970 it was almost a decade later that soy experienced its first large boom in production after the introduction of hybrid seeds,

[9] War of Triple alliance fought by Paraguay against Brazil, Argentina and Uruguay. It remains a unique war in Latin America as it was not directly related to specific boundary disagreements (Abente 2008)

[10] Brasiguayo a term used for Brazilians who have migrated into Paraguay and have established themselves in the country

[11] *Tierra Malhabidas* means ill-inhabited lands. An expression for talking about land illegitimately appropriated by elites during the Stroessner era. Since this time it has made it difficult to identify their true occupants.

mechanisation, fertilisers and herbicides that mirrored those of rice and wheat during the Green Revolution (Barsky & Gelman 2001). Argentina then became the first country globally to adopt after the introduction of genetically-modified (GM) Roundup Ready (RR) soybeans in 1996/1997 along with highly mechanized agricultural systems in what became known as the *modelo sojero*. In Argentina production had grown steadily since the 1970's, after 1996-1997 the average area increase rate doubled in just one season. This led to an increase in agricultural exports to and record farm profits. While this was due in part to the introduction of GM RR soy, it was also due to the formation of *pools de siembra* or sowing pools[12]. From interviews I conducted, a regular rhetoric stressed historical links between Argentina and Uruguay, and that these links extended to agriculture.

> *Los argentinos, siempre han influenciado lo que hacen los uruguayos...Uruguay es como el hermano chico... lo que le pasa a Argentina nos pasa a nosotros. Lo mismo paso con la soja.... compraron paquetes tecnológicos, y los trajeron acá… ayudaron a establecerlos…*
>
> [The Argentines have always influenced what the Uruguayans do ... Uruguay is like the younger brother ... what happens to Argentina happens to us. The same thing happened with soy ...they brought the technological packages here and helped establish them] (Interview with cooperative in Young, 3 March 2016).
>
> *políticamente, económicamente e incluso culturalmente, Argentina y Uruguay tienen una conexión histórica que data de hace mucho tiempo ... Durante los tiempos difíciles, los argentinos ingresaron al país porque Uruguay es más estable ... y almacenan su dinero en nuestros bancos.*
>
> [Politically, economically and even culturally, Argentina and Uruguay have a historical connection which goes back a long time... During hard times the Argentinians came into the country because Uruguay is more stable... and they store their money in our banks] (Interviews conducted with government officials in Montevideo, 10 March 2016).

The adoption of technological packages of GM soy that had taken place in Argentina spilled over into Uruguay during the Argentine economic crisis of 1999-2002 and exemplifies the close economic relationships between Argentina and Uruguay. As the first adopter of GM soy, Argentina became the

[12] See Section 6.3.1 for further definition on sowing pools

main promoter of GM biotechnology in the region. It has been argued that this is part of a strategy based in a neoliberal agro export model to support socio economic development in the Global South (Otero 2008). Bearing these facts and arguments in mind, it seems almost inevitable that surrounding countries would adopt the *modelo sojero*. However, in the case of Uruguay the timing can be fixed to the flight of capital from Argentina during the 1999-2002 financial crisis, when agribusinesses and wealthy Argentinian farmers looked for business opportunities elsewhere. Land values in Uruguay were low at this time and the country had been a favoured investment destination for Argentinians for decades because of its stable economy and close proximity. The increase in the number of sales and the total area sold and purchased due to these capital investments is clear from

Figure 5-5. As a consequence investments in agriculture poured into Uruguay, especially since land values were also at an all-time high in many parts of Argentina (Piñeiro 2012). Inevitably, these investments led to increases in land values in Uruguay, especially after 2003 (INC 2010, Piñeiro 2012). This is an example of a spill over effect *sensu lato* of the flight of capital into a safe haven economy as used in economics, which leads to land-use change. Perhaps more importantly this reflects the globalisation of land-use as a global force. There is a cascading effect of interrelationships between new forms of trade and cultural exchange, which then cascade through to land systems by multiple, interacting factors that originate from one place to another (Geist & Lambin 2002; Lambin & Meyfroidt 2011; Rueda & Lambin 2018; Robinson & Carson 2015; Eakin et al. 2014) (Geist & Lambin 2002) (Rueda & Lambin 2013; Lambin & Meyfroidt, 2011). In this case, the influence of Argentina was not only investment of capital, but the introduction of the *modelo sojero.* As numerous interviewees noted, this was a major influence at the advent of the soy boom in Uruguay.

> *Vinieron acá, compraron tierra, que estaba muy barata en ese momento, y las grandes empresas empezaron a ofrecer paquetes tecnológicos a los productores. Esto cambio la manera como los productores manejan la agricultura. Los argentinos vinieron acá y nos ensenaron como hacer negocios y manejar la agricultura… sin duda la agricultura ha cambiado drásticamente*
>
> [They came here, they bought land, which was very cheap at the time, and the big companies started offering technological packages to the producers. This changed the way producers handle agriculture. The Argentines came here and taught us how to do business and manage agriculture ... without a doubt agriculture has changed drastically] (Interviews conducted in Mercedes and Montevideo February 29 and March 14, 2016)

Image removed due to copyright restriction

Figure 5-5 Number of land transactions by calendar year and the total land area sold (ha) 1970-2010. Source; INC (2010).

However, land purchases were not the only investment in the Uruguayan agricultural sector from Argentina at this time. Large agribusinesses that were active in the soy sector in Argentina opened up branches in Uruguay, the most often quoted in interviews was El Tejar. These businesses acted in the same way as multinational agribusinesses, such as Louis Dreyfus (LDC) and ADM, and Uruguayan *barracas*, such as Copagran and Barraca Erro, do at the present time (Section 6.5).

Although Argentinian capital assisted with the adoption of soy in Uruguay, another factor that enabled outside investment flows into the Uruguayan agricultural sector was an almost simultaneous change in the law on property ownership in the late 1990s. *Ley* 13.608/67 of 1967 established that only individuals could hold agricultural property rights, and prevented ownership by groups of individuals or corporations (*sociedades anonimas*). In 1999 this was revoked, and it marked the beginning for new forms of landownership. If this was not encouragement enough for businesses to invest in land, another law promulgated in 1999, the *Ley de inversiones* (The Investment Law) (Piñeiro 2012), specifically promoted agro-industrial investments and encouraged large-scale investment projects. The combination of these two laws strongly influenced new kinds of investment in Uruguay, the very types of investment that suited the flight of capital from Argentina, i.e. Argentine businesses investing in Uruguay.

Although the researcher was not able to acquire data on the legal status of the individual persons or individual companies who buy and sell these lands (this data is confidential), there is data on land area bought and sold by groups and organisations (Table 5-1).

Table 5-1Land Bought and Sold legally by individuals and companies

Legal status of organisations	Sold (s)	Bought(b)	Balance (s)-(b)
Individual	4,615	2,704	-1,911
Corporation	1,249	3,073	1,824
Other Companies	167	242	75
State	16	14	-2
Other	43	56	13
Total	**6,089**	**6089**	**n/a**

Source: MGAP-DIEA (2011)
Note: information here only available for 2000-2009 years

Table 5-1 clearly shows that almost all land sold by individual Uruguayan farmers between 2000 and 2009 is now owned by corporations, which indicates the effectiveness of the laws introduced above, and which is essential for the successful adoption of the *modelo sojero*. The amount of land bought (or even subsequently sold) by corporations cannot be identified from this table. But it can be assumed that ownership is currently shared between national and foreign companies, as both are active in arable agriculture in Uruguay (Section 6.4). It can also be assumed (based on interviews conducted) that initially the majority of these companies are foreign, and possibly all Argentinian. For example, during the interviews, many interviewees mentioned El Tejar, the first of the large agricultural companies to establish itself in Uruguay. It was a large Argentinian agricultural company, which established itself in the Litoral departments during the early 2000's and offered technical packages to farmers to enable soybean production. It no longer operates in Uruguay.

> *El Tejar fueron unos de las primeras empresas…Vinieron con grandes paquetes, vendiéndolos a agricultores más pequeños*
>
> [El Tejar were one of the first companies ... They came with large [technical] packages and sold them to small farmers.] (Interview conducted with contractors in Paysandú and Mercedes 2016).

It is clear that El Tejar represented not only a very large financial investment from Argentina, but also introduced advanced technological capacity to farmers throughout *el Litoral.*

In summary, the effectiveness of the investments from Argentina, and the changes in laws in Uruguay, can be underlined by the following fact. Uruguay only produced 10,000 ha of soy before these financial and technological investments from Argentina were offered, but afterwards there was an exponential increase in production (Figure 5.3). The flight of capital from Argentina enabled soy to get a foothold in Uruguay, but it was the weak restrictions on FDI and on foreign businesses operating in Uruguay (its *laissez-faire* economy) and a deregulated land market that enabled it to expand and come to dominate cultivation systems.

5.3.3 The role of MERCOSUR

The combination of Uruguay's *laissez-faire* economic system; investments from Argentina; cheap, good quality land; high soy prices and a decline in sunflower yields enabled soy to become established in Uruguay and then expand from early 2000's. However, undoubtedly the Southern Common Market (MERCOSUR) has been a facilitator of the movements of goods and capital across its member countries, and this has been a factor in stimulating the soy boom in Uruguay.

MERCOSUR is a regional trade agreement which comprises Argentina, Bolivia, Brazil, Paraguay, and Uruguay (Venezuela, was recently suspended in 2016). The agreement was created in 1991 when Argentina, Brazil, Paraguay, and Uruguay signed the Treaty of Asuncion. It was created to improve relations between countries in the region and facilitate trade between countries; movement of goods, services, movement of people (within countries without a criminal record) and factors of production between countries. All countries eliminated custom duties and implemented a common external tariff.

One of the many ways this treaty has been successful has been through trade in its agricultural commodities. This is important because agriculture is a key component of all MERCOSUR economies. It accounts for more than 10% of GDP in all countries, and is growing rapidly. Moreover, Argentina and Brazil are major players in global agricultural production, both for crops and animal products. For example, MERCOSUR supplies the world with 8% of its maize and more than 40% of world soy bean world production (Stratfor 2016).

In 1999, the EU and MERCOSUR entered into an inter-regional framework cooperation agreement. This is a bilateral agreement which deals with trade-related matters and has allowed MERCOSUR access to EU markets (EC 2007). Since then agricultural exports to the EU have increased with food and agricultural commodities alone representing over half over its exports to the EU. MERCOSUR is one of the main suppliers of food products to the EU. For example, in 2016 the region's largest exports were agricultural products including foodstuffs, beverages and tobacco (24%), vegetable products including soy and coffee (18%), and meat and other animal products (24%). By way of contrast, EU agricultural exports to MERCOSUR only account for 3% of EU exports (EC 2018).

Though MERCOSUR has aspirations beyond trade, it has primarily only functioned as a unified trading bloc up to the present time. It can be inferred that this regional agreement has helped to facilitate the transformation of Uruguay's agricultural sector in the last two decades. In particular, as Uruguay and Argentina are both members, their close regional proximity and tariff-free trade must have had a major role in transforming Uruguay's agricultural sector through easy facilitation of external finance and technologies focussed on soy production and exports through early catalysts from Argentina.

5.4 Summary

This chapter has given an overview of the significant soy boom model outputs from Chapter 4. It has given a brief overview of how these events have increased soy production in Uruguay. The focus of this discussion has been on economic situations which have been influential in driving the soy market since 1961, but particularly since the early 1990s.

The chapter has also analysed the way in which the transition of arable agriculture to a soy-dominated cropping system in Uruguay systems has been driven by multiple phenomena: Such as the increase in global demand for soy; the development of free trade agreements; the decline in sunflower production; and the regional economic situation, in particular Argentina's flight of capital into Uruguay.

6 REPONSES IN AGRICULTURAL SYSTEMS AND THE SOY SUPPLY-CHAIN IN URUGUAY

6.1 Introduction

In the preceding chapter, the fact that Uruguay witnessed significant changes in agricultural production systems in over a decade around the late 1990's and early 2000's was analysed (Section 5.3). The inputs necessary for commercially-competitive soy cultivation and its sale on the global market required intensification of cropping systems, the establishment of almost entirely new internal supply-chain infrastructure, and the establishment of international market contracts to facilitate its export. The net result was that Uruguay radically adjusted the arable crop production as part of its agricultural sector, and significant investments have been made in the Uruguay link of the global soy supply-chain. Not surprisingly, these changes were felt most in the Litoral departments. This chapter analyses these impacts in Uruguay's soy boom era. Section 6.2 introduces the global soy supply-chain, and analyses the evolution of the Uruguay arm of the soy supply-chain in discussed in Section 6.3. Particular emphasis is placed on new cropping practices, links between farms and ports, the development of port infrastructure and exports (Section 6.4 respectively). The roles of local, regional and global companies in the evolution of the supply-chain in response to the soy boom are discussed in Section 6.5

6.2 The global soy supply-chain

Globally traded soy is one of the most versatile oilseeds. It is traded as whole soybeans, soy meal and oil. It is also one of the world's most important sources of animal feed, e.g., soy meal accounts for 75% of all protein used in compounded livestock rations worldwide (FAOSTAT 2016) and it is the second largest vegetable oil in terms of traded volume Figure 6-1.

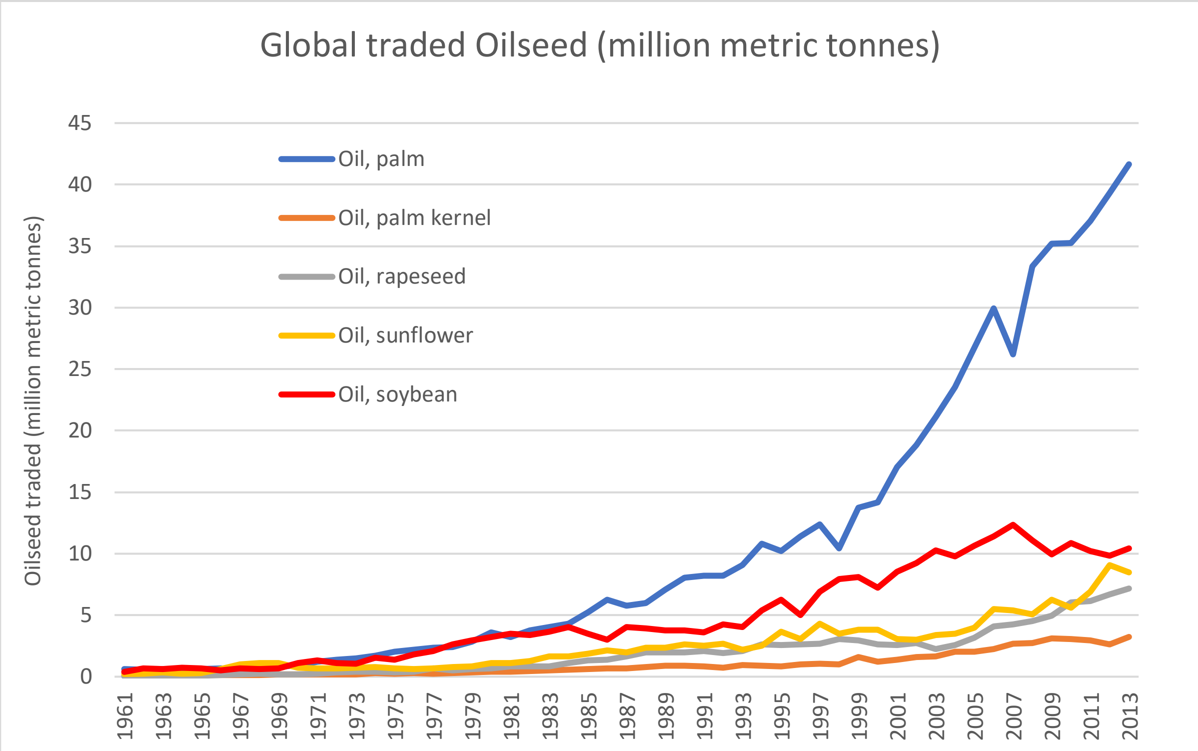

Figure 6-1 Global traded oilseed 1961-2013. Source: (FAOSTAT, 2016)

Local logistics of distribution around the world varies geographically, but more broadly the supply-chain from farm to consumer is summed up in five main stages: production, transportation, processing, trade and consumption (Figure 6-2). In the production stage almost, all soy is now grown on very large, highly mechanised farms. Soy is then transported locally, regionally or globally from sites of production to site of processing. The most common forms of transportation are by road, train or ship. These two stages of the soy supply-chain starting in Uruguay are analysed in detail in this section.

Although soy is primarily used for animal feed it has many other uses which means its processing stages are quite variable. These include processing for biodiesel, and used in the food industry as a vegetable oil used in margarines and shortenings. Lecithin, a processing by-product and a natural emulsifier, is also a common additive in processed foods, for example in chocolate bars, as well as being used in personal care products like soaps and cream. Almost regardless of the end product, soy is crushed and turned into soy meal at some stage in the processing stage. From the crushed soy both soy meal and soy oil are derived. Some countries process soy and then export oil or meal. However, not all exporting countries unhull their beans and process before shipping, some simply export the soybean in its entirety. Uruguay exports beans to be processed elsewhere.

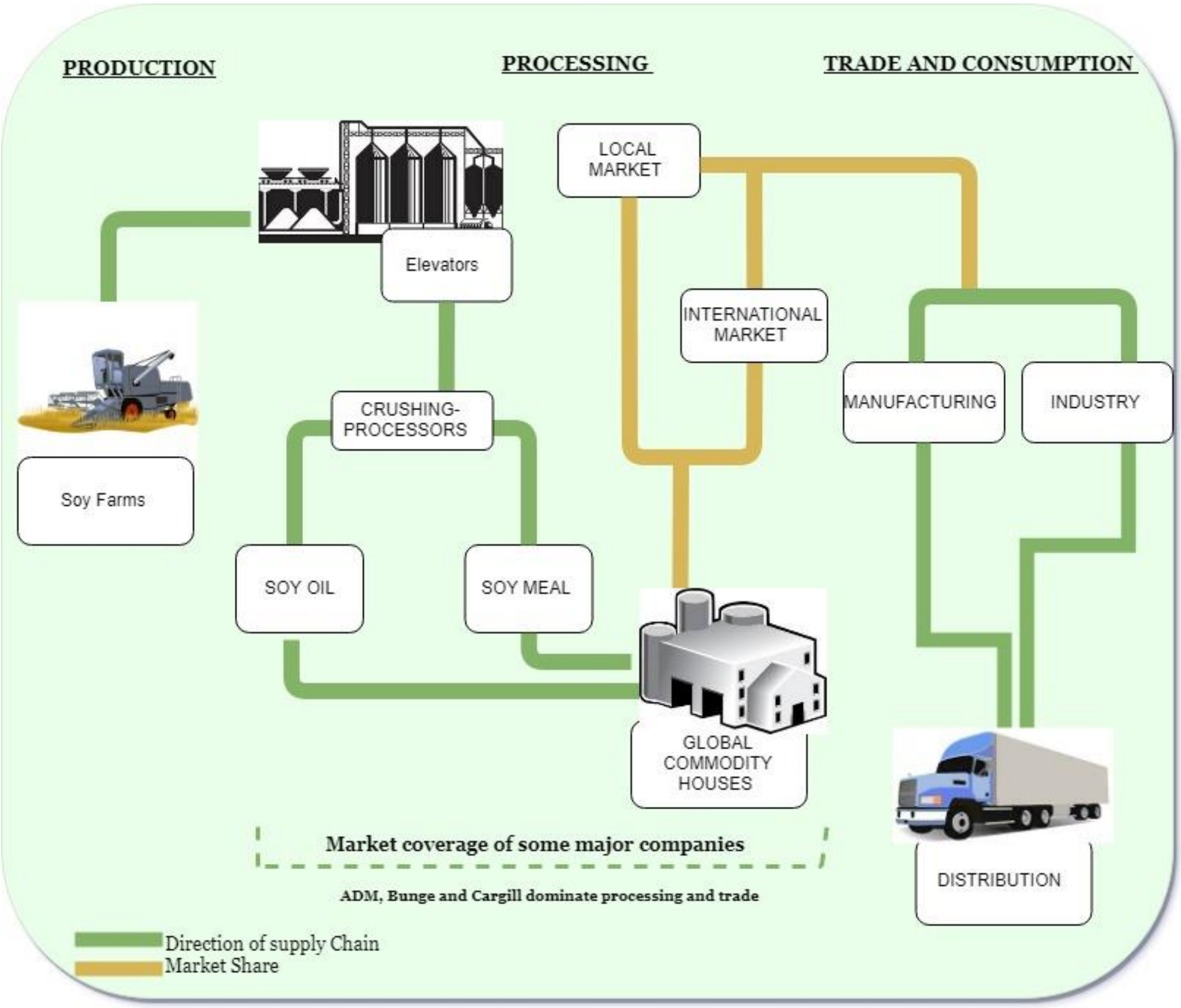

Figure 6-2 Generalised soy supply-chain. Adapted from Sustainable Smart Business (2016).

6.3 Evolution of the soy supply-chain in Uruguay

When there is an increase in the production of any commodity, various aspects of its distribution have to adjust to cope with increased volumes or different forms of product, e.g. fresh versus processed. When a new commodity is produced or global demand changes, these adjustments are more radical. In either case, the entire supply-chain has to meet the changes in order to produce and distribute the product efficiently and economically. In the case of soy, that starts with changes in cultivation practices on farms through to the distribution infrastructure within a region or country. In addition, there may be changes in the importing countries and in the modes of transportation. The adjustments that Uruguay had to make in order to become a major global soy producer and exporter were mainly internal, i.e., on farms, and between farms and the exporting ports. This was because the country was more-or-less only adding another link in an already well-established global supply-chain. The supply-chain in Uruguay has actors, elements of infrastructure, and processes. These are outlined below.

6.3.1 Actors

In Uruguay, the main actors in the soy supply-chain are:

a. Producers: The producers in this context of this research are not necessarily the farmers who grow the crop. Often, they belong to producer associations, that comprise a network of regional associations who carry out group negotiations for the acquisitions of inputs, and the individual harvests are consolidated and marketed through these associations.

b. Merchants (*acopidaroes*) and fertilizer distributors: These are commercial (for-profit) organisations that deal with conditioning (drying, sieving, disinfecting beans), classification, storage and dispatch of harvested produce. They deal directly with producers and producer associations, and provide them with agricultural inputs (i.e., seed, agrochemicals, fertilisers) and offer technical assistance through agricultural professionals they employ. In many cases in Uruguay, the *acopiadores* are involved in transport of soy from farm to port, through parallel enterprises. The *acopiadores* are in effect intermediaries who buy soy from famers (a, above) and *pools de siembra* (d, below) and sell it to larger companies, both national and international (e, below), who have the capacity to export it. Their role is commercial in nature, where they utilise the corresponding silos for a certain volume in order to realise their business goal of exporting a specified amount. Also associated with this step in the supply-chain these businesses use the sale of agricultural inputs to growers as a form of producer financing. Some companies selling inputs, especially fertilisers, such as ISUSA or MACCIO also act as *empresas acopiadores.* These companies take the soy as a guarantee and later as payment of the inputs. The company then transfers the inputs, and the producer commits to sell to that supplier. This is done through a form of contract known as an 'advance sale transaction'.

c. Cooperatives: These are non-profit associations of individual producers whose aim is to market their individual production as part of the cooperative. Being part of a cooperative enables farmers to undertake operations that would not be viable at the level of an individual producer through economies of scale. Their objectives and the services they offer do not differ significantly from those of *acopiadores*, and that includes transportation to ports.

d. *Pools de siembra* (sowing pools): This term arose consistently in interviews to describe an association of investors. *Pools de siembra* are speculative investment funds that combine investors with a management team that rents land, labour, and machinery so that production can take place at the large scale required to produce soy at a competitive price, again economies of scale come into play. Quite often they include stock investment in the commodity market. Pools vary in size. Some only control a few hundred hectares, while others control thousands. As a result that latter have become powerful actors in the technological innovation space (Bustamante & Maldonado 2009). Larger pools contract landholdings to third parties across different parts of the country and grow a mix of crops in order to have a geographical and economic diversification and reduce the risks associated with price and climate fluctuations. As noted above, these actors developed rapidly at the beginning of the soy boom in Uruguay after 2002 based on a similar model in Argentina.

e. Multinational companies: These companies are often dedicated to the trade and production of commodities and food. Large multinational companies (i.e. Cargill) often work alongside national based companies (Crop Uruguay) whose role is dedicated to the organisation of grains across Uruguay (seed inputs, cultivation, fertilisers etc). The affiliation a national company has with a multinational company is a mutually beneficial one. The national company establishes the crop and finances it through farming contracts but once that is complete, it then shifts the foreign trade activity into the large multinationals to obtain an external linkage. Multinational companies have this competitive advantage against smaller local companies, through the scale of their operations, business model, presence throughout the chain (both in Uruguay and elsewhere), and headquarters outside Uruguay.

6.3.2 Elements of infrastructure and processes

The steps in the soy supply-chain for Uruguay related to infrastructure are outlined below and illustrated in Figure 6-3. These include both elements of infrastructure, i.e. modes of transport and storage, and processes.

I. Soy cultivation and harvest on farm.

II. Transport via truck from farm to one of the following ports: Nueva Palmira, Paysandú, Fray Bentos, Montevideo (See Figure 6-4)

III. Storage of grain in a silo at the port terminal. Soy is not stored in silos in the interior of the country because it needs to be exported as beans in as fresh a state as possible. Interior silos are used for wheat and barley, and possibly for maize and sorghum.

IV. If the soy has been transported to a port on the Rio Uruguay, i.e., Fray Bentos or Paysandú, it is then transported down river by small ocean-going vessel or barge, to Nueva Palmira.

V. Soy is processing (i.e., cleaned, sampled and tested) in the silo at the port terminal. Fees and other charges related to the stage of land logistics are levied.

VI. Consolidation of shipment for export.

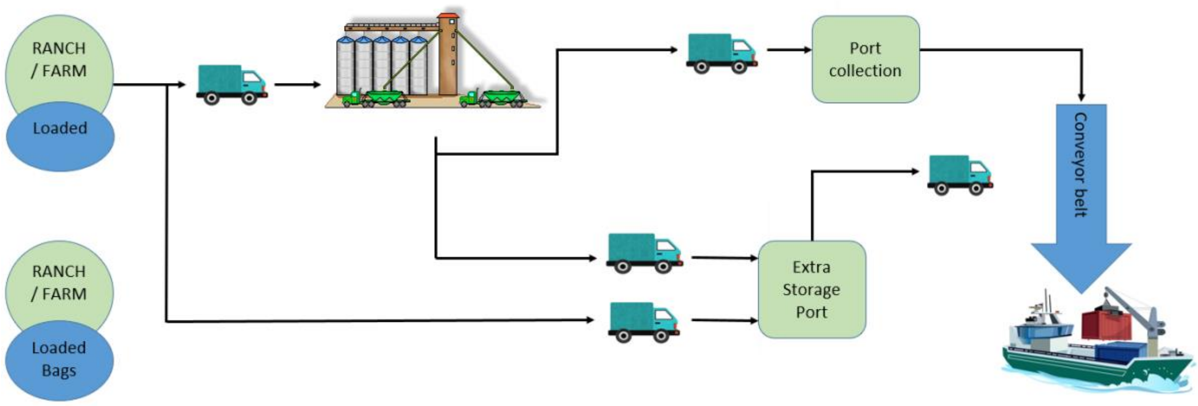

Figure 6-3Elements of infrastructure in the soy supply-chain in Uruguay. Source (CAF 2011 and interviews, 2016)

6.3.3 Cropping practices

Part of the contract between producers and either multinational and or Uruguayan companies is for the latter to provide technical advice to farmers based on surveys of their fields and analyses of their soils. This type of activity was mentioned in a number of interviews, and in addition, with staff from Garmet—an Argentinian *barraca*–the researcher was able to visit a number of farms in the vicinity of Mercedes (Soriano Department). Garmet staff stressed two things. The first was the four- to six-year nature of crop rotations in the soy-growing areas of Uruguay which include winter and summer crops; crops grown for bean and grain production (soy, maize, sorghum, wheat, barley and canola) and crops grown as green crops (soy, maize, sorghum), cover crops and fallow periods (Table 6-1).

Table 6-1 Four crop rotations used in western Soriano Department under contract to Garmet. Source: Garmet Mercedes Office, original in Spanish.

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
	Winter	**Spring**	**Winter**	**Spring**	**Winter**	**Spring**	**Winter**	**Spring**	**Winter**	**Spring**	**Winter**	**Spring**
5-year rotation I	Fallow	Soy	Canola	Soy green crop*	Wheat or Barley	Soy green crop	Cover crop	Soy	Wheat or Barley	Maize or Sorghum green crop		
5-year rotation II	Cover crop	Soy	Wheat or Barley	Maize or Sorghum green crop	Fallow	Soy	Cover crop	Soy	Wheat or Barley	Soy green crop		
6-year rotation I	Cover crop	Soy	Wheat or Barley	Maize or Sorghum green crop	Fallow	Soy	Wheat or Barley	Maize or Sorghum green crop	Fallow	Soy	Wheat or Barley	Soy green crop
6-year rotation II	Wheat or Barley	Soy green crop	Cover crop	Soy	Wheat or Barley	Maize or Sorghum green crop	Fallow	Soy	Canola	Soy green crop	Cover crop	Soy

*Green crop refers to a crop that will either be ploughed back into the soil as a green manure or grazed by cattle.

Table 6.1 shows two five-year and two six-year rotations used by Garmet on farms in the vicinity of Mercedes. In each of the rotations pairs of winter and summer seasons in which bean or grain crops are produced are interspersed with either a winter or summer fallow or green crop. For example, in five-year rotation I, fields planted to soy from which beans are harvested (known as *Soja de Primera*) in spring of Year 1 and winter canola in Year 2 are preceded by a fallow in which no crop is grown (*barbecho* in Spanish) and followed by a green soy crop (known locally as *Soja de Segunda).* Another example, from a six-year rotation, a cover crop is followed by *Soja de Primera* and either winter wheat or barley, after which a maize or sorghum green crop is grown in the first two years. A further point that is noteworthy from this rotation is that although soy dominates the agricultural system in this part of Uruguay, it is actually only a small part of each rotation. While it is grown in four of the five spring seasons in the two five-year rotations, it is only harvested as an export crop on two of these years, i.e. 40% of the time). In the two six-year rotations it is grown as an export crop in three years. This means that while soy could be found growing in spring in approximately 80% of fields under contract to Garmet in this part of Uruguay, approximately only half of these fields are producing an export crop. This can be compared to the winter situation. In the five-year rotations, a crop that can be harvested as a grain or oilseed (wheat, barely or canola) is grown in three of five years, while in the six-year rotations winter seasons with wheat, barley or canola alternate with fallow or a cover crop. Taking all four rotations into account, between 40-50% of the time land has either a cover crop, a green crop or is in fallow in any rotation,

The seasons when these fields are not cropped contribute to the agricultural system in the following ways:

a. Cattle were noted grazing on cover and green crops in a number of fields in the land-use survey (Section 7-5). This contributes to soil fertility by cattle manuring the fields during grazing. In addition, the interplay between cattle rearing and cropping has always been integral to the farming systems in this part of Uruguay (Section 7.5.3)

b. Green crops (soy, maize and sorghum) can be ploughed into the soil as green manure if they are not grazed.

c. Simply resting fields through fallowing allows recovery of soil health before the next crop is planted.

The Mercedes Office of Garmet also provided the following (Table 6-2) in association with the information on rotations

Table 6-2 Proportions of different crops (%) over a seven-year period covering the four rotations in Table 6.3. are applied to a group of farms of cultivated land. Source: Garmet Mercedes Office, original in Spanish

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Wheat and barley	29	32	27	36	41	38	41
Canola	16	6	8	10	8	10	10
Winter (all crops)	45	38	35	46	41	48	51
Soja (*Primera*)	50	66	71	59	63	67	67
Soja (*Segunda)*	27	5	6	12	10	2	2
Sorghum	6	10	12	6	4	5	7
Maize	17	20	11	23	23	26	24
Spring (all crops)	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 6.2 highlights a large difference between winter and spring crops. In spring, all cultivated land is cropped, although as noted above only that under *Soja de Primera* is harvested for soy beans for export. By way of contrast, in winter only 38-51% of the fields are cropped, the rest are cover crops or are in fallow. A key observation can be made from Table 6-2. The amount of soy that is exported from the farms under Garmet contracts in western Soriano, which is located in the most important soy producing region (*cf.* Figure 7-3 soy pie chart map) will vary considerably between years—ranging from 50% of fields in Year 1 to 71% in Year 2. Given the likelihood that yields will vary little across

these farms, this represents a significant fluctuation in export revenues earned by Garmet and onwards to farmers. As there is no evidence of fluctuations of this magnitude in soy exports, it must be assumed that when all fields under contract to all cooperatives, barracas, and multinational companies are combined, these fluctuations are evened out.

It is not entirely clear who decides on the actual crop rotation that will be used in a particular field. But it appears from discussions with Garmet staff and from interviews with producers and other agribusinesses, that it is mainly companies and cooperatives that a farmer is 'contracted' to who advise on crop rotations. This is because the companies and cooperative provide what is, in effect, an agricultural extension service that in decades past would have been a government function. As they also sell seed and agrochemicals to farmers, supplying advice on rotation is simply makes good business sense that assures sales, particularly of new GMO varieties of soy, which they advertise on the field fences along roads.

6.4 Supplying soy to ports

Soy is grown across the Litoral because of the soil characteristics and adequate rainfall (though as will be shown in Figure 7-3 there appears to be a core zone within the Litoral). But whilst western Uruguay has a strong natural asset base, the level of technological development to expand the internal part of a modern global supply-chain was lagging in the 1990s before the soy boom. Uruguay had relied on rail transport since the 1860s, with the railway system being used for both freight and local and inter-provincial transport. But by the 1970s and 1980's lack of investment meant the railway network was is a bad state. Passenger services, for example, ceased in 1988 and even lines used for freight in eastern Uruguay had generally been abandoned. As a consequence, Uruguay is poorly served by rail lines (AFE 2017). Only two lines pass through eastern Uruguay; the Tramo Piedra Soles to Fray Bentos line which passes through Young; and Linea Minas between Salto and Chamberlin, which serves Paysandú. There are no lines serving Soriano or Colonia Departments, and the main soy exporting port of Nueva Palmira is not rail served (Section 6.4.1). Investments in rail infrastructure would have been too great in the early 2000's to make it an important element in the soy supply-chain.

In the absence of an adequate existing rail network, and no investment in the railway sector, the decade of soy expansion in Uruguay resulted in the development of an entirely new supply-chain network to facilitate the distribution of soy from farms to the ports on the Rio Uruguay, most notably Nueva Palmira. This involved:

a. upgrading of main roads in eastern Uruguay;
b. installing banks of grain silos in the countryside (though according to interviews these are mainly for winter crops, in particular wheat);
c. the construction of branches of multinational grain corporations and their Uruguayan equivalents, *barracas*, who have contracts with farmers to sell seed, agrochemicals and machinery, and buy their harvest; and sell them for exporting.

As noted earlier, the soy supply-chain in Uruguay has a diversity of actors all of whom interact within this commercial network, i.e., collectors, input sales companies, *acopiadores*, local companies and multinational companies. They (middle men) interact at the phase of origin.

6.4.1 Port infrastructure developments

The port infrastructure of Uruguay has always been vital to the agricultural sector as ports along the Río Uruguay and in the River Plate Estuary have exported meat and meat products since the 1800s. The ports on the Río Uruguay—Salto, Paysandú, Concepcion del Uruguay and Fray Bentos–are limited by the small draught of the ocean-going vessels that can reach them, whilst those on the River Plate Estuary do not have these limitations. The most important port in terms of volume of overall trade is Montevideo. However, more importantly strategically and particularly in terms of the soy supply-chain is Nueva Palmira. It is strategically located in the Department of Colonia at the mouths of the Ríos

Uruguay and Parana, and therefore it is located at the southern end of the Hidrovía Parana-Paraguay– a river system that extends deep into the heart of South America and serves northern Argentina, south-central Brazil and the land-locked nations of Bolivia and Paraguay. It is also connected to the River Plate by the Martín García Canal, which has recently been dredged to a depth of 32m (Presidencia 2016).

It was founded as Puerto Higeulias in the 19th Century as a port on the Río Uruguay but investments to upgrade its facilities were boosted by the need to export soy from Uruguay. These investments which started in the early 2000's continue to the present day (Marca 2016; Presidencia 2016; MTOP 2017). It is a free port which has grain handling facilities, including transhipment facilities for barges that export soy and other products from Bolivia, Brazil and Paraguay along the Hidrovía Parana-Paraguay, a refrigerated terminal and a national wharf. It can handle Handy, Handymax, Panamax, Postpanamax and Capesize[13] vessels of up to 32-35 feet draft and is administered by the National Ports Administration of Uruguay (ANP). Some of the largest investments in infrastructure have been made by the Terminales Graneleras Uruguayas SA (TGU) consortium, which also has operations at Fray Bentos and Montevideo (TGU 2017). It owns grain storage silos, facilities for truck loading and loading onto ships, for infrastructure for the transhipment of grains from river vessels (ships and barges) to ocean-going ships. In April 2017 TGU opened new loading-unloading and loading facilities, a second barge unloading facility to aid transhipment, and three new 10,000 MT vertical silos at a cost of USD 25 million. These investments increased storage capacity by 44% to 98,000 MT (60% of this capacity is temperature controlled, which is vital for the export of fresh soybean). Ship loading speeds increased by 75% to 1,400 MT/hour, truck unloading speeds increased by 61.5% to 1,050 MT/hour, barge unloading increased by 250% to 2,100 MT/hour, and direct trans-shipment rates increased by

[13] These are names given to cargo ships or vessels. They come in different size to meet different demands of marine cargo transportation. For example the Handymax and Handysize are smaller cargo ships. As the name suggests, Panamax are ships travelling through the Panama Canal and PostPanamax are those ships created a results of the expanding canal. Further information can be found at (Maritime Connector 2017).

150% to 1,500 MT/hour (Marca Pais, 2016). TGU was specifically established to provide services to companies engaged in the international grain trade and streamline the maritime shipping component of grain agro-industrial supply-chains. The company started operations at Port of Nueva Palmira, when the Parana-Paraguay Waterway was opened, as a transit and transfer station equipped with storage silos (TGU 2017). This was a highly successful business decision by the Government of Uruguay as 70 percent of soy coming from Paraguay and Bolivia along the Hidrovía is shipped through Nueva Palmira. The great majority of the remaining 30% are shipped through the Port of Rosario in Argentina (El Eco Digital 2017).

The National Institute of Logistics (Inalog) reported that in the first eight months of 2017 the tonnage of shipments from Nueva Palmira had increased 3% compared to the same period in 2016, and that soy had increased by 1%. In late 2017 a new investment of USD15 million was announced by the government (MTOP) to increase capacity at Nueva Palmira, by extending the overseas wharf and building another dock for river barges and diversifying into the export of iron ore from Brazil and Bolivia through the Hidrovía Paraná-Paraguay. Total government investment in the last decade has exceeded USD 250 million.

It is not only the movement of soy through Nueva Palmira that has facilitated its growth. Another key exports are wheat, barley and canola from the Litoral; cellulose pulp from the forestry industry in Río Negro Department, which is transshipped after being exported through Fray Bentos; citrus and sugar (Uruguay XXI 2016).

TGU has similar facilities, although on a smaller scale, at Fray Bentos on the Río Uruguay. It has 20,000MT of storage, a capacity of 6,000 MT/day, and vessels with a draught at 17 feet which allows Panamax vessels of up to 12000 MT to use the port. The amounts of grain shipped through the two ports between 2011 and 2015 are provided in Table 6-3.

Table 6-3 Grain shipments through Fray Bentos and Nueva Palmira, 2011-2015. Source: (Repremar Shipping Services 2011).

Year	Shipped through Fray Bentos (MT)	Shipped through Nueva Palmira (MT)
2011	92,000	1,616,000
2012	79,000	1,720,000
2013	151,000	2,256,000
2014	65,500	1,608,000
2015	44,000	1,799,000

The main ports handling soy are Paysandú, Fray Bentos and Nueva Palmira. Though all of these ports are free trading zones (FTZ), the FTZ status of Nueva Palmira is an important one because it is used as a primary port for soy exports, and intermediate location where transhipment of soy exported from Paysandú and Fray Bentos (discussed later in the chapter) occurs within the Uruguay link of the soy supply-chain. This is in addition to transhipment of soy from Bolivia and Paraguay from ports along the Hidrovía Paraná-Paraguay waterway (Uruguay XXI 2016).

6.4.2 Hidrovía

Nueva Palmira is one of the largest ports in Uruguay and serves as a segue for many commodities making their way down from Paraná-Paraguay Inland Waterway (La Hidrovía Paraná-Paraguay) which was first established in the 16th century.

This water system is one of the largest navigable systems in the world and serves as an important continental axis of political, social and economic integration; an economic transport system for Argentina, Bolivia, Brazil, Paraguay and Uruguay (Bolivia and Paraguay, two of which are land locked (see Figure 6-4).The water system begins at the northern end of Puerto de Cáceres in the state of Mato Grosso (Brazil), on the river Paraguay and ends at the Port of Nueva Palmira and flows into the sea through Río de la Plata which serves as the major artery of fluvial communication transport efficiency. Export bulk commodities flow through the Hidrovía.

The waterway serves mainly as a central export and import conduit for land locked countries. Upstream landlocked Bolivia exports bulk commodities through the waterway, Brazil uses the Hidrovía as a north-south alternative route for ore such as iron and manganese and oilseed exports generated in the regions close to the Paraguayan River. Argentina uses the river for several purposes including; (i) to move domestic dry bulk from the northern regions to the transfer area; (ii) to receive freight from upstream countries for processing in its manufacturing plants (soy, iron ore); (iii) to transfer freight to ocean-going vessels; and (iv) to facilitate Paraguayan fuel and Bolivian imports such as fuel and wheat. Uruguay receives freight in dry bulk containers from upstream countries and transfers them it ocean-going vessels in its ports and vice versa. Its dry bulk goods are mainly made up of soy and its by-products (soy pellets and meal resulting from vegetable oil production) followed by other grains, iron ore and other goods. For example, between 2010 and 2015 there was a 40% growth in total shipping volume. This growth was primarily based on the increase in the transport of soybeans and its by-products as well as other grains.

Figure 6-4 The Hidrovía Paraná Paraguay with main ports in red. Soy from southern Brazil is shipped through Caceres, Corumba and Iguazu (Río Paraguay), Bolivian soy through Corumba, Paraguayan soy through Asuncion, and soy from Argentina through Santa Fe, Rosario

6.4.3 Exports

Obtaining detailed information in soy exports from Uruguay was difficult due to data accuracy and sparsity. Two sources, and confidential data on soy export contracts from Uruguay for 2015 supplied by Javier Godar, were used. These data have been aggregated and their respective percentages calculated to find the proportion of total exports by destination and proportion of total export contribution by company.

Table 6-4 and Table 6-5 show export companies' values exported to regions or countries of interest (Chine, Asia*, Holland, Germany, Africa**, Spain, Canada and USA). Table 6-4 lists and highlights the percentage contribution of an exporter to an entire region/country's exports. Larger percentages are highlighted in a deep green. Total exports to each region or country are again highlighted. Nueva Palmira amounts are excluded for reasons explained below. Table 6-5 lists the same values as Table 6-4 but highlights the contribution of a region as a percentage of a company's total value of exports. For example, Table 6-4 should read down the page. The major company exporting to China is Cereoil Uruguay SA, and Barraca Erro is the largest exporter to the Asia region. The percentages in any column will sum to 100%. Table 6-5 is read left to right. Using Barraca Erro as an example, the company exports ~55% to Nueva Palmira and ~27% to China; all Barraca Erro exports will sum to 100%.

6.4.4 Exports by regions or countries (Green Table)

Total exports to Nueva Palmira (NP) were $1.58 Billion USD followed by $608.9 million USD to China with other destinations each having exports less than $80 million USD. Combined exports to major countries and regions totalled $850 million USD, with a remaining $729 million USD unaccounted. The largest export destination is Nueva Palmira; however, when exports to NP are excluded, exports to China made up 72% of the total traffic out of Uruguay. Germany (9%), Holland (6%), and Asia (5%) make up the next largest export destinations respectively.

The largest exporter to Nueva Palmira was Crop Uruguay (28.4%), followed by LDC Uruguay (18.7%) and Barraca Erro (11.2%). Chinese exports are shared amongst four main players, Cereoil Uruguay (24.0%), LDC Uruguay (16.0 %), Barraca Erro (14.2%), and Crop Uruguay (9.7%). However, Barraca Erro (50.8%) is the dominant exporter to Germany with over half the value to that country.

NP is listed as an export destination, the reason for this is because it is considered an accounting destination. NP can also be used as a storage destination for soy or other commodities travelling down the waterway from Bolivia, Brazil and Paraguay. This would make sense considering that NP is a Zona Franca (Free Zone), which is a special commercial port that permits the duty-free entry of foreign goods intended for storage and re-exports. In the case of NP, it is a free trade zone which provides access to many commercial vessels travelling down the Hidrovía. Once soy arrives at NP it is often stored and aggregated for bulk international shipping. Therefore, NP provides Uruguayan and other Paraná-Paraguay Waterway companies with an internal transfer destination hub.

6.4.5 Exports by company (Red Table)

A total of 43 exporters do business with the countries' regions of interest, with 19 exclusively supplying a single region or country. A majority of exporters export to NP and China (24 supply each), though exporters become more selective when smaller export markets are considered. Eleven exporters have business with Asia, ten with Africa, eight each with Holland and Germany, five with the USA, two with Spain and one with Canada. The largest exporters contribute to 64% of total exports: Crop Uruguay (22.2%), LDC Uruguay (16.2%), Barraca Erro (13.3%), Garmet (6.5%), Cereoil Uruguay (6.3%).

Excluding exports to NP, the largest suppliers are Cereoil Uruguay (17.5%), Barraca Erro (17.2%), LDC Uruguay (11.6%) and Crop Uruguay (10.9%). This supports the argument that exports to NP from companies may be largely representing internal and regional movements including those from Bolivia, Paraguay, Brazil and Argentina. What is of particular interest is that exports to NP are greater than the combined exports to other regions and this supports the premise that NP is an accounting port to the rest of the world. Table 6-5 shows that although Crop Uruguay's main destination is NP (83% exports to NP), it is not a major exporter to the rest of the world supplying smaller proportions of their total value, i.e. China (10.9%), Holland (3.3%), and Spain (2.6%). Garmet is another company where the majority value of their exports go to NP (74.9%), with the rest to China (25.1%).

Table 6-4 – Exports by Region or Country. Table displays the monetary value of exports (USD) and the destination as well as the percentage that monetary sum makes to the total exported value to that destination. Green highlighting Is used in each column to draw attention to major contributors to a country or regions (larger percentage contributions values are highlighted more strongly)

	Nueva Palmira		China		Asia*		Holland		Germany		Africa**		Spain		Canada		USA		Total
	USD	%	USD	%	USD	%	USD	%	USD	%	USD	%	USD	%	USD	%	USD	%	USD
ADM URUGUAY SOC EN COMANDITA POR ACCIONES	19.8	1.3%	13.8	2.3%	5.8	12.7%			8.5	11.2%	1.3	4.4%							49.3
ADP S A	57.7	3.7%																	57.7
AGRO ACOPIO FERTIL S A			2.0	0.3%															2.0
AGROPICK S A					0.2	0.5%													0.2
AGROTERRA S A	3.5	0.2%	0.7	0.1%															4.2
ALPINO LTDA	22.3	1.4%																	22.3
BARRACA JORGE W ERRO S A	177.3	11.2%	86.4	14.2%	10.7	23.6%	7.3	15%	38.6	50.8%							1.4	9.3%	321.7
BONISTAR S A	3.5	0.2%	4.8	0.8%															8.2
BUNGE URUGUAY AGRONEGOCIOS S A	7.0	0.4%																	7.0
CALOSUR INDUSTRIAL S A															7.0	100%	0.1	0.8%	7.2
CAMINAGRO SOCIEDAD ANONIMA	3.9	0.2%	5.1	0.8%			2.3	5%			2.0	6.5%							13.3
CEREOIL URUGUAY S A	6.9	0.4%	146.2	24.0%	0.7	1.6%													153.9
CHARBONNIER AUDI GONZALO ABEL									2.1	2.7%									2.1
CHS URUGUAY S R L	36.4	2.3%	2.1	0.3%			5.0	10%											43.4

COMPANIA OLEAGINOSA URUGUAYA S A INDL					2.1	4.7%													2.1
COOP AGRARIA NAL DE R L	70.8	4.5%	10.2	1.7%															81.0
COSECHAS DE URUGUAY S A	13.3	0.8%																	13.3
CROP URUGUAY S A	447.5	28.4%	58.9	9.7%			18.0	37%			0.5	1.6%	14.0	90%					538.9
ESTANCIA LOS MOLLES S A	7.4	0.5%																	7.4
ESTERO S A											0.0	0.0%							0.0
EVERA S A C	17.9	1.1%	34.6	5.7%															52.5
FADISOL S A	59.3	3.8%	14.5	2.4%															73.8
GANADERA SUR S R L					1.0	2.3%													1.0
GARMET S A	117.6	7.5%	39.3	6.5%															156.9
GLENCORE S A			18.2	3.0%			10.0	20%	10.1	13.3%									38.2
GLORIA ISABEL ELGUERA ESPINOZA									0.4	0.6%									0.4
GRAMONT VAZQUEZ ALBERTO JOSE			1.1	0.2%															1.1
GRANICOR S A	18.9	1.2%	3.1	0.5%			4.1	8%	2.4	3.2%	6.3	21.0%							34.7
HINKELY S A																	7.2	47.0%	7.2
JONURY S A			15.6	2.6%					3.2	4.3%									18.8
KILAFEN S A	94.0	6.0%			1.7	3.8%					3.6	12.0%							99.3
LDC URUGUAY S A	294.3	18.7%	97.1	16.0%							0.2	0.7%							391.7
MIZEPLEN S A	0.6	0.0%																	0.6
MOLIMED S A													1.5	10%					1.5

NIDERA URUGUAYA S A	41.7	2.6%	12.6	2.1%	2.0	4.3%	0.7	1%			4.3	14.4%							61.3
PEGRANT URUGUAY S A			1.4	0.2%	4.6	10.2%													6.1
PLASKER S A									10.6	14.0%									10.6
PRADENOR SOCIEDAD ANONIMA	4.1	0.3%	5.0	0.8%															9.1
REYLAN S A																	6.4	41.6%	6.4
ROCALMAR S A	50.9	3.2%	20.0	3.3%			1.6	3%			5.9	19.5%							78.3
SCOULAR URUGUAY S A			3.2	0.5%	2.9	6.5%													6.1
SEMILLAS DEL SUR S A																	0.2	1.3%	0.2
TGL URUGUAY S A			13.0	2.1%	13.6	29.8%					5.9	19.8%							32.5
	1576.6	100%	608.9	100%	45.4	100%	48.9	100%	75.9	100%	30.0	100%	15.5	100%	7.0	100%	15.4	100%	2423.7

* Asia includes, Bangladesh, India, Indonesia, Japan, Malaysia, Myanmar, Singapore, Taiwan, Thailand, and Vietnam. Excludes China.

**Africa includes Egypt South Africa, Angola, Mauritania and Oman (Oman is in the Southern coast of the Arabian Peninsula in the Middle East. It is the only country from the Middle East with very small quantities. As a result, it has been included in the African variable)

Table 6-5 – Exports by Region or Country. Table displays the monetary value of exports (USD) and the destination as well as the percentage that monetary sum makes to the total exported value by the exporter destination. Red highlighting Is used in each row to draw attention to major destinations for each exporter (larger percentage contributions values are highlighted more strongly)

	Nueva Palmira		**China**		**Asia***		**Holland**		**Germany**		**Africa****		**Spain**		**Canada**		**USA**		**Total Export**
	USD	**%**	**USD**	**%**	**USD**	**%**	**USD**	**%**	**USD**	**%**	**USD**	**%**	**USD**	**%**	**USD**	**%**	**USD**	**%**	**USD**
ADM URUGUAY SOC EN COMANDITA POR ACCIONES	19.8	40.2%	13.8	28.1%	5.8	11.7%			8.5	17.3%	1.3	2.7%							49.3
ADP S A	57.7	100.0%																	57.7
AGRO ACOPIO FERTIL S A			2.0	100.0%															2.0
AGROPICK S A					0.2	100.0%													0.2
AGROTERRA S A	3.5	83.8%	0.7	16.2%															4.2
ALPINO LTDA	22.3	100.0%																	22.3
BARRACA JORGE W ERRO S A	177.3	55.1%	86.4	26.9%	10.7	3.3%	7.3	2.3%	38.6	12.0%							1.4	0.4%	321.7
BONISTAR S A	3.5	42.1%	4.8	57.9%															8.2
BUNGE URUGUAY AGRONEGOCIOS S A	7.0	100.0%																	7.0
CALOSUR INDUSTRIAL S A															7.0	98.3%	0.1	1.7%	7.2
CAMINAGRO SOCIEDAD ANONIMA	3.9	29.3%	5.1	38.5%			2.3	17.5%			2.0	14.6%							13.3
CEREOIL URUGUAY S A	6.9	4.5%	146.2	95.0%	0.7	0.5%													153.9
CHARBONNIER AUDI GONZALO ABEL									2.1	100.0%									2.1

CHS URUGUAY S R L	36.4	83.7%	2.1	4.9%			5.0	11.4%											43.4
COMPANIA OLEAGINOSA URUGUAYA S A INDL					2.1	100.0%													2.1
COOP AGRARIA NAL DE R L	70.8	87.4%	10.2	12.6%															81.0
COSECHAS DE URUGUAY S A	13.3	100.0%																	13.3
CROP URUGUAY S A	447.5	83.0%	58.9	10.9%			18.0	3.3%			0.5	0.1%	14.0	2.6%					538.9
ESTANCIA LOS MOLLES S A	7.4	100.0%																	7.4
ESTERO S A																			0.0
EVERA S A C	17.9	34.0%	34.6	66.0%															52.5
FADISOL S A	59.3	80.4%	14.5	19.6%															73.8
GANADERA SUR S R L					1.0	100.0%													1.0
GARMET S A	117.6	74.9%	39.3	25.1%															156.9
GLENCORE S A			18.2	47.5%			10.0	26.2%	10.1	26.3%									38.2
GLORIA ISABEL ELGUERA ESPINOZA									0.4	100.0%									0.4
GRAMONT VAZQUEZ ALBERTO JOSE			1.1	100.0%															1.1
GRANICOR S A	18.9	54.4%	3.1	8.9%			4.1	11.7%	2.4	6.9%	6.3	18.2%							34.7
HINKELY S A																	7.2	100.0%	7.2
JONURY S A			15.6	82.9%					3.2	17.1%									18.8
KILAFEN S A	94.0	94.6%			1.7	1.7%					3.6	3.6%							99.3
LDC URUGUAY S A	294.3	75.1%	97.1	24.8%							0.2	0.0%							391.7

MIZEPLEN S A	0.6	100.0%																	0.6
MOLIMED S A													1.5	100.0%					1.5
NIDERA URUGUAYA S A	41.7	68.0%	12.6	20.5%	2.0	3.2%	0.7	1.2%			4.3	7.0%							61.3
PEGRANT URUGUAY S A			1.4	23.6%	4.6	76.4%													6.1
PLASKER S A									10.6	100.0%									10.6
PRADENOR SOCIEDAD ANONIMA	4.1	45.5%	5.0	54.5%															9.1
REYLAN S A																	6.4	100.0%	6.4
ROCALMAR S A	50.9	65.0%	20.0	25.5%			1.6	2.0%			5.9	7.5%							78.3
SCOULAR URUGUAY S A			3.2	51.8%	2.9	48.2%													6.1
SEMILLAS DEL SUR S A																	0.2	100.0%	0.2
TGL URUGUAY S A			13.0	40.0%	13.6	41.8%					5.9	18.2%							32.5
	1576.6		608.9		45.4		48.9		75.9		30.0		15.5		7.0		15.4		2423.7

* Asia includes, Bangladesh, India, Indonesia, Japan, Malaysia, Myanmar, Singapore, Taiwan, Thailand, and Vietnam. Excludes China.

**Africa includes Egypt South Africa, Angola, Mauritania and Oman (Oman is in the Southern coast of the Arabian Peninsula in the Middle East. It is the only country from the Middle East with very small quantities. As a result, it has been included in the African variable)

6.5 Roles of Uruguayan and multinational companies and the commercialisation of soy

Perhaps the most important aspect of the shift to soy production and the development of a modern soy supply-chain in Uruguay has been the arrival of large multinational companies. As Uruguay became a relevant player in the international soy market due to the increased volume of production, international companies begin to invest in Uruguayan agriculture. Though the initial investments at the start of the soy boom were from Argentina, a much more diversified set of actors now operate in the country, the latest data (2015) shows that companies based in other countries operate in Uruguay. In effect, soy became the "magnet" for international agricultural commodity brokerage companies such as Archer Daniels Midland (ADM), Bunge, Cargill, Glencore, Luis Dreyfus Commodities (LDC), Noble and Nidera to establish themselves in Uruguay. Local companies were also established to compete in this sector. Table 6-6 shows how the companies that have been active in the Uruguayan supply-chain have diversified since 2003, when soy production began to increase markedly, to 2015. In 2003 the major exporters were Barraca Erro, Copagran (a consortium of Uruguayan business groups) Garmet (from Argentina) and Cosechas (from Costa Rica). Even a year later in 2004 other companies began participating in soy, including Crop Uruguay (Uruguayan company which has ongoing contracts with Cargill); Uruagro, ADP SA (Agronegocios Del Plata) and Cereoil Uruguay (all Uruguayan agribusinesses) and Kilafen (Argentina). The main national and regional (South American) companies distribute agricultural grains and other crops including seeds for farmers to grow which are then harvested for exports. Many of these companies also supply and finance the purchase of agricultural inputs at the beginning of each cropping season, as well as providing technical assistance. By 2009 larger multinationals had entered Uruguay. These included LDC (based in Canada) and ADM (USA); later the Anglo-Swiss company Glencore and Nidera (which recently has become part of the large COFCO (China, National Cereals, Oils and Foodstuff Corporation) conglomerate set up offices in Uruguay (Syngenta, 2018). Not all of the companies listed in Table 6-6 are multinationals, many are also local exporters. The key difference between multinational and local companies is the way in which buying, and selling are tied to different types of international trading contracts: FAS, Free Alongside Shipping; FOB, Free on board; and CFR, Cost of Freight.

FAS means that the seller delivers the goods alongside the vessel. Under this from of contract, the seller clears the goods for export and then places them alongside the vessel at the “named port of shipment”. The buyer is responsible for the loading fees, carriage on the vessel, cargo insurance and any other costs implicated. In FOB contracts, the seller clears the goods for export, takes charge of the costs and risks involved, and delivers the goods on board the vessel. This term is only used in ocean or inland waterway transport. Once the cargo has crossed the “ships rail”, the buyer assumes responsibility for risk of loss or damage, as well as any additional transport costs. Therefore, the main difference between FAS and FOB is that under FAS terms, the buyer is required to clear the goods for export and pay the cost of loading them. CFR is where the responsibility for the goods is transferred to the buyer or receiver when the ship reaches the designated destination port. This term is only used in sea and waterway transport.

In Uruguay, companies that operate in the FOB market are listed as exporters since the sale is made when the merchandise is loaded on a ship. In Uruguay, the local exporting companies are those who secure grains from the FAS market, and then sell the grain into the FOB market, i.e., to multinational companies. In the FAS market, soy producers participate as grain sellers, while the collection companies, local exporters and multinationals participate as buyers. Companies that provide agricultural inputs, e.g., cooperatives, first act as buyers and then as sellers, but are always in the FAS market. When such companies operate as sellers, the buying counterparty can be either local or a multinational exporting company. In the FAS market the final destination for merchandise is listed as the port terminals, either NP or Montevideo (Interview with Federico Garcia Suarez, Universidad dele República, Montevideo, 23 March 2016 date of interview, place of interview). The companies that operate in the FOB market are listed as exporters since the sale is made with the merchandise loaded on the ship. In Uruguay, the local exporting companies who buy the grain from producers in the FAS market then sell the grain in the FOB market to multinational companies. In fact, any local exporting companies in Uruguay only sell in the FOB market.

The last link in the chain being discussed here is the sale of soy to a buyer located in the destination country. Once the soy is on the vessel the merchandise is considered exported as it is outside the country of origin (see Table 6-4). This is where only multinationals participate. They do so by providing a sale contract in CFR. This is a contract where the multinational (the seller) is required to arrange for the carriage of goods by sea to a destination port, and then provide the buyer with the documents necessary to obtain the goods from the carrier. Under a CFR contract, the seller does not procure marine insurance against the risk of loss or damage to goods during transit (ICC 2018). In effect in Uruguay this means the multinational companies arrange for ship to dock at a port, generally Nueva Palmira, onto which soy is loaded from different local companies thereby creating a consolidated shipment. A CFR sales unit is generally a Panamax vessel, e.g., Panamax ships which leave NP cannot exceed 40,000 tons and the loading of cargo must be completed at either of Bahia Blanca or Necochea in Argentina (see Figure 6-4). It is impossible for Uruguayan companies to contract a Panamax vessel and load it at NP or a port in Argentina because the cost and risks are too high. In fact, the only way for local exporting companies to independently export soy would be to use its own containers. Perhaps this is why local exporting companies only sell in the FOB market.

While both local and multinational companies have played important roles in the commercialisation of soy in Uruguay, in the end it is the multinationals that makes international transport of soy possible. Companies have also played an important enabling role in developing the soy (and other crop) supply-chain in Uruguay, e.g., building silo banks and establishing agencies to sell agrochemicals and machinery. However, the actual investments they have made in the country remain confidential and the researcher was unable to obtain quantitative information from, nor any interviews with, multinationals.

Table 6-6 - Ranked companies by the volume of their soybean exports between 2009 and 2012. Source: Uruguay XXI (Uruguay XXI, promoción de inversiones y exportaciones, departamento de inteligencia competitiva, UY). In millions of USD

Exporter	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2015
Barraca Erro	111	142	98	177	180	242	90	132	158	209	324
Crop Uruguay			85	134	222	211	73	77	115	237	539
Garmet SA	12	57	50	63	107	197	58	73	88	114	157
Uruagro		25	48	62	115	152					
ADP SA		47	70	82	87	103	45	55	30	46	58
Agroterra		25	32	46	70	90					
Kilafen			22	28	55	53	27	39	46	72	122
Cereoil Uruguay								69	112	193	175
Copagran	17	24	28	33	48	66					
Cosechas	2				25	18					13
Talifar								9	27	87	
ADM Uruguay							10	46	41	66	49
Coop. Agraria Nacional							22	31	33	50	81
LDC Uruguay							54	68	91	130	392
Alpino LTDS											22
CAMINAGRO SOCIEDAD ANONIMA											13
CHS Uruguay SRL											47
EVERA S A C											57
FADISOL S A											74
Glencore											36
Pregant											6
Nidera											61
Reylan											6
TGL Uruguay											32
Others	36	99	24	67	45	49	77	106	117	193	45
Total	178	418	457	693	954	1179	456	705	858	1397	2311

6.6 Summary

This chapter has discussed various responses along the soy supply-chain from farm to ports in Uruguay that have occurred during the soy boom era; and has then briefly examined export markets. It has given an overview of the evolution of the supply-chain in Uruguay, including how the local supply-chain operates. Other key aspects of the chapter which are explored are post-infrastructure developments following the soy boom and the evolution of cultivation practices in soy-dominated farming systems. The chapter discussed the importance of the Hidrovía for Southern Cone countries, and how Uruguay has capitalised on this through governmental and commercial investments at the Port of Nueva Palmira. This port not only exports soy grown in Uruguay but is also a major transhipment hub for soy from upstream along the Hidrovía, i.e., soy from southern Brazil, Bolivia, Paraguay and northern Argentina; as well as soy from other ports in Uruguay on the Río Uruguay. The final section of the chapter stresses the important roles local and multinational companies have played in the commercialisation of soy in Uruguay.

7 THE GROWTH IN SOY PRODUCTION AS A DRIVER OF AGRICULTURAL LAND-USE CHANGE IN URUGUAY

7.1 Introduction

This chapter analyses how the growth in soy production in Uruguay has changed agricultural land-use patterns. The main geographical emphasis is on the four Litoral departments, Colonia, Paysandú, Río Negro and Soriano, though spill over effects experienced in other departments in Uruguay are considered as well. Section 7.2 evaluates the predictions of soy area in Uruguay from time-series modelling and it mirrors Section 5.2. Section 7.3 presents and evaluates a map of soy cultivation from the 2015/2016 summer growing season, while Section 7.4-7.5 analyses the spatial and temporal dynamics between soy-dominated cultivation and pastoral agriculture. Section 7.6 brings land-use themes together and discusses them in a comparative approach alongside other similar studies.

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In Section 2.7 it was argued that soy as a driver of land-use change in South America has for the most part focussed on large areas where soy production has increased at a rapid rate. In addition, it was noted that much of the research had focussed on the expansion of soy cultivation at the expense of natural vegetation and in areas where it had replaced cattle ranching. Regionally, less effort has been expended on the introduction of soy and agricultural intensification as a factor in land-use dynamics, particularly in areas where soy-dominated agricultural systems have replaced other forms of arable cultivation. As the evidence presented in this chapter will show, in Uruguay the majority of land-use change consequent upon the introduction of soy falls into the latter category, i.e., soy-dominated systems replacing other arable systems, but there have also been areas where soy has replaced cattle ranching.

7.2 Results from TCM

This next section summarises the model output from Chapter 4. Much like the previous Chapter (5), the main models discussed are the results from the soy boom era. Figure 7-1 and Figure 7-2, show the observed and predictive series for both inflation model 21 and import model 27.

7.2.1 Soy boom era area modelling

The models discussed here in this section below are the first-order inflation models and the export quantity models (Table 4-9). The second-order Macroeconomic- Import-Export models (Table 4-11) will be referred to the previous chapter intermittently as the results are the same for both production and area models (Brazilian and Canadian imports to China). The significant variables for area were: the EU, Argentina and Brazil inflation rates and Argentine and Canadian export quantities. These models are again focussed on global trade in soy.

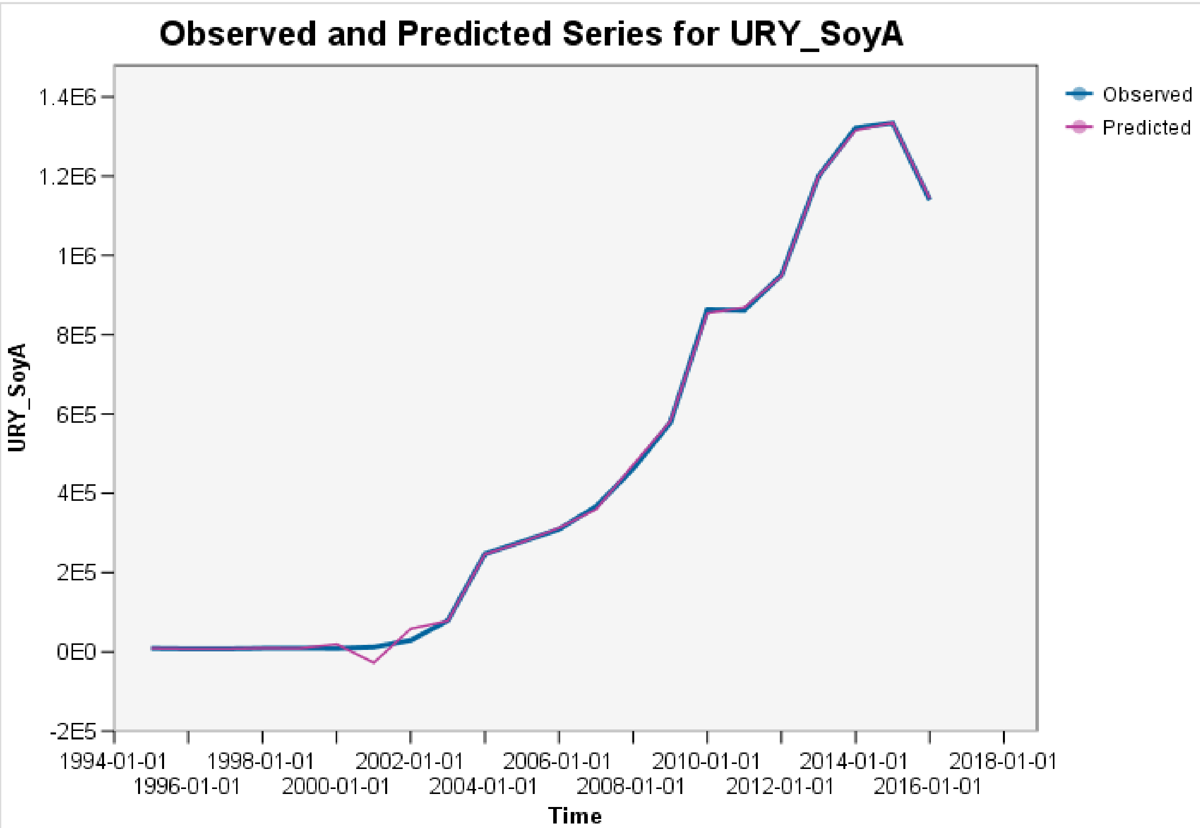


Figure 7-1 Inflation Model; Model 21- 1990-2016.

The two predictor variables in this model are EU, Argentina and Brazil inflation rates (Table 4-9). The model itself shows a very strong relationship between the predicted and observed soy area in Uruguay (Figure 7-1). Prior to the 1990's, several EU countries experienced high inflation rates in the 1970's and 1980's (Hann et al. 2015). For example, The Netherlands faced high inflation and low economic growth in the 1980's. Towards the end of the 1980's and in the early 1990's central banks of EU member states started emphasising price stability as their main objective and inflation rates began declined (Hann et al. 2015). This coincided with many EU countries having to pursue disinflationary policies in order to comply with the convergence criteria required to become members of the Eurozone (Davis & Fagan 1997). Inflation rates in EU countries were markedly similar in the middle years of the 1990's (World Bank 2014b).

Similarity in trends between the EU member states are unsurprising and symptomatic of an integrated regional economy. But the trends were witnessed outside the EU at the beginning of the 1980's, as many developed countries began to reduce trade barriers to stimulate a more liberalised trading system (Wise 2016; E.C 2007; Milner 1999; Gunderson 2014; Torres 2018). A few years later, the global to market-based economies enabled many developing countries to join the World Trade Organisation (WTO). Similarly, the Uruguay or 8th Round multilateral trade negotiations within the Global Agreement on Tariffs and Trade between 1986 and 1994 promoted the reduction of trade barriers which facilitated trading between less developed countries (Sanguinetti & Bianchi 2004).

As discussed in the previous chapter (5), during the late 1980's the Argentine economy fared badly during the global debt crisis. Growth in real output stagnated, financial markets collapsed, prices rose as the Argentine peso steadily depreciated, inflation rates were at their highest, and capital fled to safer havens (World Bank 2014b). Brazilian inflation rates were also high during this time period, as the country had adopted inflation targeting after a brief period of exchange-rate targeting in a major currency crisis. Specifically, from 1994 to 1998 high domestic interest rates and privatisation were used to reduce inflation: the main objective of Brazilian economic policy at this time (Barbosa-Filho 2008). Similarly, to what was discussed in the previous Chapter (5), this model (Model 21, Table 4-9) again shows the relationship and the interdependency between regional countries in the MERCOSUR. In regards to what this means for Uruguayan soy area, is perhaps what has been mentioned previously around flight of capital from neighbouring countries i.e. Argentina in particular. Model 27 (Table 4-9) had the same results for the import quantity (i) China imports from Canada and (ii) China imports from Brazil (Model 26, Table 4-10). Refer to chapter 5, Section 5.2.1.

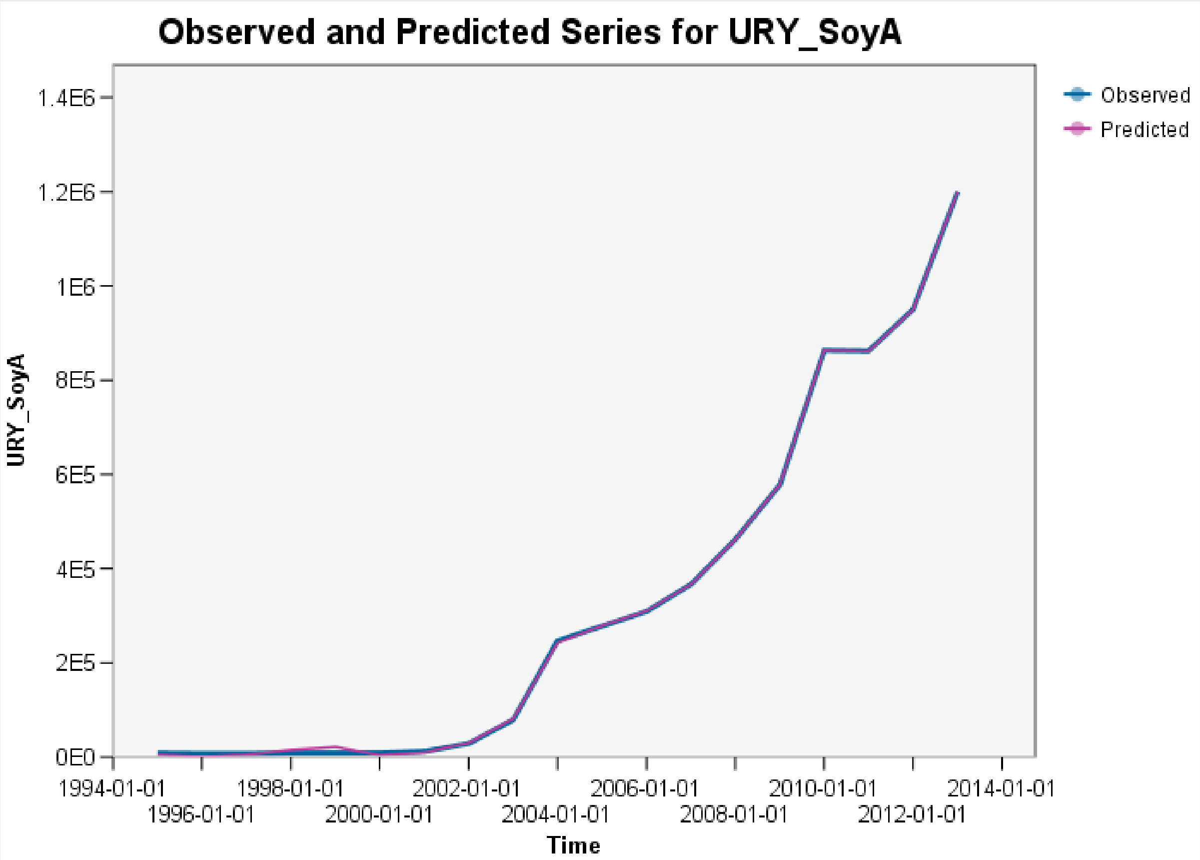


Figure 7-2 Export quantity model; Model 25 Argentina Export quantity, Canadian export quantity

The statistically significant variables in this model are Argentina Export quantity and Canadian export Quantity. Although it is not clear why Canadian export quantity would have come up as a significant variable, Argentina export quantity provides insight. Given what was discussed in the previous Chapter (5); including Argentina's global debt crisis in the late 1980's and later in the 1990's which led to the collapse of their financial markets. A crisis affects a country's credit conditions and aggregate demand, crisis in either exporting or importing countries are disruptive to exports (Worldbank 2016). During this time, financial shocks in Argentina would have meant a shock in their exports due to their limited access to capital, and ability to enter the export markets. For example, during the late 1990's as a proportion of the total export value between Argentina (5%), Brazil (79%) and Paraguay (16%), Argentina's soy value was the lowest (FAOSTAT 2016). The predictors for Uruguay soy area seem to be important in suggesting the way Uruguay and Argentina share an interdependence. Although, there is no suggestion that this was the only cause, it assists in supporting the interdependency within the Mercosur but more specifically the strong bilateral relations between Argentina and Uruguay. In summary, this section again highlights the importance of global and regional markets and their interconnectedness and the way economic situations play out depending on the region.

7.3 Survey of soy cultivation during the 2015/2016 summer growing season

A survey of soy cultivation during the 2014/2015 summer growing season was undertaken in Colonia, Paysandú, Río Negro and Soriano departments using the sampling plan and methods outlined in Chapter 3 (Section 3.4.1)

The aim of this survey was to acquire a snapshot of the geographical distribution and proportions of land-uses associated with the soy-rotation systems (Table 6-2 Section 6.3.3) that are currently prevalent in the main soy growing area of Uruguay. This is important because it is very difficult to convert the examples of rotations obtained during interviews and field visits into proportions of fields in different land uses at any one time, let alone their variation in the main soy growing area that was articulated by all interviewees. An alternative approach to the snapshot survey would have been to map land-use for individual fields from sequences of remotely-sensed imagery. But this would have given false indications of inter-annual land-use change on a field-by-field basis because every field in the main soy-growing area will be planted to soy at some time in a five- to six-year field rotation. The field counts of land-use types along each 30-40 km road transect are presented in Table 7-.1 and visualised in Figure 7-3.

The land-use types recorded in Table 7-1 are:

- soy, which includes *soja primera* and *soja segunda*, as it is not possible to differentiate this in the middle of the growing season;
- maize, which is combined with sorghum in the 'other summer crops' category in Figure 6.1;
- sorghum, which is combined with maize in the 'other summer crops' category in Figure 6.1;
- summer crops, which is the sum of the soy, maize and sorghum;
- natural pastures, i.e., fields that were unambiguously identified as natural grassland. The decision to classify these fields as such was based on the lack of any evidence of cultivation, moderate amounts of scattered tree and shrub cover, and natural grasses;
- artificial pastures, i.e., pastures which had either been improved or had been planted after arable crops. The decision to classify these fields as such was based on evidence of cultivation, very low amounts of scattered trees (if any at all), and sown grasses;
- all fallows and pastures, which is the combination of artificial and natural pastures, and fields that could not be classified as pastures but had evidence of grazing or areas of summer crops that were being grazed. These included cereal fallow, maize fallow, forage, rotation sorghum, and are labelled 'other fallows' in Figure 7-3;
- orchards, which are mainly in the south of the area were surveyed and included
- vineyards, which are restricted to coastal areas in Colonia Department;
- plantation forests, which are mainly found in Rio Negro and Soriano Departments;
- orchards, vineyards and plantation forests are combined as 'Other land-uses' class in Figure 7-3 .

Table 7-1 Field counts by transect

Transects (the initials after each transect are used in Figure 7-3)	Length (km)	Field count by crop									
		Soy	**Sorghum**	**Maize**	**Summer crops**	**Pasture Natural**	**Pasture Artificial**	**Fallows and Pastures**	**Orchard**	**Vines**	**Forestry**
Paysandú-Quebracho PQ	40	18	11	1	30	12	75	3	0	0	0
Estancia Paz+ EP	20	29	3	14	46	0	23	2	0	0	0
Paysandú-Young PY	40	49	6	10	65	8	23	5	0	0	0
Young-Route 3/22 Junction Y322	30	27	14	3	44	9	31	22	0	0	0
Young-Tres Bocas YTB	30	32	6	1	39	0	27	13	0	0	0
Mercedes-Palmitas MP	30	51	7	10	68	3	25	14	1	0	3
Palmitas-JE Rodo PJER	30	37	7	6	48	1	39	14	0	0	1
Palmitas-Dolores PD	30	56	10	13	79	1	25	4	0	0	0
East of Mercedes EM	30	35	3	5	43	3	30	36	3	9	6
Tres-Bocas-Mercedes TBM	30	31	2	0	42	5	16	5	0	0	2
Mercedes-Fray Bentos MFB	20	46	1	0	47	5	19	5	0	0	1
José E. Rodo-Ombues de Lavalle JEROL	30	39	2	11	52	7	50	14	0	0	0
Ombues de Lavalle-Route 21/55 Junction OL2155	30	65	3	3	71	5	49	25	0	0	1
Mercedes-Dolores MD	30	58	5	1	64	5	30	13	1	0	0
Dolores-N. Palmira DNP	40	84	2	6	92	10	46	11	0	0	0
N. Palmira-Route 21/55 Junction NP2155	40	84	2	25	122	15	104	13	3	5	5
Route 21/55 Junction=-Colonia 2155C	30	62	3	12	77	15	80	8	0	3	1

+ This road segment was only 20km in length

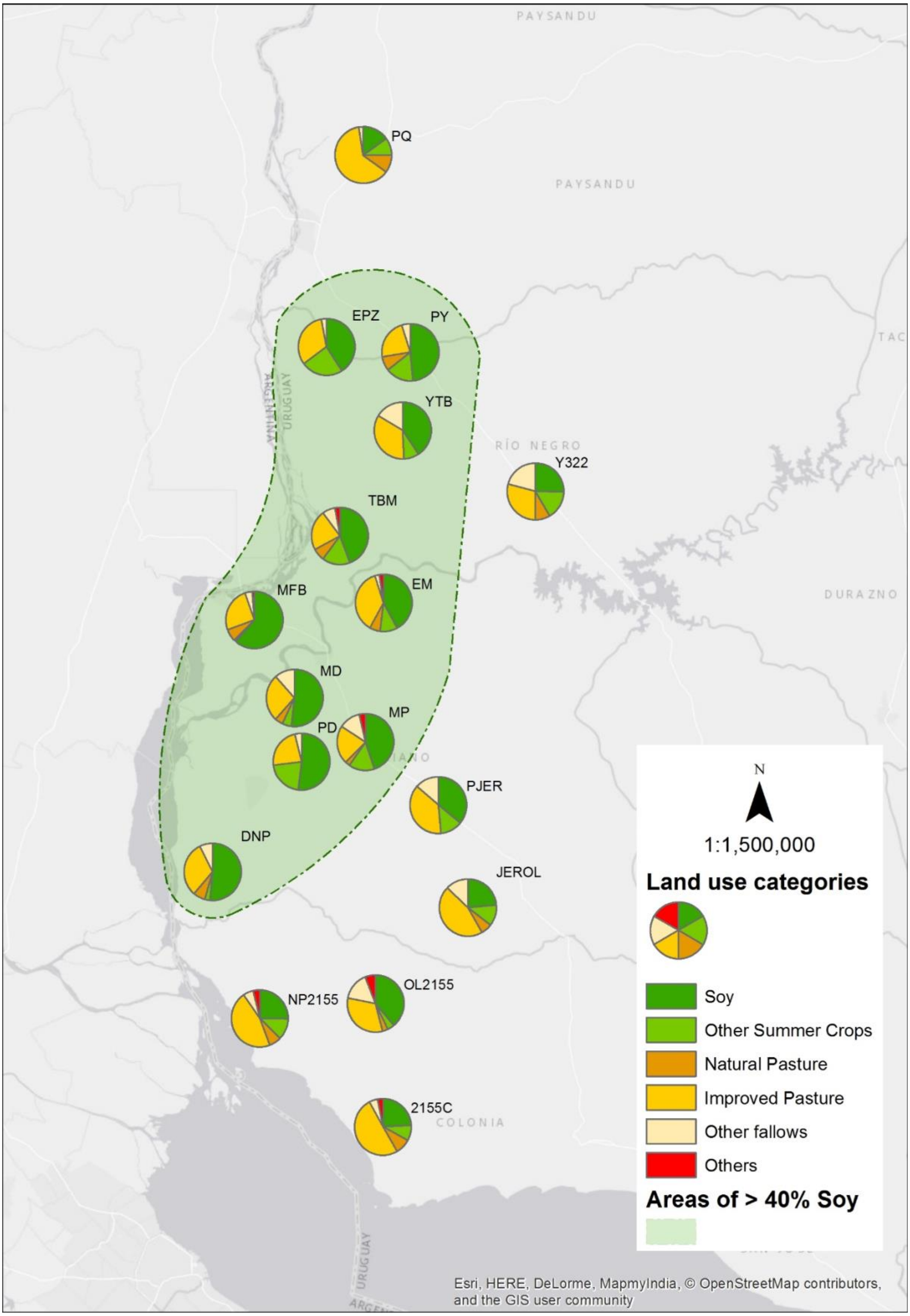


Figure 7-3 Distribution of soy, pasture and other land-uses categories in the areas surveyed in the Uruguay Litoral, summer growing season 2015/16.

Figure 7-3 shows clear patterns in the distribution of agricultural and related land-uses in the area covered by the 17 transects. The most important aspect of the distribution is the dominance of soy in the summer cropping season in an area that is adjacent and somewhat parallel with the Río Uruguay extending from south-west Soriano Department to the north-west Río Negro Department. This is mapped in green in Figure 7-3 and is defined as the area where soy fields comprised >40% of each transect. The highest soy percentages by transect where mainly in the southern part of this zone, transects DNP, MD, MFB and PD, where they exceeded 50% of all fields. Also important in the context of this thesis is that soy cultivation declines very rapidly north of the city of Paysandú (*cf.* transect PQ) and markedly but less rapidly to the east in Río Negro and Soriano Departments (transects JEROL, PJER and Y322) where, in both directions, pastures take up a larger proportion of the landscape which can be partitioned between summer crops, and pastures and fallows. To the south in Colonia Department, the proportion of soy also declines, but here there is a greater mixture of summer crops, pastures and fallows, orchards and vineyards (*cf.* transects NP2155, OL2155 and 2155C).

7.4 Evaluation of the snapshot of summer arable land-use patterns

The information on soy rotations from Garmet was presented in Section 6.3.3 Table 6-2 and it is analysed here. Initially, evidence about soy being grown was very general and came from regional remote sensing of cropland (Volante et al. 2016; Redo & Millington 2011; D. Redo et al. 2012) and some of the early interviews. The general impression obtained was that at the present time soy is grown throughout the four Litoral departments (though most was grown in the Department of Soriano), and that its cultivation petered out to the north due to lower rainfall.

However, the current situation of cultivation of soy and its margins may also relate as much to the expansion of soy and its contraction in the recent past, and the tradition of mixed agriculture to the south, in Colonia Department as well. For example, during Uruguay's soy boom period and its highest soy cultivation period (Section 6.2 peak land under soy) between 2003-2013 respectively, it expanded eastwards at least as far as western Flores and Durazno Departments. During this time, natural pastures used for cattle grazing were converted to soy. Elevated prices due to the high global demand for soy prompted farmers to expand into Flores at this time, even though the soil is less fertile and less productive compared to the Litoral provinces. As a result, even though soy yields were relatively low, because of the high price even small outputs of soy were profitable.

> *…aunque el suelo no es tan fértil en estas partes, todavía vale la pena plantar soja…los precios superan el esfuerzo…*
>
> [Although the soils in these parts of the country are not as fertile, it is still worthwhile planting soy… the price outweighs the effort] (Members from AUSID, Mercedes Feb 15th, 2016).

The eastward expansion occurred progressively from 1990 onwards, but after 2013 the soy area has contracted, and the first soy areas abandoned have been those that are most marginal such as western Durazno and Flores. The contraction has occurred to such an extent that it is evident from the modelling (Figure 7-4) and most soy is now restricted to a core region shown on Figure 7-3.

An examination of the evidence suggests there are some obvious generalisations about the early assumptions noted earlier, that can be made regarding the cultivation of soy in Uruguay. The first, that soy cultivation occurs in all four Litoral departments (Paysandú, Río Negro, Soriano and Colonia), is more or less true. Though it is questionable whether Paysandú could be termed a major soy-producing department given the distribution of soy in Figure 7-4, compared to the other three provinces. Nonetheless, it is far greater than in the other provinces in Uruguay.

However, the story that the data and interviews tell is that there are other stories at play. The pattern revealed from the land-use survey shows that within these four departments there is a core area where soy dominates (Figure 7-3). Interviews also confirmed this core area. However, through interviews it was indicated that the expansion of soy had moved into the eastern margins during

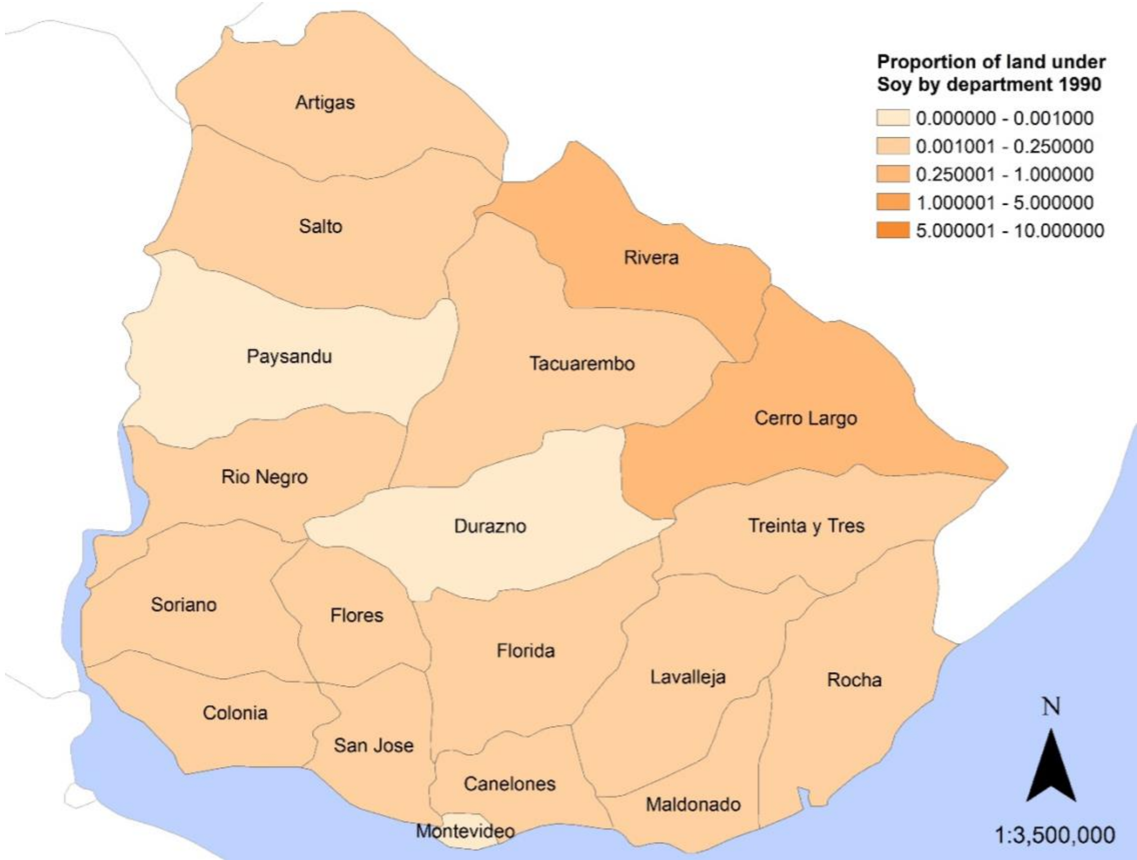
Uruguay's peak production period in 2013. During this time soy cultivation expanded into departments such as Flores and Durazno and even North of Paysandú into Salto.

> *La soja comenzó a expandirse en departamentos como Flores y Durazno y Salto… por esta razón el ganado fue desplazado más al Noreste.*
>
> [soy began to expand into departments such as Flores, Durazno and Salto. cattle was displaced further north-east for this reason…]. (Interview with members from AUSID, Mercedes, 8 March 2016)

In the early stages of the project it was assumed that soy had only ever been grown in the Litoral. Email correspondence with Pedro Arbeletche confirmed this was the case. However, the complexities around soy cultivation and its expansion began unfolding. Interviews along with past agricultural statistics at the departmental level show that soy was grown in small amounts in the north-east of the country in Cerro Largo and Rivera Departments.

> *La soja se cultivó en pequeñas cantidades en esta región muy temprano. Fue enviado principalmente a Brasil. Cuando la soja creció exponencialmente a principios del 2000, el litoral se expandió a la soja. Logísticamente, el lado noreste del país no era ideal para el cultivo de soja. En ese tiempo avían dos problemas 1) que el transporte de soja a los puertos de envío iba a ser costoso y 2) la infraestructura de Uruguay no está construida para ese tipo de transporte…*
>
> [Soy was grown in small amounts in this region very early on. It was mainly shipped across to Brazil. When soy grew exponentially in the Litoral (in the early 2000's), logistically the north-east side of the country was not ideal for growing soy. The two main issues at the time were 1] transporting soy across the country to the shipping ports (on the Rio Uruguay) was going to be expensive and 2] Uruguay's infrastructure is not built for it...]. (Interview with agronomist, at MGAP, Montevideo, 8 February 2016)

Figure 7-4, which shows the proportion of land under soy by department in 1990 and 2006, clearly shows the shift in soy production from north east to south west and western Uruguay.



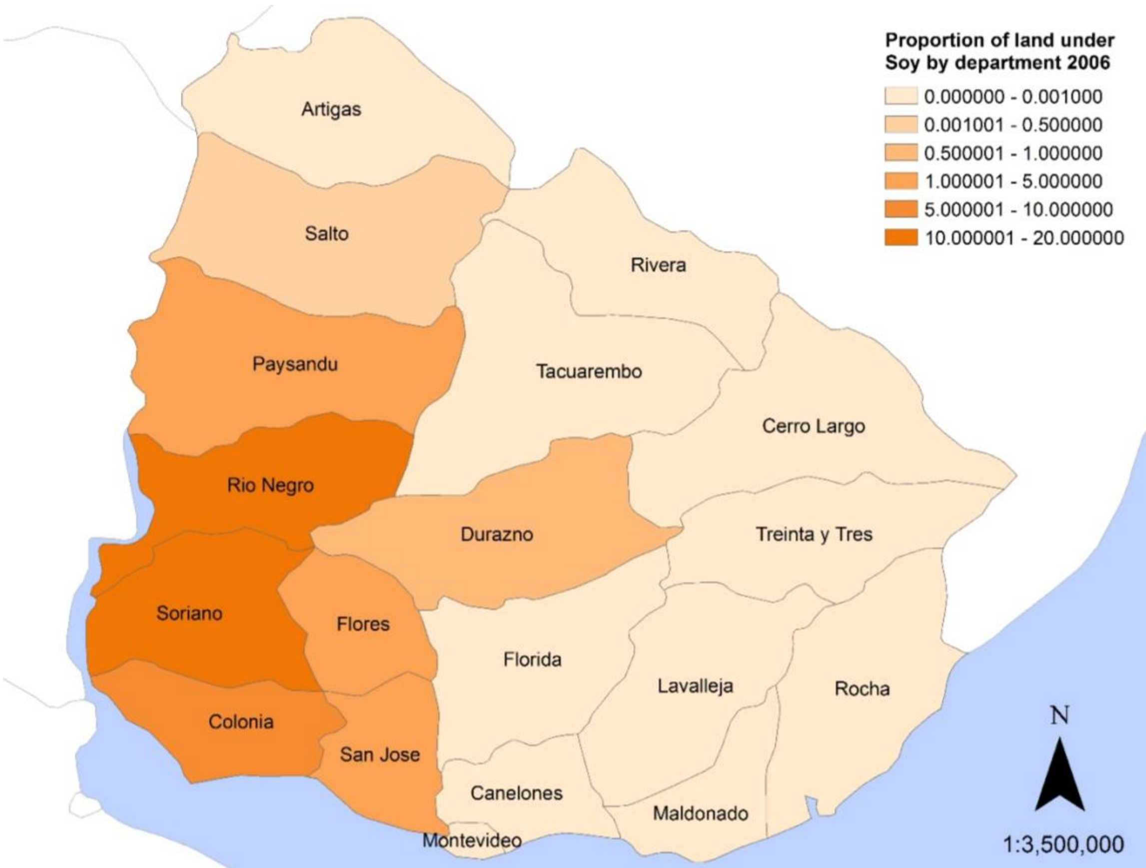


Figure 7-4 Distribution of soy in the departments of Uruguay. A comparison between 1990 and 2006.

Figure 7-4 shows that the majority of soy is grown the department of Soriano. However, Figure 7-3 shows that although the department of Soriano is clearly an important part of the core zones identified not all of Soriano fits into the core zone. Eastern Soriano has lower proportions of soy fields than the west; and the core zone extends north westwards into Río Negro Department.

The final observation was that soy is an important crop in the Paysandú Department (Figure 7-4). The survey conducted shows, however; that soy gives way to pasture very rapidly north of Paysandú city. This is confirmed in the MGAP map of agricultural regions (Figure 7-5). In fact, most of Paysandú Department is too arid to be considered a major soy producing area, especially in the north east. Western Paysandú tends to be prone to flooding from the Río Uruguay and therefore is also not ideal for soy. As a result, soy expanded onto natural pastures at the height of soy production in the early 2000’s, as was the case in Durazno and Flores. Evidence for this is clear in Figure 7-4 but soy has since contracted and has been replaced by pastures for rearing cattle (Figure 7-5 Forestry and dairy farms also have strong presence in the rest of the department).

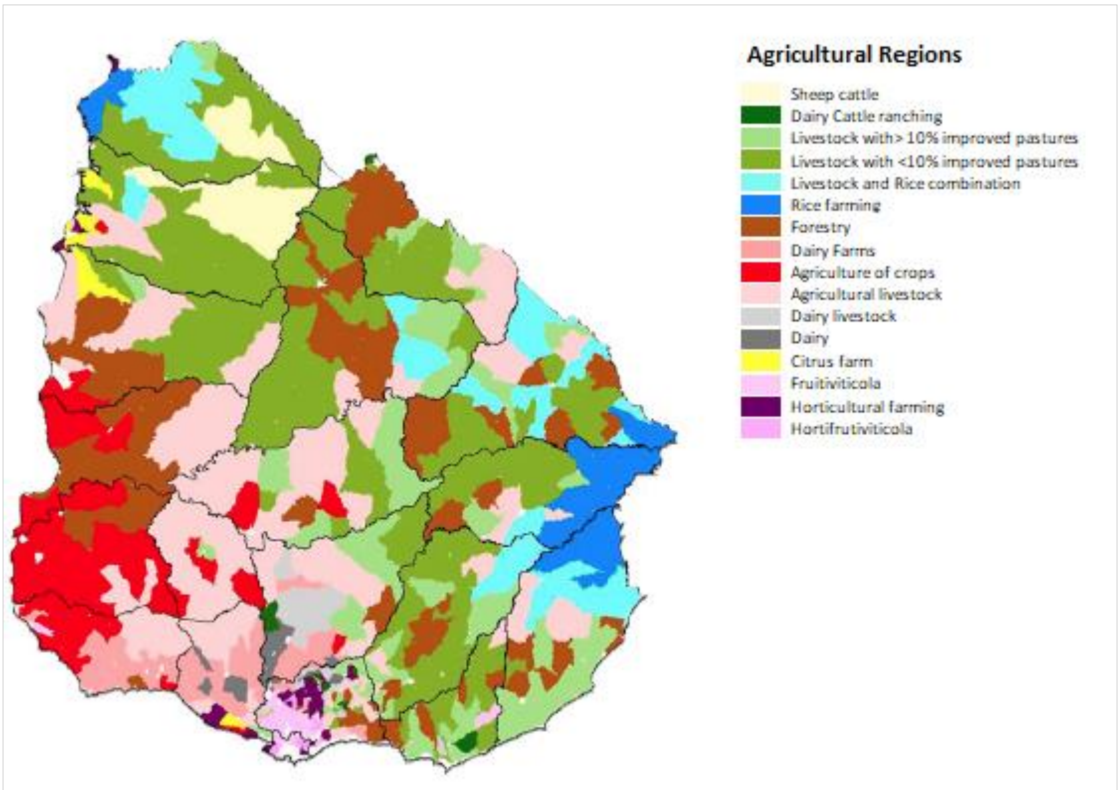


Figure 7-5 Dedicated Agricultural land-use in Uruguay 2011 (MGAP)

The above figure (Figure 7-5) shows a mixture of arable and dairy farming in Colonia and San Jose. There is in fact a clear division between West and East and East Colonia. San Jose shows greater mixture of farming systems than Colonia. Also, North East Colonia and North of San Jose there is more pasture for cattle. East of Soriano and East of Rio Negro pasture for cattle is also prominent. Pasture for cattle also exits in Flores and Durazno. There is a small encroachment of agricultural cropping in South of Paysandú. This was during a time (2011) when soy expansion was on the rise (Uruguay's biggest production year was 2013).

There is a history of mixed arable cultivation in the Litoral departments since the Second World War, i.e., before soy became the dominant crop, in which wheat and sunflower were the main winter and summer crops respectively (Figure 5-3). This history of mixed arable cultivation based on two cropping seasons was an important pre-cursor for the adoption of soy-based cropping systems and two-season rotations. It can be argued that this history of arable cultivation, though only 30-40 years in length, was a pre-cursor for three reasons. First, many farmers had already switched from pastoral to arable agriculture, and psychologically a switch to a new crop would have been relatively easy. Secondly, a business infrastructure of agricultural merchants and banks used to deal with arable farmers would have already developed, alongside a logistics infrastructure moving harvest to ports of the Rio Uruguay. This would have provided the initial infrastructure needed to service soy production. Finally, many farmers in these provinces would have made the psychologically-important switch from a pastoral system, which was well-embedded in Uruguayan culture, to arable farming in the lifetimes of the cohorts of farmers who later switched from pastoralism to soy-cultivation. This surely would have informed the decisions of the later adopters.

What is clear from the evidence and discussion above, is that the spatial and temporal dynamics of the interplay between pastoralism and cattle rearing, and soy cultivation, is vital in understanding the influences of the expansion of soy on land-use in Uruguay. This is a theme that has also been explored in Argentina, Bolivia and Brazil (Grau et al. 2005; Aide et al. 2013; Piquer-Rodríguez et al. 2018; Macchi et al. 2013; Le Polain de Waroux et al. 2018; Gasparri & de Waroux 2015; Kaimowitz & Smith 2001; Barona et al. 2010; Huang et al. 2009).

7.5 Soy-pasture dynamics

In the previous section, the expansion of soy cultivation between 1990-2013 and the subsequent contraction (Figure 7-4) was postulated as one of the explanations for changes in the distribution of soy in the 2015/2016 summer cropping season. Other important aspects of contemporary agricultural land-use distribution in the four Litoral departments that can be explained in terms of the expansion and contraction of soy either side of the millennium, are the distributions of summer crops more broadly, natural and artificial pastures, and fallows.

7.5.1 The distribution of pastures and fallows in relation to summer crops

The distribution of natural and artificial pastures, and fallows, in relation to the three summer crops, maize, sorghum and soy are clear from Figure 7-3. Though pastures and fallows occur through the area surveyed, there are some geographical biases in the distribution of each of these. There are many more artificial (i.e., improved) pastures than either natural pastures in all 17 transects surveyed. The highest proportions of artificial pastures were found in transects NP2155 and 2155C in Colonia Department, JEROL in eastern Soriano Department and PQ in Paysandú Department. In these four transects over 40% of fields were categorised as artificial pasture. The lowest proportions of fields in this land-use category, generally around a quarter of all fields, were in MD, MFB, MP, PD, PY and TBM transects. Unsurprisingly, all of these transects are in the soy core zone. Natural pastures are far less common that artificial pastures. Relatively high percentages are found in the north and north-east, PQ, PY and 332Y transects (these occur within and outside the soy core zone) and in the southern most transect 2155C in Colonia Departments. Of the remaining 13 transects, there are few fields that can be categorised as natural pasture, which reflects the fact that this was predominately an extensive grazing area until the mid-20th Century. However, the switch to soy-cultivation systems has been so extensive in the transects, that no natural pastures were recorded in the EPZ, PD or YTB in the soy core zone or JEROL to the east. Fallows were recorded in all transects, but relatively high percentages, between 15-25%, were encountered in YTB and Y322 in eastern Río Negro Department; MD and MP in the heart of the soy core zone in western Soriano, and PJER, JEROL and OL2155 in western Soriano and Colonia. What is clear from the distribution of pastures and fallows is that high proportions of each land-use category can occur inside and outside the core zone. Pastures, whether artificial and natural are greater in (some) areas where soy has expanded to and subsequently contracted in the north and east, and in the south where it was always an important part of mixed farming.

Many of the fallows that were recorded in the land-use survey are part of soy rotations (Table 6-1) and were undergoing a resting period to allow the soil to recover when surveyed. A few fallows were maize or soy that were being grown for fodder or grazing, as evinced by stooks of whole plants in fields or cattle grazing.

The inferences made above about summer crop-pasture and fallow dynamics from the 2015/2016 summer cropping map can be supported by department-level agricultural statistics (Section 3.4) and interviews with stakeholders (Section 3.4.1). The agricultural statistics provide the clearest visualizations of soy-pasture dynamics in Uruguay; however, one has to be potentially wary about interpretations as they are not collected and published every year.

Departmental-level data for soy only exist for 1990 (before the soy-boom) and from 2000 to 2006 (during the soy-boom) (Table 7-2). In 1990 the largest areas of soy were sown in Cerro Largo and Treinta y Tres Departments; though this was less than 1% of the land area in each of these departments. Three of the four departments that now grow the majority of soy (Colonia, Río Negro and Soriano) had 175 ha (<0.1% of the land area), 1255 ha (0.1%) and 1865 ha (0.2%) under soy respectively in 1990. No soy was grown in Paysandú. Overall, the geographical distribution in 1990 shows the highest proportions of land sown to soy in Cerro Largo and Rivera along Brazilian border, as noted above, and a number of departments where 0.1-0.49% of their land area was sown to soy in the east and in a line extending south westwards from the Brazilian border to the Río Uruguay.

Table 7-2 Proportion of land area under soy by department (Source: MGAP, 2017)

	Soy Area (ha)	**Soy as a prop of land area (%)**	**Soy Area (ha)**	**Soy Area (ha)**	**Soy Area (ha)**	**Soy Area (ha)**	**Soy as a prop of land area (%)**
Region	1990	1990	2003	2004	2005	2006	2006
Artigas	67						
Canelones	110						
Cerro Largo	10,359	0.8	2,635				
Colonia	175		22,537	20,100	27,524	31,294	5.13
Durazno	10		5,457	10,000	5,816	6,265	0.54
Flores	92		8,784	15,000	18,696	23,946	4.66
Florida	278		1,125				
Lavalleja	1,587	0.2	2,190				
Maldonado	55						
Montevideo							
Paysandú			34,996	21,800	17,019	16,830	1.21
Río Negro	1,255	0.1	55,218	60,300	76,825	94,952	10.13
Rivera	2,380	0.3	1,155	5,600	330		0.00
Rocha	2,033	0.2	1,215				0.00
Salto	15		1,877			5,057	0.36
San José	103		5,786	6,000	8,651	10,055	2.01
Soriano	1,865	0.2	101,073	122,600	144,820	169,297	18.79
Tacuarembó	1,908	0.1	1,532	5,800	1,358		
Treinta y Tres	5,416	0.1					

By 2003, after the global soy boom had initiated a major agricultural response in Uruguay, the geographical distribution of soy had changed dramatically. Each of the four departments in the Litoral had over 20,000 ha under soy. The areas ranged from 22537 ha in Paysandú to 101073 ha in Soriano. These four departments were followed by three departments on the eastern fringes of the Litoral (Durazno, Flores and San José) that each had between 5000 and 9000 ha. Of the remaining departments, the next highest area was 2635 ha in Cerro Largo, the department that had had the largest area under soy (10359 ha) in 1990. No soy was grown in Treinta y Tres in 2003, and by 2005 it had stopped being grown entirely in Cerro Largo as well.

Between 2003 and 2006 the area under soy in Colonia varied from 20100 ha (2004) to 31294 ha (2006). In Río Negro the area sown increased from 55218 ha in 2003 to 94952 ha in 2006, while in Soriano it grew from 101073 ha in 2003 to 169297 ha in 2006. In contrast, the area under soy in Paysandú declined from 34996 to 16830 ha over the same time period (Table 6.2). The proportions of land sown to soy in each department for 1990 and 2006 are shown in Figure 7-4.

An important trend in these data is that between 2003 and 2006 soy was continuing to expand in Colonia, Rio Negro and Soriano Departments, but that it had already began to contract in Paysandú. At Uruguay's largest year of production (2013) soy had expanded into the peripheral areas of Durazno, Flores, San Jose and Salto during the 2006/07 cultivation season; Soriano during this year planted 170,000 ha of soy. Río Negro 95,000 ha, Colonia 31, 000 ha, Paysandú 17,000 ha Flores 234,000 ha, San José 10,000 ha, Durazno 6,000 ha and Salto 5,000 ha (MGAP 2017). By 2016, the departments of Salto, Durazno, and San José had already contracted into the what is currently the core soy area.

7.5.2 Cattle stocking density

Statistics in cattle stocking density are provided on an annual basis from 1997- 2013 (Table 7.3). The trends in these data relevant to soy-pasture dynamics are highlighted below. In Colonia, cattle density decreased by -4.4% between 1997-2013. The ten-year period between 2003-2013 witnessed the biggest change (-28%) in cattle stocking density. Paysandú and Río Negro also showed significant trends over time. In the period of 1999-2003, Paysandú cattle stocking density increased by 15.4%, and over the entire 1997-2013 period it increased by 4.7%. However, it decreased every other year from 2003-2006 (-3.5%) and decreased again between 2006 and 2013 by -0.4%. Río Negro saw a significant decrease in cattle in the 2006-2013 period of -25%, while overall from 1997- 2013 there was a decrease of -8.2%. The entire period between 1997 and 2013 Soriano showed the largest percentage decrease (-36.6%) in cattle density out of all four Litoral departments. Between the 1999 and 2003 and 2003 and 2006 period, Soriano saw a large decrease in cattle density: -5.2% in 1999 to 2003, and -9.8% (2003-2006) compared to 5.2% in the previous period (1999-2003).

The biggest decreases in cattle stocking rates in the three departments to the east of the Litoral provinces—Durazno, Flores and San José–were in the period 2006-2013; densities decreased by -7.0%, -22.9% and -13.6% respectively. The fall in the number of cattle in these departments coincides with the expansion of soy and its spill over eastwards from the Litoral provinces and can be attributed to the conversion of pasture to arable land.

Table 7-3 Changes in cattle stocking density for selected ranges of years between 1997 and 2013 (Source: MGAP, 2017)

	Percentage change in cattle density					
Region	1997-1999	1999-2003	2003-2006	2003-2013	1997-2003	2003-2013
Artigas	-1.2	18.9	-16.8	23.0	18.0	10.1
Canelones	9.1	0.9	16.1	4.9	9.1	20.1
Cerro Largo	-4.8	6.3	5.4	-4.0	1.6	1.6
Colonia	7.5	5.3	7.8	-28.5	11.9	-18.5
Durazno	-1.9	11.8	5.6	-7.0	10.0	-1.0
Flores	5.7	11.1	9.0	-22.9	15.9	-11.9
Florida	14.8	13.2	-0.2	-0.6	24.4	-0.8
Lavalleja	-6.3	11.5	-1.0	-1.6	5.6	-2.6
Maldonado	2.2	13.6	4.5	-10.4	15.4	-5.4
Montevideo	0.0	50.0	-100.0	0.0	50.0	-100.0
Paysandú	*-7.7*	*15.4*	*-3.5*	*-0.4*	*8.3*	*-3.9*
Río Negro	*1.9*	*10.6*	*1.0*	*-24.4*	*12.2*	*-23.2*
Rivera	-12.6	8.2	6.2	-0.4	-5.0	5.8
Rocha	-1.5	7.5	1.1	4.6	6.1	5.7
Salto	-0.3	20.8	-18.8	21.8	20.6	7.1
San José	6.3	11.9	-0.5	-13.6	17.1	-14.1
Soriano	*6.1*	*5.2*	*-9.8*	*-39.1*	*10.6*	*-52.8*
Tacuarembó	-14.2	13.1	-2.9	12.2	-1.2	9.7
Treinta y Tres	-0.5	10.0	2.7	1.2	9.5	3.9
Mean	0.0	11.1	0.6	-4.2	11.1	-3.5

Choropleth maps of cattle stocking densities are provided and changes in stocking densities from 1997 to 2003, and 2006 to 2013 are shown (Figure 7-6) visualising the changes discussed above. It is clear from these two maps that there were modest increases in cattle stocking densities in all departments between the 1997-2003, with the exception of Salto Department north of Paysandú where increases where higher than all other departments. This overall picture of increasing cattle numbers is in stark contrast to the situation between 2006 and 2013, where in the soy-growing departments and those adjacent too them cattle numbers were decreasing (the yellow and red classes in Figure 7-6b). The remainder of the country also witnessed slow growth in cattle numbers at this time, compared to 1997-2003, with the exception of Artigas, Salto and Tacuarembó departments in the north west. Soriano had the largest negative change in cattle per hectare at this time, though the decrease in cattle numbers in Colonia, Flores and Río Negro were also high. San José, adjacent to both Colonia and Flores, also witnessed significance decline in cattle numbers. Figure 7-6b provides reasonable support for the spill over of soy cultivation into the departments of Durazno and Flores that are not considered major soy-producing provinces at the present time. It also confirms the massive loss of pastures in Soriano as soy-based cropping systems came to dominate, and the large losses due to the same change in agriculture in Colonia and Río Negro (Figure 7-6b). Paysandú witnessed a modest increase in cattle numbers between 2006 and 2013 unlike the other four soy-producing departments and the department adjacent to north eastern Paysandú, Tacuarembó, had a similar increase is stocking density over the same period. Central and northern Paysandú and Tacuarembó are essentially traditional cattle grazing terrain (Figure 7-6a), and the fact that their behaviour in terms of stock density (Figure 7-6a) and the relatively low proportion of land under soy in 2006 in Paysandú compared to Colonia, Río Negro and Soriano(Figure 7-4), indicates that the expansion of soy cropping systems into southern Paysandú was limited in geography and possibly began to contract earlier than the departments to the south (Figure 7-5). The decline in stocking density in San José, to the east of Colonia, fits the general regional pattern of decline in cattle numbers and therefore a loss of pastures.

However, it is noticeable that the decline is of a similar magnitude to Maldonado, which is located in a similar position to San José but to the east of Montevideo. The coastal departments between Colonia and Maldonado are characterised by higher levels of urban and industrial development than those to the north. Therefore, some of the decline in pastures or cattle numbers is likely due to the expansion of non-agricultural land-uses. In addition, the relatively lower decrease in stocking density in San José, compared to the departments bordering it to the north and west, may be due to the fact that a high proportion of the pastures in this department are linked to the dairy industry (Figure 7-5) that services the cities along the coast (Professor Pedro Arbeletche, Universidad de la República personal communication, Feb 2016). The values of these pastures would be greater than those used for beef cattle, and therefore more resistant to conversion to soy.

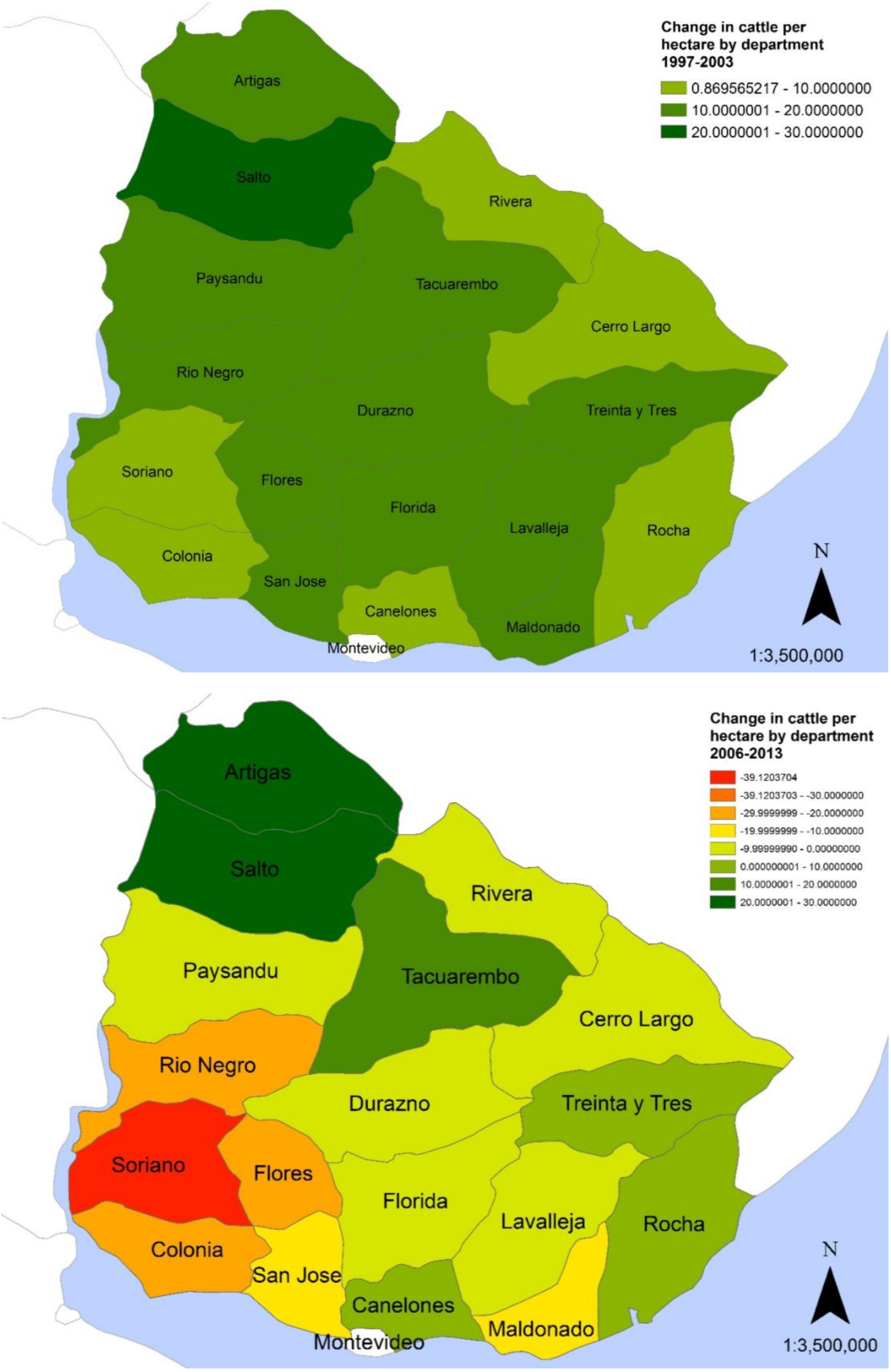


Figure 7-6 Uruguay: changes in cattle stocking density by department, 1997-2003 (a) and 2006-2013 (b). Derived from data supplied by MGAP

7.5.3 Explaining soy-pasture dynamics in Uruguay

Evidence from the land-use survey, interviews and MGAP cattle and soy statistics, reveals that more has happened in south-western Uruguay in terms of land-use than the expansion of soy. It was possible to draw up connections and build a narrative and make inferences made these lines of evidence. Though the expansion of soy cultivation has displaced other crops and pastures, it has been a process which has, from the start, followed an unforeseen chain of events of which neighbouring Argentina's economic crises was only the beginning.

The MGAP statistics (Table 7-2, Figure 7-4) show that soy was grown in very small quantities in all departments except Montevideo in 1990, and that by 2006 its cultivation had become concentrated in eight departments, with 87.3% of the area under soy being in the four Litoral departments. Concentrated investments by government and business offered technical agricultural packages geared towards climates with higher rainfall and humidity and the fertile soils along the Uruguayan Litoral that were attractive to the region's farmers as well as investors from Argentina. The concentration of such investments were facilitated mainly by those Argentine companies looking to capitalise elsewhere (See Chapter 5).

This capitalisation required an overhaul of the region's agricultural infrastructure, with upgrades to roads and ports (particularly Nueva Palmira) and the construction of storage silos. The geographical focus on the Litoral was helped by the government policies' somewhat *laissez faire* attitudes to investment (ref sections in C5) and its decision to concentrate rice cultivation in some eastern departments to ease exports to Brazil. As a consequence, rice is now farmed on a large scale in Treinta y Tres, Rocha and Cerro Largo with 70-90% of rice exports going to Brazil. However, since 2013 Uruguay is exploring new export markets for rice, as Brazil is approaching self-sufficiency in rice and has reduced rice imports from Uruguay

Uruguay siempre ha exportado arroz a Brasil… han sido nuestro mayor importador… también porque es fácil de transportarlo porque Brasil está cerca…. La soja es otra cosa. Para cultivar la soja en esta parte del país no hubiera sido posible por los costos logísticos.

[Uruguay has always exported rice to Brazil ... they have been our biggest importer ...also because it is easy to transport because Brazil is close... Soy is something else. Cultivating soybeans in this part of the country would not have been possible due to logistical costs] (MGAP, Government official 14 February 2016)

The commercialisation of soy production in Uruguay and increases in production in the early 2000's also brought a dramatic landscape change. During field work, the researcher began to appreciate and understand that more had occurred in the landscape apart from increases in soy cultivation. New rotations systems around soy had been set up, including fallow farming and loss and displacement of pasture. Therefore, although the global soy market has been an important driver in the expansion of agriculture in the four Litoral departments (Sections 5.2 and 6.2), interviews confirmed that land selected for large-scale soy agriculture occurred through expansion onto grasslands in the four Litoral departments and those adjacent to them to the east. Much of this expansion led to natural grasslands, which were used for extensive grazing, being converted to arable land.

7.5.4 Interactions between pasture and cropland

Distinguishing between cropland and pastureland is important because both systems vary in land-use intensity and efficiency, particularly when it comes to food production. The manner in which both systems are produced has important implications for natural resource conservation and food security (Macchi et al. 2013). Typically, croplands are a more efficient way to produce food than pastureland. Pastures are often extensive systems, while arable land usually comprises more intensive land-uses. What this means is that cropland is able to produce more calories and protein per hectare than pasture. The expansion of pastures throughout South America since the 1950s has mainly been for the production of beef, even though this is now recognised as one of the most inefficient ways to produce meat (Cassidy et al. 2013). Much of the expansion of pasture in Latin America has been into forested areas. When cropland expansion occurs, it tends to move into pastureland where it is then used for that purpose (Marriott and Pettitt, 1997; Barona *et al.*, 2010; Redo and Millington, 2011). What has happened in the four Litoral departments of Uruguay, and in Durazno, Flores and San José, is that significant areas of pasture were converted into arable land for soy cultivation, as well as soy replacing existing crops. This means that the pasture-to-soy cropping system has led to intensification of agricultural production. It can also be argued that intensification of production has also occurred where soy-rotations have replaced other crops in existing arable land. This intensification of agriculture on former pastures does not always lead to land-sparing of other land covers of high conservation importance, as is argued by Graesser et al. (2015) in Uruguay. This is a particular issue which Uruguayan grasslands have been faced with since soy cultivation began to expand in the 1990s (Blum & Narbondo 2008; Ran et al. 2013). Since its expansion, livestock grazing has moved to interior regions of the country, as can be seen from the continued increase in cattle stocking density in most of the interior and northern departments (Figure 7-6) and traditional grazing regions in the Uruguayan grasslands have been transformed as a result of the expansion of soy in the south-west due to increase in grazing pressure. This can be defined as a spill over effect as defined by Lambin and Meyfroidt (2011) *sensu stricto*.

Often land-use researchers have conducted place-based studies of different drivers of land-use change somewhat in isolation, particularly in the context of the expansion of soy in South America. More recent research relevant to this thesis has focused on a range of drivers over a broader region simultaneously (Redo et al 2012, Waroux, 2016, Garrett et al, 2013) enabling the development of an understanding of how drivers of land-use change are different, similar or interconnected in different places over a large area. The three studies identified above, have done this for soy and cattle and are therefore highly relevant to this thesis. The land-use dynamics related to soy agriculture and cattle have been examined in Brazil, particularly in relation to deforestation in the Amazon and both dLUC and ILUC have been identified (Schleifer 2017; Gasparri & de Waroux 2015; De Sy et al. 2015). Further south, in the dry woodlands and wooded grasslands of Argentina, Bolivia and Paraguay debate exists around whether deforestation is driven by the expansion of cattle ranching rather than the expansion of soy farming, as was first suggested. Research has shown how soy is replacing previously cleared woodlands and wooded grasslands, some of which were grazed pastures (Le Polain de Waroux et al. 2017; Barona et al. 2010). Redo and Millington (2011) found a sequence of grazing, to rainfed soy cultivation, to irrigated two-season cropping in south Bolivia. In all of these cases, the land-use changes under investigation could be described as dLUC of either natural or semi-natural vegetation or existing farming systems. However, there are studies that have examined how increasing soy production in Mato Grosso has geographically displaced cattle ranching into forested areas further north in Brazil (Baumann et al. 2016b; Brown et al. 2005; Gollnow & Lakes 2014); which is unambiguously indirect LUC.

Research coupling soy and cattle dynamics in terms of land-use change has recently begun to switch from densely forested areas in the Amazon, to dry forests and woodlands in Bolivia, Paraguay and Argentina (Grau, Gasparri and Aide, 2008; Aide *et al.*, 2013; Hansen *et al.*, 2013). This research has examined the spatial distribution of changes in land cover across extensive areas within South America evaluating the slowdown in deforestation rates in the context of the dynamics of cropland and pastureland (Clark et al. 2010; Graesser et al. 2015). Others have extended this line of research beyond South America to include all of Latin America and the Caribbean to provide a comprehensive assessment of the spatial distribution of these processes (Graesser et al. 2015; Aide et al. 2013). What all these studies have in common is that they cover extensive areas of the continent, thereby analysing dynamics at a continental scale with a focus on land-use/land cover changes. More studies have drawn attention to the relationship that both soy and pastureland have developed. The story of Uruguay is a similar one. Through the expansion of large crop cultivation, in this case soy, its impact has been evident through the land-use processes which have occurred; apart from the displacement of other crops the dynamic between pasture and soy is evident.

Uruguay has an extensive history of cattle rearing (*cf.* Section 1.6). Through most its history, cattle have been Uruguay's primary agricultural commodity and 70-80 % of the country's land area has been classified as permanent meadows and pastures, the latter category including all natural, improved and cultivated pastures (FAOSTAT 2016). The sector remains important. Combined domestic production and exports of beef doubled from just under 300,000 in 1961 to almost 600,000 tonnes in 2005 (Figure 7-7). Since then the combined amount has declined to around 500,000 tonnes, though the exports remain high the proportion of beef in the domestic market has declined. This decline in combined export and domestic production since 2005 lends further support to the arguments made earlier about the decline in pastures in Colonia, Durazno, Flores, Río Negro, San José and Soriano Departments during the soy boom, and the fact that cattle did not return to these pastures in great numbers once soy cultivation began to retreat in Durazno, Flores and San José. The effect of the soy boom can be seen clearly in the increase in soy production from approximately 70,000 tonnes in the late 1980s to 3 million tonnes in 2013 (Figure 7-8)

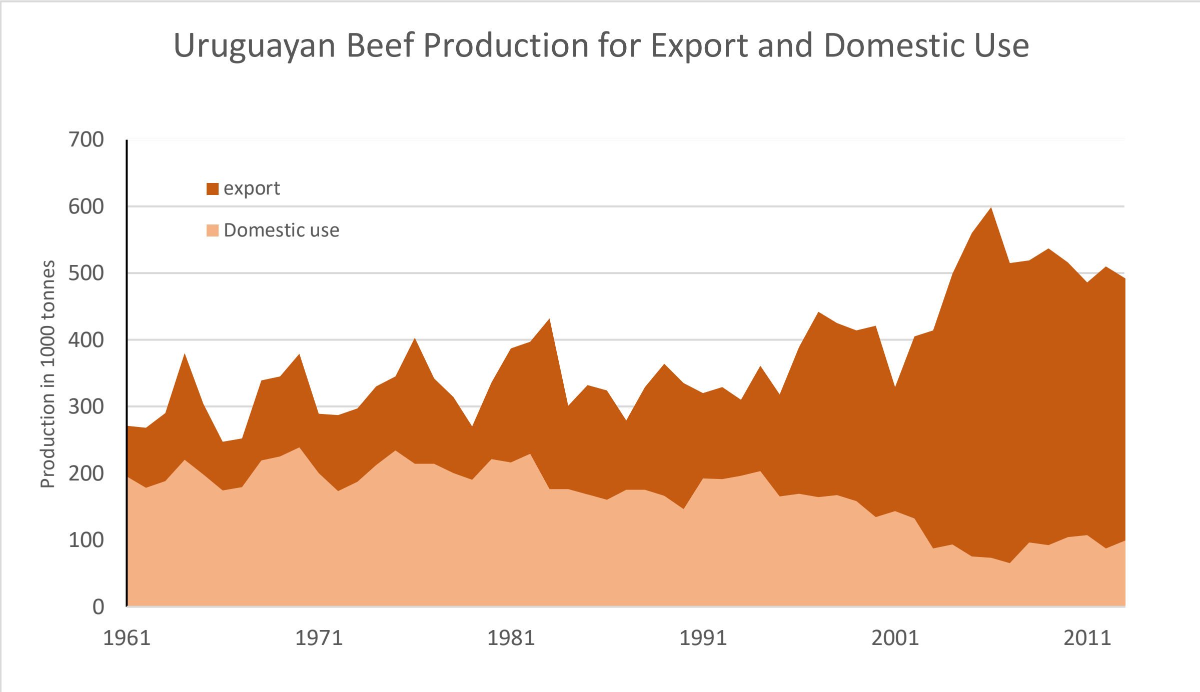


Figure 7-7 Uruguayan beef production- export and domestic use, 1961-2013 (FAOSTATS, 2016)

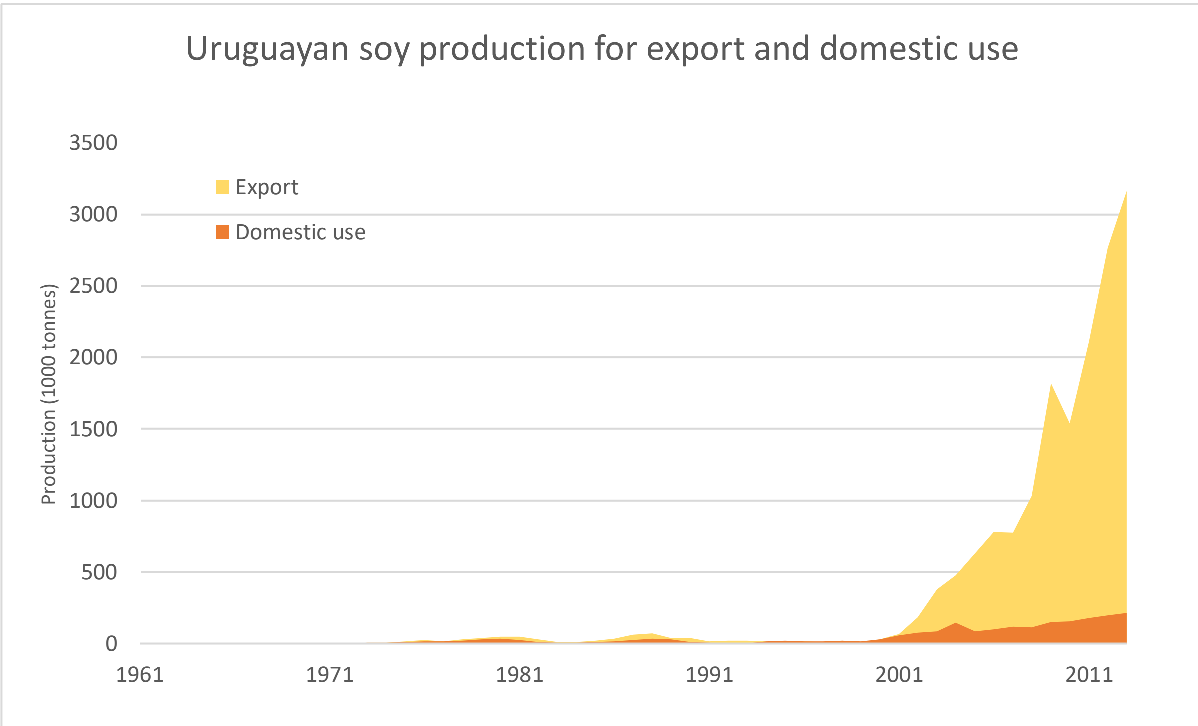


Figure 7-8 Uruguayan soy production for export and domestic use, 1961-2013

These trends were evident during interviews and they confirmed that much of the expansion of crop area for soy has been at the expense of permanent pastures and cattle on natural grasslands, and some areas of improved pastures and fodder crops. The departments where pastureland has contracted to make room for cropping are clear in Figure 7-9. However, the reduction in pastureland in south-west Uruguay did not just affect land-use in Uruguay. In the 2000's many Uruguayan ranchers began to sell increasing amounts of land to Argentinian farmers who moved to purchase cheaper land in Uruguay (Piñeiro 2012), particularly those looking to grow soy. Many Uruguayan rancher's used their capital windfalls to purchase land and established a new cattle frontier in the Chaco of Paraguay (Bertello Fernanado 2008; Gozales David 2013). This land-use spill-over effect *sensu stricto* was confirmed during interviews.

> *…muchos agricultores tomaron el dinero y compraron tierras en Paraguay. Sabían que sería más barato para ellos a largo plazo "*
>
> […many farmers took the money and bought land in Paraguay. They knew it would be cheaper for them long-term] (Interview with a Uruguayan intermediary, Paysandú, 20 February 2016)
>
> …los ganaderos que se dirigen a Paraguay pueden ganar más dinero allí y luego pueden regresar a Uruguay para recuperar sus inversiones…
>
> […cattle ranchers that head up Paraguay can make more money up there and then end up returning to Uruguay to reinvest in farm land] (Group of Uruguayan farmers, AUSID, Mercedes, 3 March 2016).

While the spill-over effect in Paraguay is interesting, the key finding of this thesis focuses on Uruguay itself. It is very clear that the trend of soy expansion has been the proximate cause of land-use change in both arable and pastoral systems in the four Litoral departments, and the departments immediately to the east. This expansion of arable agriculture and corresponding loss of pasture is not, however, just a regional phenomenon in south-west Uruguay. It has changed the proportional shares of the main types of agriculture nationally (Figure 7-5) and it has also changed the seasonality of arable agriculture by changing it from an arable system that was once somewhat balanced between winter and summer cropping seasons to one that is now dominated by summer cropping (Figure 7-10).

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Figure 7-9 Area under wheat, soybean, other crops and pastures, Uruguay, 1980-2010 (MGAP, 2017)

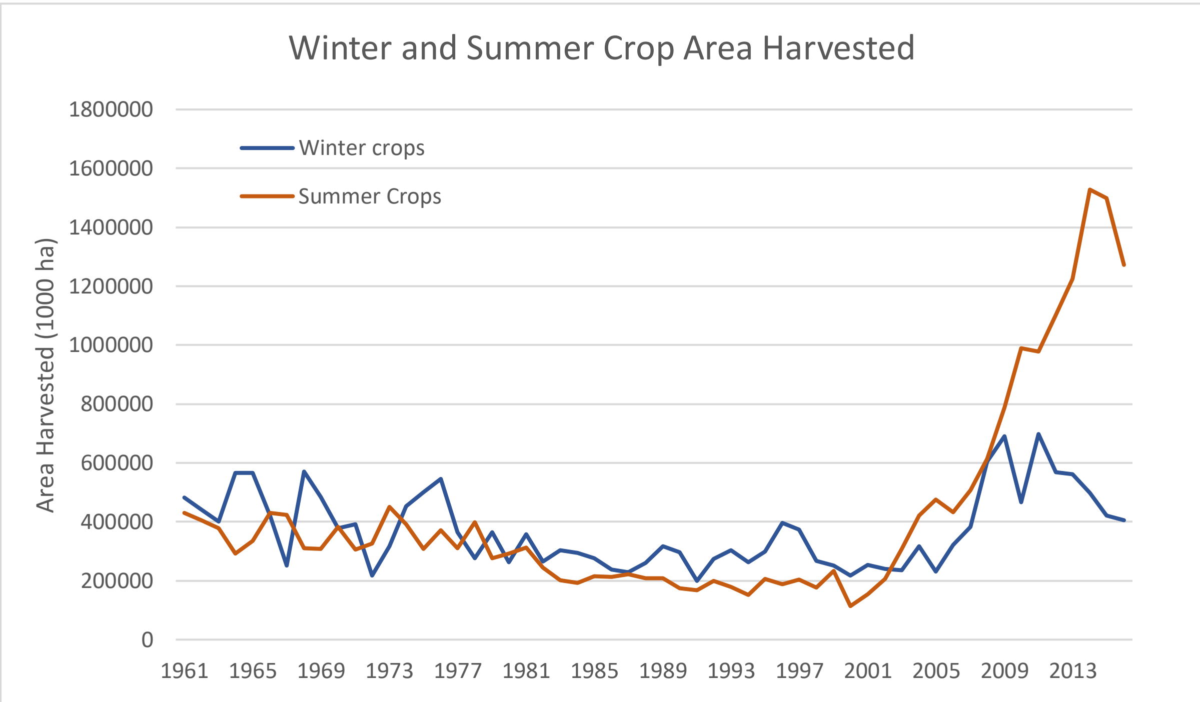

Figure 7-10 Areas of summer and winter crops harvested 1961-2016. Source: (FAOSTAT, 2016).

7.6 Comparisons with research on land-use change in Uruguay

Research conducted by Volante et al. (2015) and Redo et al (2012) are important in the context of the research in that they can be used as comparisons. Volante et al (2016) (2015) mapped spring, winter and double-cropped areas in Argentina, Bolivia, Chile, Paraguay and Uruguay for 2000/01 and 2010/11. The areas for Uruguay are provided in Table 7-4.

Table 7-4 Uruguay: winter, summer and double cropped areas in 2000/01 and 2010/11. Source: Volante et al. (2016). Though Volante et al. use the term spring cropping, it has been converted to summer cropping in the table and in the discussion below so that it corresponds with the terminology used in Uruguay.

Country	**Cropping season**	**Cropped area (ha)**		**Difference in cropped area**	
		2000/01	**2010/11**	**(1000 ha)**	**(%)**
Uruguay	Winter	306	0	-306	-100
	Summer (Spring)	122	990	868	+711
	Double cropped	109	685	576	+528
	Total	647	2359	1712	+265

The cropped area increased almost 2.5 times in the first decade of the century due to large increases in areas under summer crops and winter and spring double cropping. This ties in with the expansion of soy, which is a spring crop and the introduction of the soy rotations (Section 5.3) which have both winter and summer components. Fields that were only cropped in the winter (barley and wheat) disappeared from the landscape have been replaced by summer-only and double-cropped fields. The research carried out in this thesis therefore supports their findings. However, it also provides strong evidence of the reasons behind the changes in cropping patterns that they mapped.

The other three countries that cultivate soy that were mapped by Volante et al. (2016) also recorded increased crop areas. Argentina recorded the largest increase, while those in Bolivia, Paraguay and Uruguay ranged from 1134 to 1913 ha. The largest relative increase (+265%) was in Uruguay. The areas cropped during the summer (spring) increased in all countries except Paraguay which witnessed a 60% decline. Argentina recorded the largest increase, while Bolivia, and Uruguay both had very large relative growth (+551% and +711% respectively). Both Uruguay and Argentina witnessed decreases in the area of winter crops. The areas that were double cropped increased in all four countries. The largest increase in area was in Argentina, and the largest relative increase was in Uruguay (+528%). In summary, Uruguay witnessed a large growth in cropped area, and this was built around large increases in spring and double cropping, with the loss of all land that was only cultivated in the winter. These data indicate that the changes in agricultural land-use consequent upon the introduction of modern forms of soy cultivation are probably similar to those in Argentina, but somewhat different to Bolivia and Paraguay. This similarity probably is as much to do with the similar soils and climates of south-west Uruguay and adjacent parts of Argentina, as it does with the strong socio-economic links between the two countries.

Similarly the results in this research are comparable to the analyses by Redo et al. (2012). Their research used MODIS to map land-use and land cover changes in Uruguay form the period of 2001 and 2009. Their research confirms the soy production boom which Uruguay underwent between 2000 and 2009 and how it surpassed wheat as Uruguay's most dominant crop. For example, in Uruguay in 2009, herbaceous vegetation had decreased by 15% and was largely replaced by the expansion of agricultural land-use. The similarities with this current study help to confirm the changes and expansion which Uruguay underwent from 2001-2009. Redo et al. (2012) explain the expansion which Departments such as Florida and San Jose have undergone as a result of agricultural cropping. The results from the study also found that much woody vegetation had decreased as a result of both herbaceous plants (6495 km2), and agriculture (3022 km2). The research carried out in this thesis therefore supports their findings. However, it also provides strong evidence of the peripheral areas into which soy continued to expand into (Flores, Durazno) after 2009. However, more importantly the results in this thesis show how the expansion of soy has also retracted, especially after 2013. This thesis shows the interactive relationship which agriculture (in this case soy) shares with land used for pasture. One other similarity both studies share is that Argentina is regarded as being an underlying cause for the soy boom expansion in Uruguay.

7.7 Summary

Time-series modelling shows unambiguously that main underlying cause of agricultural land-use change in south-west Uruguay has been the process of agricultural globalisation, specifically the incorporation of Uruguay into the global soy trade since the early 1990s. The dominant proximate cause of agricultural land-use change in the departments of Colonia, Río Negro, Soriano and southern Paysandú has been the progressive switch to more intensive forms of modern soy production. This argument can be applied to parts of Durazno, Flores and San José Departments to a lesser extent as well.

The adoption of soy as a major crop in Uruguay and its subsequent expansion and slight contraction has been very significant in terms of agricultural land-use in Uruguay. Soy-dominated rotational cropping systems have replaced the dominant wheat cultivation systems that prevailed in south-west Uruguay. This was the fundamental crop in a winter cropping system. The growth has not replaced this system in a spatial sense, i.e. direct land-use change (dLUC), but has also replaced it with more-intensive two-season (summer and winter) cultivation. Therefore land-use intensity will have increased.

Soy-dominated rotational cropping systems have also replaced pastures used for rearing beef in eastern Río Negro and Soriano, parts of southern Paysandú and western Durazno and Flores Departments, whereas in eastern Colonia and San José Departments that have replaced some pastures used for rearing both beef and dairy cattle. As the area under soy has contracted since 2005/2006, as evinced by soy core zone mapped in February 2015 (Figure 7-3), some of the areas that had been converted from pasture to soy, reverted to pasture. However, in many cases it can be postulated that the natural grassland pastures that had been converted were replaced by artificial or improved pastures, or even pastures and fallows as part of soy rotations. Again, these are forms of dLUC. There is evidence of iLUC and spill over effects in the ranching sectors in the Chaco of Paraguay as a consequence of the expansion of soy in Uruguay.

8 CONCLUSION

8.1 Introduction

The research reported in this thesis has explored the expansion of soy production in Uruguay and its influences on arable agricultural systems, the soy supply-chain and arable and pastoral land-use in Uruguay's four Litoral departments (Colonia, Soriano, Río Negro and Paysandú) as well as adjacent Durazno, Flores and San José since the early 1960's.

Section 8.2 discusses the main findings under each of the research themes introduced in Chapter 1. Section 8.3 discusses the main limitations and how they affected the research; and the concluding section (8.4) outlines the main contributions to knowledge emanating from this research. The remainder of this section briefly summarises each chapter of the thesis as an aide-memoire to reader.

The introductory chapter introduced the three main research themes and provided a contextual introduction to Uruguay. In Chapter 2 literature was reviewed that enabled overviews of soy as crop (including its genetic modification) and a commodity; its global expansion, with particular emphasis on its arrival and expansion in South America; and its impacts on land-use change on that continent to be written. Research methods were introduced in Chapter 3, with the exception of temporal causal modelling (TCM) which was considered in Chapter 4. The lines of research introduced in Section 1.2 were reported on in Chapters 4-7. Chapter 4 used a new form of time-series analysis, TCM, to model soy production and area under soy in Uruguay a wide range of regional and global parameters from 1961-2016. Statistically significant models of soy production were discussed in Chapter 5, along with the causes of the arable land-use regime shift to a soy-dominated production system in the early 1990's. As global economic parameters were found to be important in many production models and because well over 90% of soy grown in Uruguay is exported, Chapter 6 considered the link in the global soy chain that developed in the country in response to the 1990s soy boom and its subsequent development. This ranged from the nature of production systems through to export markets. Chapter 7 examined the statistically significant models of the land area under soy in Uruguay that were introduced in Chapter 4. It focused on how increased soy production led to an increase in the area of arable cultivation in the Litoral and adjacent departments; how it has displaced other crops; and discussed the soy-pasture dynamic that evolved as soy came to dominate arable agricultural systems in Uruguay.

8.2 Review of research themes

In this section each research themes are re-stated, and the main findings are discussed.

Research theme 1: How and why has soy evolved as the main crop in Uruguay, and what factors have led to the growth of soy cultivation in Uruguay in the last 30 years? (Chapters 4 and 5)

Inferences regarding this research theme can be made from TCM modelling using data from the major soy exporting and importing countries from 1961-2016. Statistically significant predictor variables in the 1961-1989 pre-soy boom models of soy production and area under soy in Uruguay were quite variable compared to post-1990 soy boom models. They included inflation and exchange rates, trade volumes, and soy production and land areas under soy. Many of the significant variables were from neighbouring South American countries, though not exclusively so. This is indicative of the fact that soy was a minor arable crop in Uruguay at this time, an inference that is supported by MGAP statistics. The soy-boom models (post 1990) clearly infer that the global demand for, and trade in, soy has been the major driver of the growth of the soy in Uruguay since the 1990, both in terms of production and land-use. This is due to the fact that soy-boom models (1990 onwards) had fewer predictor variables than pre-soy boom models and that they were more global in their geography, rather than regional in their origin.

The TCM models show that soy has not always been the dominant agricultural crop in the Uruguay Litoral. Prior to the soy boom period soy was not a major crop in Uruguay although it had already gained momentum in other countries; in fact, the farming systems in the Litoral were dominated by winter wheat and barley, and to a lesser extent, sunflower and sorghum as summer crops. Since the early 1990s arable cultivation in this area is dominated by soy-based rotations over five to six years. These rotations include both winter and summer elements, though soy (a summer crop) is the dominant crop by area and production.

Therefore, a significant shift in land-use regimes occurred in this part of Uruguay during the late 1980s and early 1990s. The timing of this regime is coincidental with a number of global phenomena, i.e., post-Cold War trade liberalisation, the opening up of the Chinese economy, and increasing global demand for soy. However, analysis of the modelled predictions, interviews with stakeholders in Uruguay, and secondary sources indicate that the following phenomenon were most influential proximate influences on this regime shift:

- Argentina's deep financial economic crisis of the late 1980's (which was influenced to a large extent by global economic crises) led to a flight of capital from Argentina to Uruguay by individuals farmers and agribusinesses in the 1990's and early 2000's. Lower land prices; the ability of foreigners and foreign businesses to own land and businesses in Uruguay; and lower export taxes in Uruguay were attractive Argentine investors. The Argentinians brought more than capital to Uruguay at this time. They had experience cultivating soy back to the 1970's and were the first country in the region to adopt GM RR soy in the mid 1990's. The agrotechnological packages that had been developed in Argentina were found suitable and were introduced to Uruguay at this time. This transition was enabled by businesses such as El Tejar establishing branches in Uruguay, and the capital investments being managed through *pools de siembra*.

- The establishment of the Mercosur in 1991 meant that the movement of people, goods and services between Argentina and Uruguay aided this flight of capital and technology.
- Production of the main summer crop prior to the soy boom, sunflower, was seriously compromised in the Litoral provinces of Uruguay and adjacent parts of Argentina by the *Phomopsis* fungus.
- After this land-use regime shift occurred, the increased demand for soy from China and the EU led to further increases in soy production in Uruguay that were aimed at the export market. Although Uruguay's export volumes to China were not as large as Brazil and Argentina, the significant increase of soy cultivation in Uruguay over the last 15 years and export data are evidence they are contributing to the demands from both China and the EU.

Research theme 2: How have agricultural production systems* i*n Uruguay responded to the post-1990s soy boom? (Chapter 6)

The large external investments which poured into Uruguay from Argentina in the 1990s, were followed by further external and internal investments which have enabled soy exports from Uruguay to be commercially-competitive on the international market. However, it is not as much the level of investment but how capital has been spent that has elevated Uruguay's position of a soy producer globally. There are two components to the research findings:

- the introduction and subsequent intensification of soy-based rotational cropping systems; and
- the development of an almost entirely new internal supply-chain infrastructure, which led to the establishment of internal contracting system that facilitates exports.

Prior to the expansion of soy arable farming practices were less intensive than at present. Furthermore, the associated infrastructure was simpler, but nearing the end of its life as it had been established with the dual purposes of serving an internal market as well as exports and designed mainly with beef sector exports in mind. The overhaul of both of these elements occurred through system systems first introduced by farmers and businesses from Argentina in the 1990s, and then taken up by investments from Uruguayan business and multinational agricultural commodity brokerage companies. Although, each type of business operates slightly differently, the overall processes are more-or-less the same.

The main changes on farmland have been the introduction of five-to-six-year crop rotations that include summer and winter crops, and arable cropping, fallowing and pastures. These rotations are designed for each field by companies and cooperatives with whom many farmers are associated with or are under contract. The companies and cooperatives provide financing for the seeds, herbicides and fertilisers they sell, and often buy the harvest.

The supply of soy to ports is relatively straightforward as the three ports used—Fray Bentos, Nueva Palmira and Paysandú–are located in Río Negro, Colonia and Paysandú departments. Fray Bentos and Paysandú are served by road and rail, and Nueva Palmira by road. The emphasis since the late 1980's has been to upgrade the road network, install banks of storage silos and establish branches of the companies and cooperatives in the main towns in the soy-growing departments. However, the largest government and private investments have been in upgrading the port of Nueva Palmira. Therefore, since the establishment of soy as the major crop, it can be argued that an entirely new supply-chain network has been developed to facilitate its distribution.

Port infrastructure development has been vital to the soy industry and have enabled its production and exports to grow. Investments for the upgrading of Nueva Palmira began in the early 2000's and these funding decisions have been made because of the important strategic location in terms of soy exports from Bolivia and Paraguay, and to a lesser extent Argentina and Brazil, as well as Uruguay. It has become a port that is capable of storing and handling large quantities of soy and other commodities, and has vast truck unloading facilities. Importantly it has large volume transhipment facilities for soy (and other goods) which travel downstream along the Hidrovía Paraná Paraguay from

Bolivia, northern Argentina, Paraguay and southern Brazil. Importantly in this context it is a free port. It has captured over 70% of this trade, its only rival being Rosario in Argentina. It also tranships soy exported through Fray Bentos and Paysandú on smaller vessel that ply the Río Uruguay. The scale of investment in the facilities than Uruguayan farmers and businesses benefit from at Nueva Palmira would have been much less without its ability to capture export trade from neighbouring countries.

That is one aspect of the geographical location of Uruguay that has been beneficial to the development of soy. A further aspect of geography that is important is that the climate and soils of the Litoral are similar to adjacent soy-producing areas in northern Argentina; and another is that there are strong social, cultural and economic links between Argentina and Uruguay.

The importance of soy to the Uruguayan economy in the last three decades has been paralleled by very large government and commercial investments. These have been in on-farm production systems and in the development of a modern soy supply-chain geared towards the export market.

Research theme 3: How important has the switch to, and the growth in soy, been in shaping changes in agricultural land use (both cultivation and grazing systems), and how are these changes coupled to global trade and institutions? (Chapter 7)

It is clear from TCM modelling that changes in the area of land planted to soy from the 1990's onwards are related to global trade in soy, particularly fluctuations in demand from China and the EU. Prior to the soy boom, soy was grown in very small amounts in almost all departments with slightly higher amounts of land under soy being found in departments bordering Brazil. However, the soy boom witnessed a significant concentration of soy cultivation in Colonia, Soriano, Río Negro and southern Paysandú departments as well as adjacent western parts of Durazno, Flores and San José. Other arable crops gave way to soy, and as production expanded pastures eastern Colonia, Soriano, and Río Negro, and southern Paysandú and western Durazno, Flores and San José departments were converted from grazed natural grasslands to arable agriculture. After soy peaked in the mid- to late-2000’s the amount of land under soy increased and many of the grazed natural grasslands that had been converted to soy were converted back again to pastures, though these are artificial or improved pastures. These research findings and secondary sources (see Section 1.6) have allowed for a conceptual model of soy-pasture dynamics to be developed (Figure 8-1).

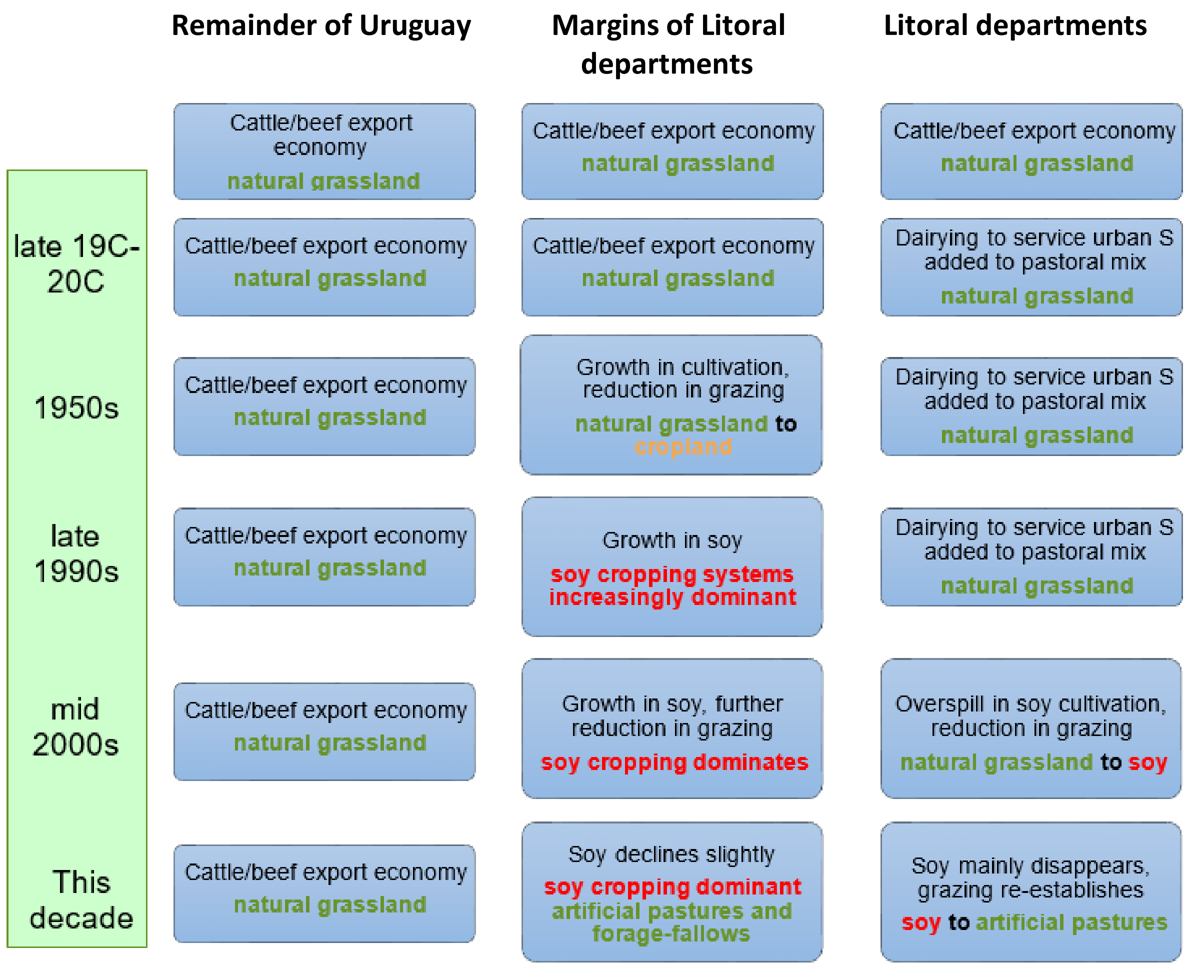

Figure 8-1Conceptual model of soy-pasture land-use dynamics for Uruguay from the late 19th Century to the present.

The model is constructed around three geographical areas: the main soy producing area of the four Litoral departments Colonia, Soriano, Río Negro and southern Paysandú (labelled ‘Litoral departments’ in Figure 8,1); eastern Colonia, Soriano, and Río Negro and western Durazno, Flores and San José departments (‘margins of Litoral departments’); and the rest of Uruguay (‘remainder of Uruguay) and considers the status of arable and pastoral land in from the late 19th Century to the present day.

Prior to the 1950's the cattle rearing, and beef export sector was the main driver of Uruguay's economy, and beef exports were Uruguay's largest agricultural commodity (Uruguay XXI, 2017, EU Commission, 2016). The majority of Uruguay, including the Litoral, was mainly under natural grasslands that were extensively grazed by beef cattle. By the early 20th century a dairying was added to pastoral mix: it is likely a dairying occurred in natural and improved pastures. In terms of land-use, the switch from beef to dairy occurred in eastern Colonia, San José and other departments adjacent to Montevideo.

This pattern continued until the 1950's when the growth in arable agriculture began in the Litoral provinces. This led to a reduction in grazing, and natural grasslands were converted to cropping. However, the amount of land cultivated was relatively small in the Litoral and pastures continued to dominate the agricultural sector, especially in eastern Colonia, Soriano and Río Negro and over much of Paysandú. Extensive grazing still other departments, and the dairying would have expanded around Montevideo as the urban population grew.

The 1990's witnessed more intensive production in the Litoral based on soy, and soy-based rotation systems would have replaced the former arable used based on winter cereal production. However, by the early 2000's soy rotation began to expand and from 2003-2013 soy rotations encroached in extensively grazed natural grassland in western Durazno and Flores, and the eastern parts of the Litoral departments, and into the dairying areas. There was a major conversion of pastures to arable land. After 2013 soy production declined, and much of the arable land that had been created between 2003 and 2013 was abandoned as arable farmland. This led to another land-use change from arable to artificial (sown) pastures.

8.3 Limitations

As with all research, this project was constrained by a number of limitations. These were mainly related to issues around interviews with stakeholders, though there were some other limitations.

There were fewer than anticipated responses by potential interviewees because of the means used to arrange interviews. E-mail was used, and many people were not prompt in replying. In fact, some replied too late to be interviewed and others did not reply at all, despite follow up e-mails and phone calls. Many potential interviewees were selected through a random process, and even though this was guided by staff from the Universidad de al República, it was difficult to discern if they were the right people to answer questions. A further limitation related to interviews conducted outside Montevideo, was that many locations that were convenient for the interviewee were a long way from the researcher's base at the agricultural station of the Universidad de al República just south of Paysandú. As the researcher did not always have access to a vehicle from the university, interviews were not always conducted in a timely manner.

In addition, the multinational companies that are highly active in the soy sector in Uruguay were very reluctant to participate in interviews. Numerous e-mails and phone calls were made to try and set up interviews. Most of the time there was response. Phone messages were left but calls were never returned. Rarely there was correspondence but even then, it proved impossible to arrange a time and location for an interview. As a result of this sleuthing, interviews were undertaken only with national and regional (Argentine) companies who were willing to be interviewed.

There were two other limitations. The first of these was that distances covered during the summer land-use survey were significant and only possible because the researcher was able to undertake this work with the thesis supervisor. Nonetheless, some road sectors were inevitably not sampled.

However, it is unlikely any major differences would have been apparent in the agricultural land-use map of summer crops in 2015/2016 as there were only two reasonably road sectors unsampled and these were located within spaces bounded by sample road sectors.

The second of the other limitations was that research focused along the four Litoral departments. This decision was made after consultation with researchers from MGAP and the Universidad de la República at the start of fieldwork. As interviews progressed and more statistical data became available to the researcher, it became clear that soy had expanded eastwards between 2003 and 2013 but it had then contracted. It would have been advantageous to extend sampling into the Departments of Durazno, Florida and San José immediately east of the Litoral departments. However, this expansion and contraction was revealed too late during fieldwork (and even then, the situation was not that clear until post-fieldwork analysis of data and interviews had been carried out) for sampling to be undertaken as time and finances were limited.

8.4 Contributions to knowledge

There are three main contributions to knowledge given the nature of the thesis. The first is a detailed understating of how the adoption of soy in the Litoral provinces has altered many aspects of agricultural systems and exports in Uruguay. One might term this the recent and contemporary agricultural geography of Uruguay. It is based on the synthesis of the data and evidence obtained in Uruguay. Given that these data are fragmentary, that the research community in Uruguay is small, and there is little written about Uruguay from a geographical perspective this is potentially and important contribution to knowledge. Of particular importance in this context, is that the research has highlighted soy-pasture dynamics in Uruguay and considered how two important agricultural commodities, soy and beef, have influenced land-use changes that have occurred in Uruguay. This is an important contribution due to understanding nature of both agricultural systems and the way that land-use intensity and efficiency in both have changed and the manner in which both are produced and have implications for natural resource conservation.

The main focus of the thesis had been on the land-use science. Important findings in this domain in this thesis have been have been in:

- Determining the relative contributions of direct (dLUC) and indirect (iLUC) land-use change. Most of the land-use change in the Litoral and adjacent departments can be categorised as dLUC where arable land has been replaced by soy-based arable systems. This is a different situation to many case studies on soy in South America, where soy has replaced natural woodland and grassland. However, the replacement of extensively grazed natural grasslands by soy-based arable agriculture had also taken place on the margins of the core soy zone in Uruguay, in some areas the new arable land has been replaced by artificial pastures as the area under soy has contracted. This expansion and contraction has led to two dLUC processes (natural grassland to soy, and soy to artificial grassland) and this has rarely been recorded in the South American research literature on soy.

- iLUC related to the expansion of soy was elucidated anecdotally during interviews. Pastoralists, who had sold farms to people wanting to establish soy farms land formerly used to raise cattle, moved to the Chaco of western Paraguay and cleared dry woodland to create new ranches. This is similar to iLUC due to the expansion of soy that has been recorded in Brazil. It is also spill over effect from one country to another.
- The knowledge gathered about land-use change due to the expansion of soy in Uruguay over the time period researched fits the underlying drivers and proximate causes theory of land-use change proposed by Lambin et al. (2003) is driven by complexity of drivers. Some of these drivers are complex and do not directly cause land-use change, but rather set of a chain of events that ultimately lead to change, e.g., the establishment of free trade agreements which require time to take effect.
- The major shift in arable land-use is Uruguay in the early 1990s. This was a critical point in the changing land use pattern in Uruguay. Such points are called land-use regime shifts by Ramankutty and Coombes (2016), who that argue that recording and understanding "…the preconditions, triggers and self-reinforcing processes…" related to these events, as this thesis has done, is one of the most important contemporary frontiers in land-use change research.

The third contribution is that this research is the first to used Granger causality modelling in any form in the field of land-use change and, as far as the researcher is aware the study will be one of the first studies to be published using temporal casual modelling released by IBM in SPSS. This is important because many land-use change studies develop time-series around available evidence of land use (i.e., from satellite data and aerial photography) and the try and fit economic and policy drivers around the evidence. This research has shown a different approach in which time-series can be used to create hypotheses about land-use change that can then be tested with available data and evidence. This seems a scientifically sound way to approach understanding land-use change. Its widespread adoption is to be encouraged.

8.5 Summary

Agriculture in Uruguay has changed land-use patterns and the landscape as agricultural systems have evolved. The country's economy has benefited from two major agricultural transformation. The first was the development of beef extraction methods, which facilitated the export of beef products to Europe before refrigeration. The second was the growth in soy to the extent that Uruguay in now one of the world's leading exporters. Interestingly, this later transformation has created interesting tensions between farmers and ranchers and led to arable land-pasture dynamics which have spill over as far as western Paraguay. Uruguay is not the largest soy producer and exporter in South America, but there are lessons to be learnt by agriculturalists and land-use scientists from this recent adopter of soy. Soy currently dominates arable agriculture in Uruguay and it rivals the beef sector, the global demand for soy indicates that this will not be change any time soon.

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Appendix A – Field Study Documentation including Ethics Approval

Interview Questions

INTERVIEW QUESTIONS GOVERNMENT OFFICIALS AND AGRIBUSINESSES

1. Why, in your opinion, has there been a big push for soy bean production in Uruguay since 1997?

2. How do you think this push/growth in production has affected agriculture generally (e.g., other crops, pasture, farming practices) and land use in Uruguay?

3. In your opinion, is foreign investment a major factor in Uruguayan agriculture? Is it constantly, growing or declining? How has foreign investment grown over the last 10 years compared to domestic investment? Who are the major investors – domestic and foreign? Are they government developments, banks or commercial?

4. What government incentives are there for soy bean production? How do these operate? In your opinion, what are their pros and cons?

5. Have agricultural policies changed in the last 5- 10 years or more? Have these changes been beneficial or not?

6. How have land use policies changed in the last 5-10 years? Have these changes been beneficial or not?

7. **Optional question, depending on how 1 answered:** In your opinion, what have been the impacts of the growth in soy bean production on natural resources (soils, water, nature conservation etc.)?

8. Do you know about Decreto 405.2008 (the national resource management policy)? How does it/or how much should it influence soy bean cultivation?

Ethics Approval

HE Human Research Ethics
Tue 10/04, 2:45 PM
Ingrid Tejada; Andrew Millington; Udoy Saikia; Harpinder Sandhu

Reply all

Inbox

Dear Ingrid,

The Executive Officer of the Social and Behavioural Research Ethics Committee (SBREC) at Flinders University reviewed the annual report that was submitted for project 7113 and it has been approved. Your annual report approval notice can be found below.

ANNUAL REPORT (No.2) APPROVAL

Project No.:	**7113**	Ethics Approval Expiry Date:	**30 November 2019**
Project Title:	Modelling soybean supply chain influences on agriculture and land-use in Uruguay		
Principal Researcher:	Miss Ingrid Tejada		
Email:	teja0001@flinders.edu.au		
Address:	School of the Environment		

Consent for Participation in Research

Flinders
UNIVERSITY

CONSENT FORM FOR PARTICIPATION IN RESEARCH

For government officials and agribusinesses

Modelling soybean supply chain Influences on agriculture and land-use in Uruguay

I ………………………………………………………………………………………………

Am over the age of 18 years hereby consent to participate as requested in the completing structural interview for the research project on soybean expansion in Uruguay

1. I have read the information provided.
2. Details of procedures and any risks have been explained to my satisfaction.
3. I agree to audio recording of my information and participation.
4. I am aware that I should retain a copy of the Information Sheet and Consent Form for future reference.
5. I understand that:
   - I may not directly benefit from taking part in this research.
   - I am free to withdraw from the project at any time and am free to decline to answer particular questions.
   - While the information gained in this study will be published as explained, I will not be identified, and individual information will remain confidential.
   - I may ask that the recording be stopped at any time, and that I may withdraw at any time from the session or the research without disadvantage.

Participant's signature……………………………………Date…………………...

I certify that I have explained the study to the volunteer and consider that she understands what is involved and freely consents to participation.

Researcher's name……………………………….……………………….................

Researcher's signature…………………………………..Date…………………….

6. I, the participant whose signature appears below, have read a transcript of my participation and agree to its use by the researcher as explained.

Participant's signature……………………………………Date…………………...

7. I, the participant whose signature appears below, have read the researcher's report and agree to the publication of my information as reported.

Participant's signature……………………………………Date…………………...

V:\Ethics\SBREC\WEBSITE docs\Consent.doc
Updated 28 June 2006

Ethics Introduction Letter

Professor Andrew Millington

School of the Environment
Flinders University
GPO Box 2100
Adelaide SA 5001
Tel: +61 8 8201-2287
Fax: +61 8 8201-3399
e-mail: Andrew.Millington@flinders.edu.au

CRICOS Provider No. 00114A

Uruguay's government officials

Dear Sir/Madam

Re: Approval to interview government officials and use statistical, trade and policy information on Uruguay

I am writing regarding the subject above. Ingrid Tejada is a PhD student at Flinders University in Adelaide, Australia. The research she is undertaking for her PhD thesis will examine soybean cultivation and global trade and the influences it is having on agriculture and land-use in Uruguay.

Ingrid will be doing her field work in Uruguay February 2016 and March 2016.

To assist her research, I would be extremely helpful if she could

(i) interview relevant staff in government department and

(ii) Obtain statistical and policy information

This will enable to her carry out her PhD project. Therefore, she is seeking approval from your office to interview and access the necessary information mentioned above.

Complete anonymity regarding the people she interviews will be maintained throughout the project and in subsequent publications.

I thank you in advance for your cooperation

Yours Sincerely,

Professor Andrew Millington

School of the Environment

Flinders University, Adelaide, Australia

inspiring achievement

Questions for exporters

Questions for exporters

1. When did you start operations in Uruguay and why?

   1.1 Where else do you have operations and was Uruguay one of the last countries in the MERCOSUR to where you became established?

2. What other commodities is your company involved with in Uruguay beyond soy?

3. What infrastructures do you have in Uruguay?
   For example, number/volume; what is the capacity and location of silos?

4. Which port do you use (Montevideo, Nueva Palmira) and what other infrastructure do you have access to?

   4.1 Do you have your own trucks to get products from farm to silo, farm to port or do you use independent companies? How do you contract them?

5. How do you interact with farmers? For example; do individual farmers or cooperatives contact you to sell their crops OR does you company look for soybeans to "fill a ship"?

Contract/purchase workings

6. How is the price set for your transaction in Uruguay?

7. Do you sell inputs lie seed, fertilisers, herbicide, machinery etc? do you have ties with particularly companies that provide these inputs?

8. How does the soy supply chain in Uruguay differ from wheat, barley, sorghum and maize? Are they more or less extensive?

Appendix B - Temporal Causal Modelling (example data set)

Temporal Causal Modelling

Notes

Output Created		22-JUN-2018 16:28:51
Comments		
Input	Data	E:\recover\NewTCM\New folder\6 Models\TCM_Trade.sav
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	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	24
Syntax		TCM MODEL /DATASETTINGS TIMETYPE=DATETIMEVAR TIMEVAR=Year_new INPUTINTERVAL=YEAR (INCREMENT=1) ANALYSISINTERVAL=USEINPUT GROUP=SUM AGGREGATE=SUM DISTRIBUTE=SUM CROSSDAYHRS=EXCLUDE INTERPOLATE=LINT MAXMISSING=25 USERMISSING=EXCLUDE /BUILDOPTIONS ESTIMATIONPERIOD=ALL CILEVEL =95 MAXINPUTS=5 LAGS=AUTO TOLERANCE=0.001 OUTLIERTHRESH=95 /TARGETFILTER DISPLAY=BESTFIT(N=10 FITSTAT=RSQUARE) /SERIESFILTER FIELDS=URY_SoyP URY_soyA /FILTEREDOUTPUT INCLUDE=TARGETS NETWORKGRAPH=YES(SIGLEVEL=0.05) PRINT=MODELFIT OUTLIERS MODELEFFECTS PARAMETERS FORECASTS PLOT=SERIESPLOT NRESIDUAL TOPINPUTS IMPACTDIAGRAMS=CAUSES(3) EFFECTS(3) /FILTEREDOUTPUT INCLUDE=SERIES NETWORKGRAPH=YES(SIGLEVEL=0.05) PRINT=MODELFIT OUTLIERS MODELEFFECTS PARAMETERS FORECASTS PLOT=SERIESPLOT NRESIDUAL TOPINPUTS IMPACTDIAGRAMS=CAUSES(3) EFFECTS(3) OUTLIER_ROOTCAUSES=YES(LEVELS=3 DISPLAY=INTERACTIVE) /SYSTEMOUTPUT MODELFIT=RSQUARE TRANSFORMATIONS=YES OUTLIERPLOT=YES /FIELDSGROUP /FIELDS TARGETS=URY_SoyP URY_soyA INPUTS=EU_Imports_ARG EU_Imports_URY EU_Imports_BRA EU_Imports_CAN EU_Imports_USA EU_ImBOL EU_ImPRY CHN_ARG CHN_BRA CHN_URYU CHN_CAN CHN_USA.
Resources	Processor Time	00:00:02.09
	Elapsed Time	00:00:03.59
Files Saved	Model File	C:\Users\teja0001\AppData\Local\Temp\spss6292\ascontfi.142

Model Information

Model Specifications

Number of Forecast Periods	0
Maximum Number of Predictors per Target	3
Maximum Lag	5
Model Tolerance	0

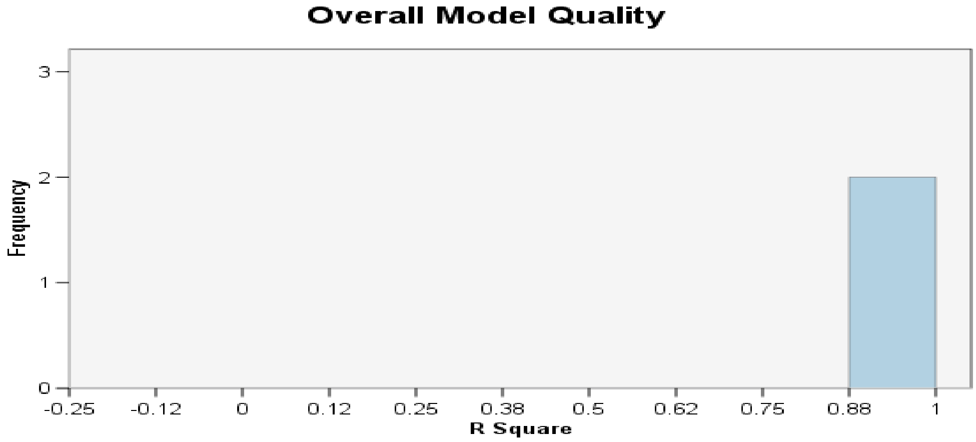
Temporal Information Summary

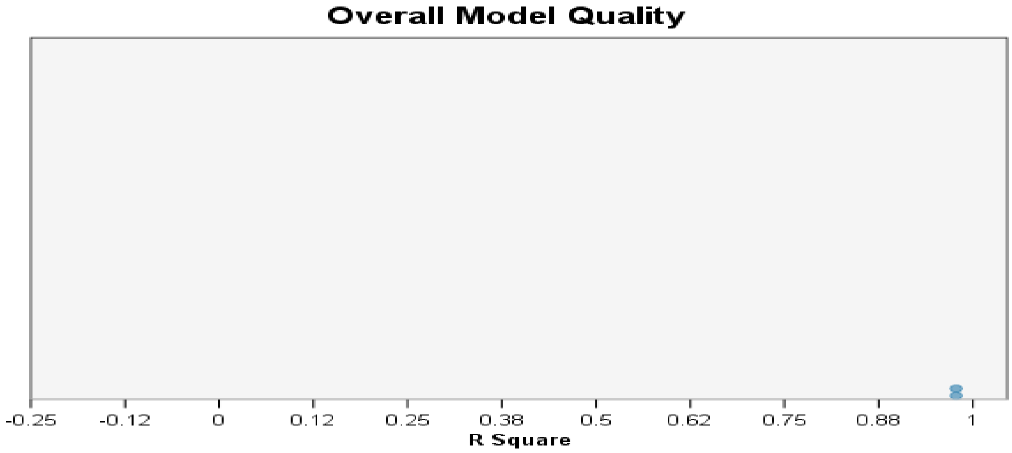
Time Field	61-2013
Increment	1 Year
Starting Point	1990/01/01
Ending Point	2013/01/01
Unique Points	24

Transformed Time Series

Missing Value Imputed	0	CHN_ARG
	1	CHN_URYU

Evaluation





Tests of Model Effects

URY_SoyP

Input Series	F	Sig.
URY_SoyP	69.06	0.003
CHN_CAN	46.19	0.005
CHN_BRA	185.44	0.001

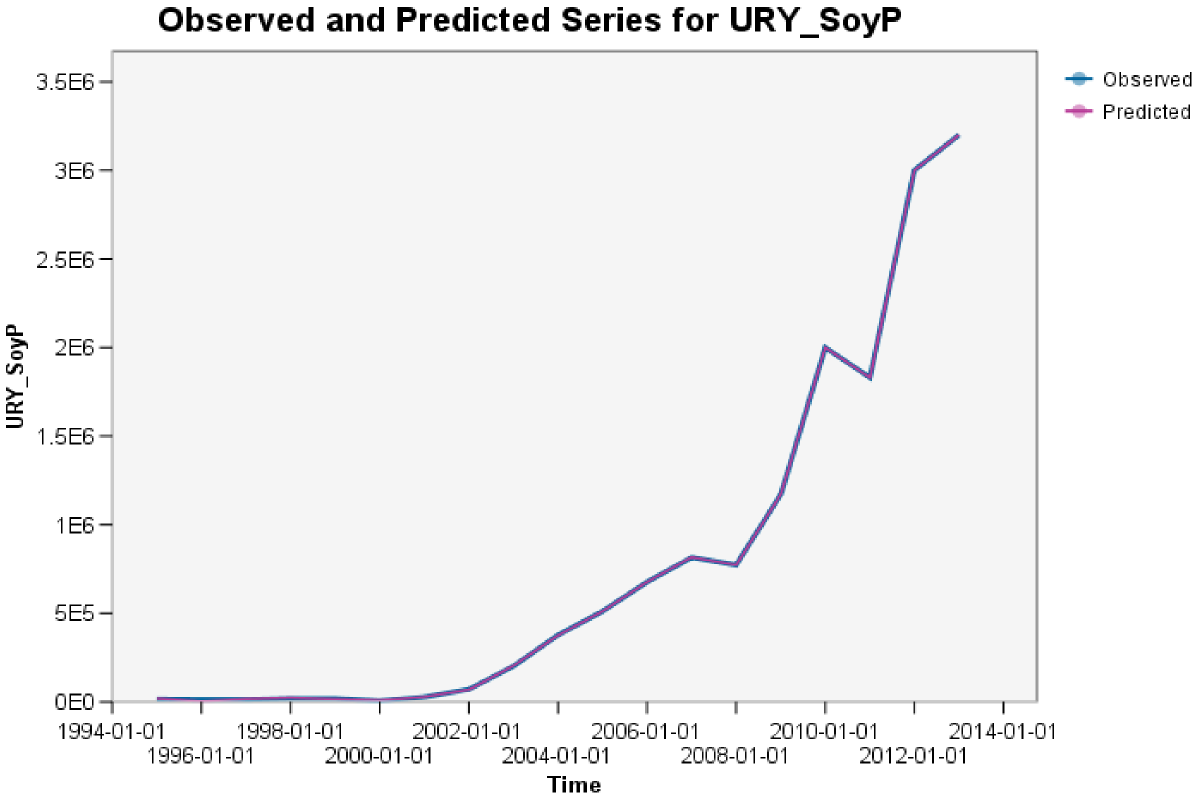
df1 = 5, df2 = 3

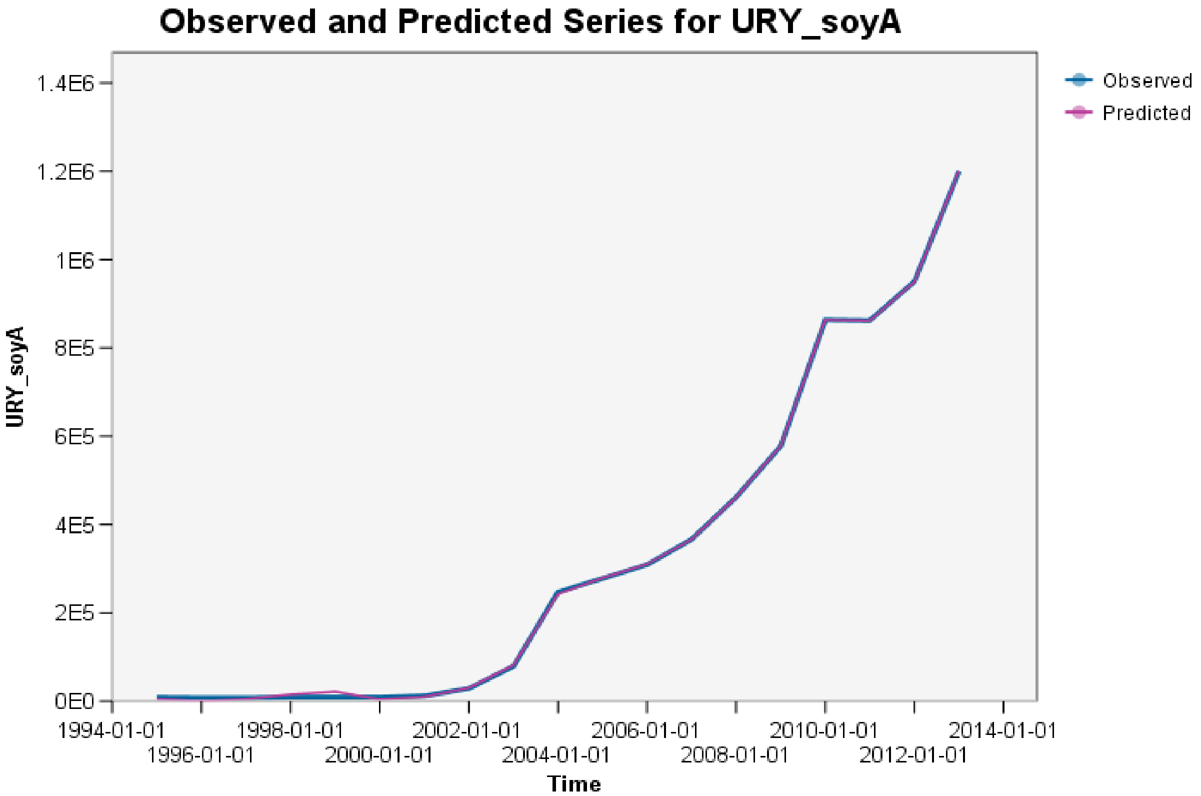
URY_soyA

Input Series	F	Sig.
URY_soyA	7.58	0.063
CHN_CAN	22.19	0.014
CHN_BRA	33.75	0.008

df1 = 5, df2 = 3

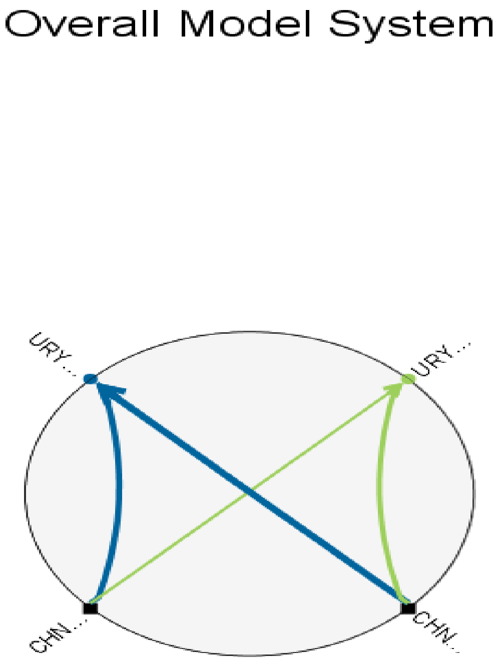
Observed and Predicted Series





Interpretation

Overall Model System

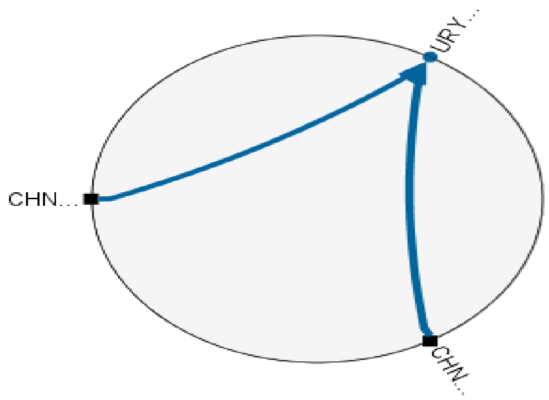


Fit Statistics for Top Models

Model for Target	Model Quality				
	RMSE	RMSPE	AIC	BIC	R Square
URY_SoyP	8,265.56	0.23	339.68	354.79	1.00
URY_soyA	10,461.45	0.46	348.64	363.75	1.00

RMSE = Root Mean Squared Error, RMSPE = Root Mean Squared Percent Error, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion

Overall Model System



Fit Statistics for Models Associated with URY_SoyP

Model for Target	Model Quality				
	RMSE	RMSPE	AIC	BIC	R Square
URY_SoyP	8,265.56	0.23	339.68	354.79	1.00

RMSE = Root Mean Squared Error, RMSPE = Root Mean Squared Percent Error, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion

Model Fit Statistics

Top models

Model for Target	Model Quality				
	RMSE	RMSPE	AIC	BIC	R Square
URY_SoyP	8265.56	0.23	339.68	354.79	1.00
URY_soyA	10461.45	0.46	348.64	363.75	1.00

RMSE = Root Mean Squared Error, RMSPE = Root Mean Squared Percent Error, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion

URY_SoyP

Model for Target	Model Quality				
	RMSE	RMSPE	AIC	BIC	R Square
URY_SoyP	8265.56	0.23	339.68	354.79	1.00

RMSE = Root Mean Squared Error, RMSPE = Root Mean Squared Percent Error, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion

URY_soyA

Model for Target	Model Quality				
	RMSE	RMSPE	AIC	BIC	R Square
URY_soyA	10461.45	0.46	348.64	363.75	1.00

RMSE = Root Mean Squared Error, RMSPE = Root Mean Squared Percent Error, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion

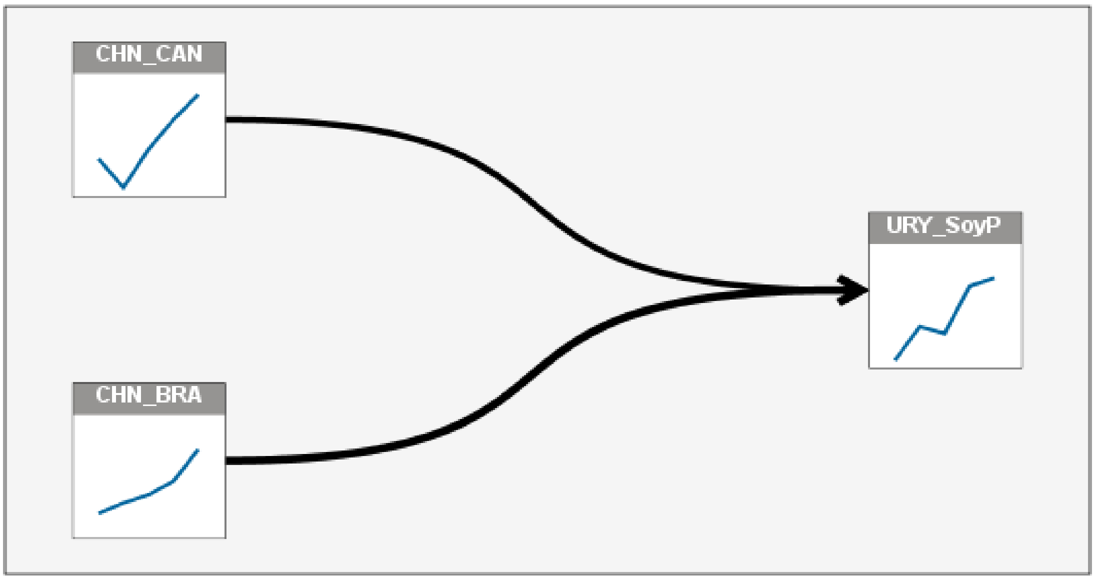
Outlier Root Cause Analysis

URY_SoyP
There are no outliers for this series.

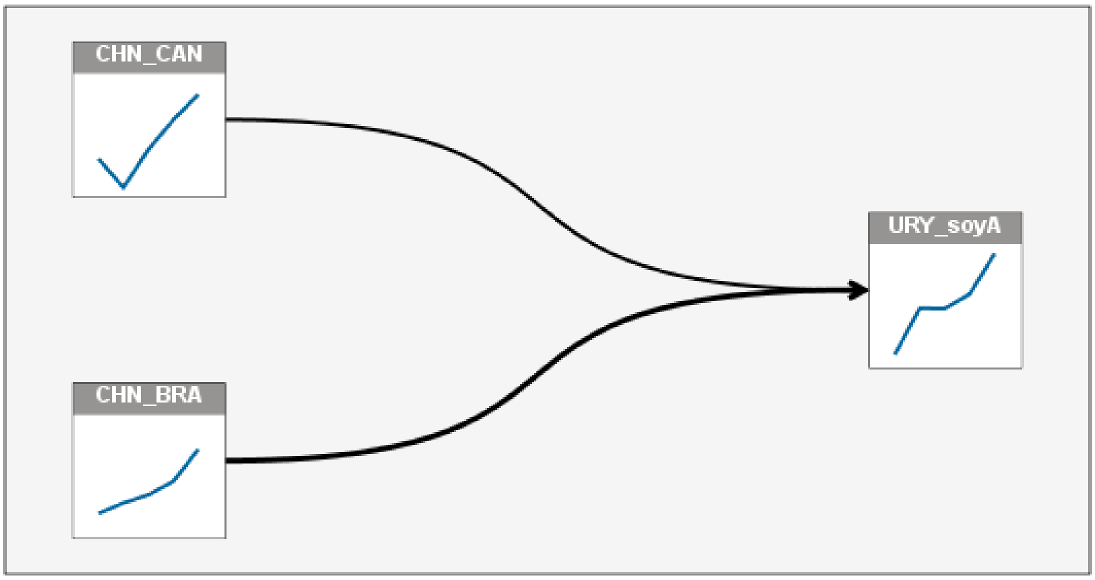
URY_soyA
There are no outliers for this series.

Impact Diagram

Impact Diagram



Impact Diagram



Parameter Estimates

URY_SoyP

Model Term		Coefficient	Std. Error	t	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept		-26995.30	5438.60	-4.96	0.016	-44303.34	-9687.26
URY_SoyP	Lag 1	1.32	0.23	5.74	0.010	0.59	2.05
	Lag 2	-0.88	0.27	-3.27	0.047	-1.74	-0.02
	Lag 3	0.50	0.30	1.65	0.198	-0.47	1.46
	Lag 4	-0.05	0.51	-0.10	0.930	-1.67	1.57
	Lag 5	0.67	0.35	1.91	0.151	-0.44	1.77
CHN_CAN	Lag 1	0.18	0.14	1.28	0.291	-0.27	0.63
	Lag 2	-2.03	0.23	-8.75	0.003	-2.77	-1.29
	Lag 3	3.72	0.50	7.49	0.005	2.14	5.30
	Lag 4	-1.97	0.97	-2.03	0.136	-5.05	1.12
	Lag 5	4.19	0.87	4.81	0.017	1.41	6.96
CHN_BRA	Lag 1	0.01	0.01	1.29	0.287	-0.02	0.04
	Lag 2	-0.06	0.01	-5.82	0.010	-0.10	-0.03
	Lag 3	0.05	0.01	5.51	0.012	0.02	0.08
	Lag 4	0.05	0.03	1.78	0.173	-0.04	0.13
	Lag 5	-0.03	0.03	-0.85	0.459	-0.13	0.07

URY_soyA

Model Term		Coefficient	Std. Error	t	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Intercept		-12774.84	7438.72	-1.72	0.184	-36448.15	10898.47
URY_soyA	Lag 1	0.60	0.91	0.66	0.559	-2.30	3.50
	Lag 2	0.63	0.60	1.05	0.371	-1.28	2.53
	Lag 3	-1.16	0.64	-1.81	0.168	-3.20	0.88
	Lag 4	1.02	1.04	0.98	0.398	-2.29	4.33
	Lag 5	0.53	0.78	0.68	0.545	-1.94	3.00
CHN_CAN	Lag 1	-0.07	0.14	-0.53	0.632	-0.51	0.36
	Lag 2	-0.84	0.19	-4.50	0.020	-1.43	-0.25
	Lag 3	-0.62	0.44	-1.41	0.253	-2.03	0.78
	Lag 4	1.48	0.53	2.77	0.069	-0.22	3.18
	Lag 5	0.91	2.61	0.35	0.749	-7.39	9.22
CHN_BRA	Lag 1	0.03	0.01	2.47	0.090	-0.01	0.06
	Lag 2	0.00	0.02	-0.12	0.912	-0.05	0.05
	Lag 3	-0.03	0.01	-2.42	0.094	-0.07	0.01
	Lag 4	0.01	0.02	0.80	0.481	-0.04	0.07
	Lag 5	2.49E-05	0.05	0.00	1.000	-0.15	0.15